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ICSM2023

(04-11 MAY 2023)

Plenary Session & Public Outreach

04.05.2023 THURSDAY

Abstract ID: 99

ORGANIC-BASED MAGNETS - NEW MAGNETIC MATERIALS FOR THIS MILLENNIUM

Joel S. Miller

University of Utah, Dept. of Chemistry, University of Utah, Salt Lake City, UT 84112 USA
E-mail: jsmiller@chem.utah.edu

Organic-based materials exhibiting the technologically important property of bulk magnetism have been pioneered in our laboratory and studied in collaboration with many research groups worldwide. These magnets are prepared via conventional organic synthetic chemistry methodologies, but unlike classical inorganic-based magnets do not require high-temperature metallurgical processing. Furthermore, these magnets are frequently soluble in conventional organic solvents and have saturation magnetizations more than twice that of iron metal on a mole basis, as well as in some cases coercive fields exceeding that of all commercial magnets (*e.g.,* Co_5Sm). Also several magnets with critical temperatures (T_c) exceeding room temperature have been prepared. In addition to an overview of magnetic behavior, numerous examples of structurally characterized magnets made from molecules will be presented. Four examples magnetically order above room temperature and as high at 127 ^oC. These will include $[M^{III}(C_5Me_5)_2][A]$, $[Mn^{III}(porphyrin)][A]$ (A = cyanocarbon etc. electron acceptors) as well as $M[TCNE]_x$ (TCNE = tetracyanoethylene), which for M = V is a room temperature magnet that can be fabricated as a thin film magnet via Chemical Vapor Deposition (CVD) techniques. A newer class of magnets of $[Ru_2(O_2CR)_4]_3[M(CN)_6]$ (M = Cr, Fe; R = Me, *t*-Bu) composition will also discussed. For R = Me an interpenetrating, cubic (3-D) lattice forms and the magnet exhibits anomalous hysteresis, saturation magnetization, out-of-phase, $\chi''(T)$, AC susceptibility, and zero field cooled-field cooled temperature-dependent magnetization data. This is in contrast to R = *t*-Bu, which forms a layered (2-D) lattice. Additionally, new magnets possessing the nominal Prussian blue composition, $M'[M(CN)_6]_x$ and $(Cation)_yM'[M(CN)_6]$, but not their structure, will be described. This forms a series of cation-adaptive structures with $[NEt_4]_2Mn_3(CN)_8$, $[NEt_4]Mn_3(CN)_7$, $[NMeEt_3]_2Mn_5(CN)_{12}$ and $[NMe_4]_3Mn_5(CN)_{13}$ stoichiometries that order as antiferromagnets or ferrimagnets. Finally, Li[TCNE] magnetically orders as a weak ferromagnet (= canted antiferromagnet). Magnonic applications of the $V[TCNE]_x$ (x ~ 2) room temperature magnet will also be discussed.

Abstract ID: 597

QUANTUM FEEDBACK ENHANCED METROLOGY

Irfan Siddiqi

University of California, Berkeley, USA
E-mail: irfan_siddiqi@berkeley.edu

In modern metrology and communication technology, information is encoded in electro-magnetic waves, typically as an amplitude or a phase. While current classical hardware can perform near-ideal measurements of photon number or field amplitude, a device that can perform an ideal quantum mechanical phase measurement has remained elusive. I will describe the implementation of a single-shot, canonical phase measurement of a one-photon wave packet that surpasses the current standard of heterodyne detection, and is optimal for single-shot phase estimation. By applying quantum feedback to a Josephson parametric amplifier, our system adaptively changes its measurement basis during photon arrival and allows us to validate the detector's performance by tracking the quantum trajectory of the photon source. These results provide an important capability for optical quantum computing, and demonstrate that quantum feedback can both enhance the precision of a detector and enable it to measure new classes of physical observables.

Abstract ID: 600

GLOBAL ROOM-TEMPERATURE SUPERCONDUCTIVITY IN GRAPHITE

Y.V. Kopelevich[1], J.H.S. Torres[1], R. Ricardo da Silva[1], M.C. Diamantini[2], C.A. Trugenberger[3], V.M. Vinokur[4]

[1]*Universidade Estadual de Campinas-UNICAMP, Instituto de Física "Gleb Wataghin", 13083-859, Campinas, BRAZIL*
[2]*NiPS Laboratory, INFN and Dipartimento di Fisica e Geologia, University of Perugia, I-06100, Perugia, ITALY*
[3]*SwissScientific Technologies SA, CH-1204, Geneva, SWITZERLAND*
[4]*Terra Quantum Corporation, CH-9000, St. Gallen, SWITZERLAND*
E-mail: vmvinokour@gmail.com

Room temperature superconductivity under normal conditions has been a major challenge of physics and material science since the very discovery of superconductivity. We report the global room-temperature superconductivity observed in cleaved highly oriented pyrolytic graphite carrying dense arrays of nearly parallel surface line defects. The multiterminal measurements performed at the ambient pressure in the temperature interval 4.5 K $\leq T \leq$ 300 K and at magnetic fields $0 \leq B \leq 9$ T applied perpendicular to the basal graphitic planes reveal that the superconducting critical current $I_c(T,B)$ is governed by the normal state resistance $R_N(T,B)$ so that $I_c(T,B)$ is proportional to $1/R_N(T,B)$. Magnetization $M(T,B)$ measurements of superconducting screening and hysteresis loops together with the critical current oscillations with temperature that are characteristic for superconductor-ferromagnet-superconductor Josephson chains, provide strong support for occurrence of superconductivity at $T >$ 300 K. We develop a theory of global superconductivity emerging in the array of linear structural defects which well describes the experimental findings and demonstrate that global superconductivity arises as a global phase coherence of superconducting granules in linear defects promoted by the stabilizing effect of underlying Bernal graphite via tunneling coupling to the 3D material.

Abstract ID: 629

POSSIBILITY OF SUSTAINABLE DEVELOPMENT WITH EMERGING QUANTUM TECHNOLOGIES

A. Gencer[1,2]

[1] *Ankara University, Science Faculty, Phys. Dept., 06100-Tandogan- Ankara, TURKEY*
[2]*Ankara University, Center of Excellence for SUperconductivity Research, (CESUR), 06830- Golbasi-Ankara, TURKEY*

E-mail: aligencer06@gmail.com

Sustainable Development is to meet the needs of societal development goals while simultaneously sustaining the ability of natural systems to provide the natural resources and ecosystem services on which the economy and society depend on. Science Education and R&D with Technology development efforts need to be associated with the sustainable development goals. In this presentation, a brief summary of Turkey's efforts and the leading countries in quantum technologies will be provided along with historical progress of the low temperature physics, Quantum Science & Technology and cryogenics engineering. Technology has become more advanced with many sophisticated functionalities over the recent times after long period of industrial revolutions. The impact of superconductivity in the global world with technological development will be discussed mentioning the potential highlights of the ICSM2023 conference in view of energy, environmental and quantum materials. We shall explore to find the answer for the question of "Is the real Quantum Computer is coming for use in the whole world?"

Plenary Session

05.05.2023 FRIDAY - 10.05.2023 WEDNESDAY

Abstract ID: 109

MOLECULAR SPIN QUBITS FOR QUANTUM COMPUTER AND HIGH-DENSITY MEMORY DEVICES BASED ON MOLECULAR MAGNETS

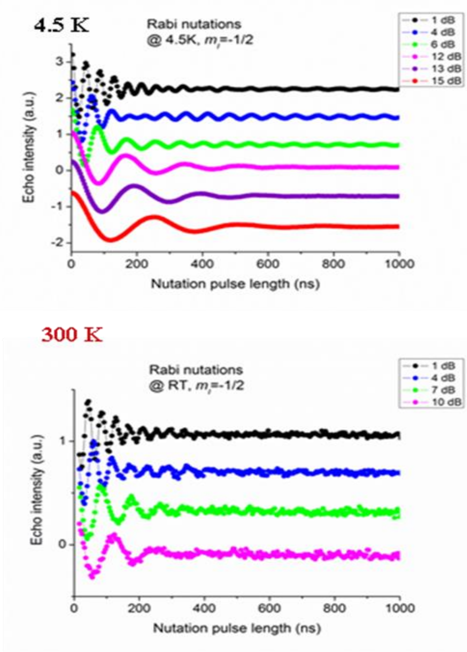
Masahiro Yamashita

Department of Chemistry, Faculty of Science, Tohoku University, 6-3 Aramaki-Aza-Aoba, Aoba-Ku, Sendai 980-8578, JAPAN

E-mail: yamasita@agnus.chem.tohoku.ac.jp & yamasita.m@gmail.com

Spintronics, based on the freedoms of charge and spin of the electron, is a key technology in the 21st century. Magnetic random access memory (MRAM), which uses giant magnetoresistance (GMR), has several advantages compared with electronics. Although conventional magnets composed of transition metals are normally used, in our study, we use single-molecule magnets (SMMs) to overcome "Moore`s Limitation". SMMs are also available for quantum computer. I will talk about the molecular spin qubits for quantum computer as well as high-density memory devices such as single-molecule memory device, SMMs encapsulated into SWCNT, and metallic conducting SMMs with negative magnetoresistances.

As for molecular spin qubits for quantum computer, we must increase T_1 (spin-lattice relaxation time) and T_2 (spin-spin relaxation time). Therefore, we will focus on the following three strategies:**(1) Crystal Engineering Method;** To compare 0D [VO(TPP)] and 3D [VO(TCPP-Zn_2-bpy)] (3D-MOF) to investigate the influence of the spin-lattice relaxation (T_1) in 0D and 3D lattices. Due to the rigid lattice of 3D-MOF, the Rabi nutation was observed even at room temperature (Fig.1). **(2) g-Tensor Engineering Method;** To compare [VO(TPP) and [CrN(TPP)] to investigate the contribution of the anisotropy of their g-values for the spin relaxation. Due to the large anisotropy of g-values, [CrN(TPP)] shows the short life time. **(3) Orbital Engineering Method;** To compare [Ni(cyclam)X_2]ClO_4 and TBA[Ni(mnt)$_2$] to investigate the relationship between the different occupied orbitals and spin relaxation. [Ni(cyclam)X_2]ClO_4 has the longer life time due to the rigid molecular structure.



As for the single molecule memory, we have used STM and STS for $TbPc_2$ SMM. By using tunnelling magnetoresistance, we have realized the single memory effect of up-spin and down-spin on $TbPc_2$. As for the negative magnetoresistances for high-density memory devices, we have synthesized (BEDO-TTF)$_3$[Co(pmdt)$_2$] (**BO3**) and (BEDO-TTF)$_4$[Co(pmdt)$_2$] (**BO4**). **BO3** show the metallic behavior around room temperature and M-I transition around 12K. Moreover, **BO3** shows the negative magnetoresistance for the first time by the interaction between conducting electron and SMMs. We have succeeded the encapsulation of $DySc_2N@C_{80}$ SMMs into Single-Walled Carbon Nanotubes (SWCNTs). After encapsulation, the coercivity increase by one order by suppression of the quantum tunnelling. Finally, we have observed the negative magnetoresistance by using Ni electrode. Moreover, we have observed Coulomb blockade effect by the interaction of conduction electron of SWCNTs and SMMs.

Abstract ID: 162

OPTIMIZING FLUX-PINNING VIA ENGINEERING NANOSCALE DEFECTS IN COATED CONDUCTORS

A. Goyal

State University of New York at Buffalo, Buffalo, NY 14221, USA
E-mail: agoyal@buffalo.edu

Engineered nanoscale defects within $REBa_2Cu_3O_{7-\delta}$ (REBCO) based coated conductors are of great interest for enhancing vortex-pinning, especially in high-applied magnetic fields. In this talk, we will report on advances made in research related pinning in in-situ deposited PLD films as well as ex-situ fabricated films. Previously we have reported excellent J_c' s and flux-pinning in YBCO films with self-assembled BZO columnar defects at intermediate operating temperatures 30-77 K via correlated pinning from extended defects. It was found that these PLD films also exhibited very high-J_c' s at low-operating temperatures where weak collective-pinning dominates and this was attributed to pinning from oxygen point defects arising due to the local strain near YBCO/BZO interfaces. This also resulted in a T_c suppression as a function of BZO additions in these PLD deposited films which affects performance at 77 K. We will report on ongoing studies exploring mitigation of T_c via incorporation of additional dopants and their effect on microstructure, J_c and flux-pinning in in the operating regime of 5-77 K. In addition, we are conducting microstructural studies to improve flux-pining in thick, ex-situ MOD REBCO films having thicker HTS layers and with enhanced pinning achieved via rapid and continuous ion-irradiation of Au^{5+}. Control of microstructural defects is correlated with J_c and flux-pinning to optimize performance.

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Abstract ID: 192

ADVANCES IN UNDERSTANDING RADIATION DAMAGE OF COATED CONDUCTORS FOR FUSION ENERGY

S.C. Speller

University of Oxford, Centre for Applied Superconductivity, Oxford, OX1 3PH, UK
E-mail: susannah.speller@materials.ox.ac.uk

High temperature superconductors (HTS) are an enabling technology for the next generation of compact nuclear fusion reactors that require very high magnetic fields to confine the plasma. However, in operation, the superconducting magnet windings will be exposed to a flux of fast neutrons which will inevitably introduce structural damage that affects superconducting properties. Studies dating back to the late 1990s using fission spectrum neutrons have shown that critical current density (J_c) of HTS materials initially improves slightly upon irradiation, before degrading at higher neutron fluences [1]. This has been attributed to nuclear collisions creating amorphous damage cascades that are tens of nanometres in size and act as effective flux pinning sites [2]. However, the superconducting transition temperature (T_c) is found to decrease monotonically with neutron fluence, which suggests the entire superconducting volume is being degraded by the irradiation. This cannot be explained by the isolated amorphous damage cascades, instead indicating that point defects have been created throughout the entire superconducting lattice.

Here, I will discuss two different studies being carried out by a team of researchers at the University of Oxford, UK Atomic Energy Authority (UKAEA) and Tokamak Energy. The first experiment aims at understanding the nature of the lattice defects responsible for the degradation in T_c using He^+ irradiation as a proxy for neutrons [3]. Atomic resolution electron microscopy studies show that, even when the irradiation dose is high enough for superconductivity to be entirely lost, the cation lattice is still intact (Fig. 1). Therefore, to study the defects that are responsible for the loss of superconductivity, high energy resolution x-ray absorption spectroscopy has been used to probe small changes in the bonding environment of the copper ions. The nature of the defects responsible has been investigated by comparing spectra calculated from a range of defect structures using DFT.

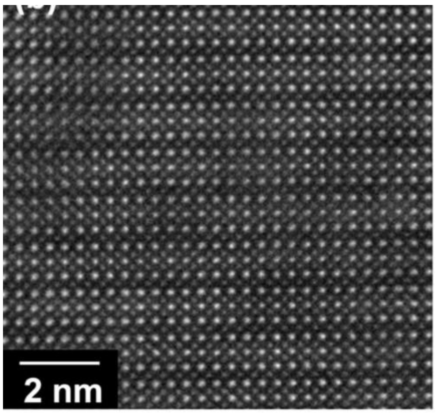

Fig. 1: *HAADF STEM image of He+ irradiated coated conductor [3].*

The second experiment is aimed at more closely replicating the conditions under which the superconductor will be operating, by performing He^+ ion irradiation at cryogenic temperatures and measuring J_c in situ without warming up the superconductor. The results indicate that the superconductor damages at a similar rate at 40 K and room temperature, but the superconducting properties of the cold-irradiated samples can be partially recovered by warming to room temperature [4]. In addition, a preliminary experiment has shown that the current carrying capacity of the coated conductor temporarily drops by a considerable amount when the ion beam is illuminating the sample, which may have consequences for fusion magnet applications.

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Abstract ID: 207

SUPERCONDUCTING GLOBAL ALLIANCE (ScGA) FOR ZERO EMISSION TARGETS BY 2050

Ziad Melhem

Oxford Quantum Solutions Ltd., Oxford, OX2 9SB, UNITED KINGDOM
E-mail: ziad.melhem@oxqsol.com

Superconducting technologies are ready to be scaled up and deployed in diverse applications beyond their present usage (MRI, NMR, and physical sciences and engineering). Superconductivity has the potential to provide means towards zero-emission targets, enabling extensive usage of wind power generation, facilitating zero-emission transportation, realising robust and resilient electricity, enabling fusion power, superconducting quantum computing, water purification, new medical diagnosis and therapy tools, and new scientific breakthroughs.

To realise the potential of superconductors in addressing our societal future needs as identified in the United Nations' 17 Sustainable Development Goals (SDGs, also called the Global Goals; will require new thinking and innovations on how to deploy superconducting technologies and translate it into successful market applications.

This talk will present an update on the Superconducting Global Alliance (ScGA) initiative for a cleaner and sustainable future and address providing superconducting technologies for zero emissions targets by 2050.

Abstract ID: 95

BOTTOM-UP DESIGN OF UNCONVENTIONAL SUPERCONDUCTORS IN MAGNET-SUPERCONDUCTOR HYBRID SYSTEMS

Roland Wiesendanger

Dept. of Physics, University of Hamburg, Jungiusstr. 11, 20355 Hamburg, GERMANY
E-mail: wiesendanger@physnet.uni-hamburg.de

Magnet-superconductor hybrid (MSH) systems provide exciting platforms for realizing unconventional types of superconductivity. I will discuss various types of 1D and 2D model systems [1-12] where topological superconducting states [1,3,6,8], topological nodal-point superconductivity [12] as well as p-wave superconductivity have been demonstrated by a bottom-up design approach, starting from atomically clean substrates of elemental superconductors and the assembly of 1D or 2D magnetic adatom arrays. Spin-polarized scanning tunneling microscopy and spectroscopy [13] provide simultaneous access to the magnetic ground states of the 1D or 2D nano-scale magnets as well as to the exotic types of superconducting phases emerging in the MSH systems. The direct measurement of a topological band structure inside the energy gap of a superconductor at a micro-eV energy scale [6] will be demonstrated as well as the emergence of associated zero-energy Majorana modes which are a direct consequence of the topologically non-trivial superconducting state [8].

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Abstract ID: 140

SURPRISES IN THE HP SYNTHESIS OF HTSC *CUPRATE* MATERIALS SUBSTITUTIONS IN $RuSr_2RECu_2O_8$: LANTHANIDE CONTRACTION, REDOX BEHAVIOR & ORDER-DISORDER

Miguel A. Alario-Franco

Laboratorio Complutense de Altas Presiones. Facultad de Química. Universidad Complutense. Ciudad Universitaria. 28040. Madrid. SPAIN

E-mail: maaf@ucm.es

We have been working for some time on the synthesis at high pressure (P ~12.5 < GPa) and high temperature (T ≤1400 K) of new materials of the type MSr2RECu2O8 (RE <>Rare Earth), which formally derive from YBCO (i.e. CuBa2YCu2O7) by replacing the [Cu-O4] squares in the basal plane of the structure by [M-O6] octahedra (M <> Ru, Cr or Ir). Interestingly, the adequate formation of these cuprates as majority phases, can only be performed in a particular and relatively narrow window of P and T, outside which they cannot be obtained pure or even obtained at all¡[1].

Even more, these "***optimum conditions***" bear a remarkable Gaussian correlation with the Rare Earth ion size, --the Rare Earth cation being at the centre of the unit cell in the YBCO setting--, and ***they do not follow the classic lanthanide contraction*** so often observed in the chemistry of those elements. Instead, **interelectronic repulsion** appears to play a major role in fixing the synthesis conditions. Moreover, the position of the Gaussian tip in the Pressure-Ionic Radii space is also dependent on the transition metal that sits in the octahedron, in a way that appears to be related to the thermodynamic stability of their simpler oxides.

A second surprise concerns the partial substitution and oxidation of $Mo_{0.3}Cu_{0.7}Sr_2ErCu_2O_y$, one of the superconducting perovskite derivative members of the above family [2]. As shown by a detailed study of its high oxygen pressure oxidation, the appearance of superconductivity is related to the ***oxidation of Molybdenum in parallel to the reduction of copper.***

The third example shows the correlation of P & T in the ***ordering in the A & B positions*** of a quadruple perovskite ***"$Sr_2RECu_2IrO_{9-\delta}$"*** [3].

I thank my students for their contribution to this work.

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Abstract ID: 542

HTS CUPRATES: NEW ADVANCES TOWARD UNDERSTANDING AND APPLICATIONS

Ivan Božović[1,2]

[1]*Brookhaven National Laboratory, USA*
[2]*Department of Chemistry, Yale University, USA*
E-mail: bozovic@bnl.gov

In my talk at the 7th ICSM meeting, I listed some key open questions in the physics of HTS in cuprates. Indeed, the most important question is still wide open: what the pairing mechanism is, and why *is TC* so high? But the "normal" state above T_c also presents major puzzles. What is the microscopic origin of the pseudogap? What causes the so-called "strange metal" behavior, the linear temperature (T) and magnetic field (B) dependence of resistivity? Why do T_c and the superfluid density N_{s0} decrease and vanish on the overdoped side? Why is the rotational symmetry of the electron fluid spontaneously broken, the so-called "electronic nematicity"? And how are all these related to one another? We use Atomic-Layer-by-Layer Molecular Beam Epitaxy (ALL-MBE) to synthesize single-crystal thin films and atomically precise heterostructures, which we pattern into devices and study their physical properties. We custom-design the samples to enable incisive experiments that target the above questions. [1]

I will present some new results. (i) Spectroscopy of HTS trilayer tunnel junctions shows new evidence of strong coupling of charge carriers to specific phonon modes and electronic excitations. (ii) A systematic study of the doping dependence of superconducting and normal-state transport properties shows that increasing disorder is *not* the cause of the demise of T_c and N_{s0} with doping. (iii) Magnetoresistance data reveal an unexpected resistivity scaling with *the linear* sum of thermal and magnetic field energies. (iv) A study of the effects of magnetic field on nematicity brought about the discovery of colossal *transverse* magnetoresistance due to quasi-1D superconducting fluctuations.

As for the applications, a breakthrough is the fabrication of the first HTS-nanowire single-photon detectors.[2] We are also making progress in fabricating HTS SIS junctions.

I will also review some important discoveries and results from other groups, complementing ours but raising new questions.

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Abstract ID: 554

CHIRAL SPINTRONICS

Stuart S.P. Parkin

Max Planck Institute of Microstructure Physics, Halle (Saale), GERMANY
E-mail: stuart.parkin@icloud.com

Chirality is a fundamental property of nature that plays a dominant role in the formation of novel spin textures in certain classes of both bulk materials and thin film magnetic heterostructures [1]. The simplest chiral spin texture is a one-dimensional (1D) Néel or Bloch magnetic domain wall that separates two magnetic regions that are magnetized in opposite directions. Under the influence of spin orbit torques, that are derived from spin currents that carry angular momentum, these walls can be driven at high speeds exceeding 1 km/sec along magnetic nano-wires that, thereby, form "magnetic racetracks". This is the basic principle of the magnetic racetrack memory that stores digital data in the form of the presence or absence of such chiral domain walls [2]. Recent developments show that racetrack memory is highly promising as a next generation high-performance, non-volatile memory that could, on the one hand, surpass the fastest memories of today – namely static random-access memory – and, on the other hand, replace magnetic disc drives that store most of today's digital data.

Chiral domain walls are, however, just one member of an ever-expanding family of chiral spin textures that are of great interest from both a fundamental as well as a technological perspective [1]. Recently a zoology of complex 2D and 3D spin textures stabilized by volume or interface Dzyaloshinskii-Moriya vector exchange interactions have been discovered including, in our work, anti-skyrmions [3], elliptical Bloch skyrmions [4], two-dimensional Néel skyrmions [5] and fractional antiskyrmions [6]. Such nano-objects are potential candidates as magnetic storage bits on the racetrack [2]. Another class of chiral spin textures are Kagome antiferromagnets: we have recently shown how their complex spin textures can be manipulated by a previously unobserved seeded spin orbit torque (SSOT) mechanism [7]. These chiral spin textures become superconducting when placed in proximity to a conventional superconductor and support long range triplet supercurrents [8]. Triplet supercurrents are highly interesting in that they can carry spin angular momentum, unlike conventional superconductors, and, therefore, could be used, in principle, to manipulate chiral spin textures at ultra-low temperatures. This is the basic principle of the SUPERTRACK memory device that I have recently proposed [9]. I will briefly discuss this proposed device in which the spin textures would be detected by a nonreciprocal Josephson Diode Effect that we have recently discovered in 2D van der Waals layers [10] as well as in proximitized platinum [11].

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Abstract ID: 142

SEARCHING FOR NEW ELECTRONIC PROPERTIES IN ULTRATHIN FILMS OF CORRELATED MATERIALS VIA IN SITU ARPES

Changyoung Kim[1,2]

[1] *Center for Correlated Electron Systems, Seoul National University, Seoul 08826, KOREA*
[2] *Department of Physics and Astronomy, Seoul National University, Seoul 08826, KOREA*
E-mail: changyoung@snu.ac.kr

Since the discovery of graphene in 2004, research on 2-dimensional van der Waals materials is at the core of the condensed matter physics research. This is due to the fact that these 2D materials not only show distinct physical properties from those of 3D materials but also can lead to novel properties through stacking. For example, Mott insulating and superconducting states, unavailable in single layer graphene, are realized in twisted bilayer graphene. While these novel 2D systems are built through exfoliation of van der Waals materials, a more conventional way is via thin film growth. In this presentation, I wish to introduce the research efforts to find new electronic properties in a few unit cell (uc) thick thin films by using thin film growth and in situ angle resolved photoemission (ARPES).

We started with ARPES studies on a few thick films of $SrRuO_3$, a prototypical metallic ferromagnet with spin-orbit coupling. It was found that nodal lines and quadratic band crossing points are generic features of ultrathin perovskite films. These symmetry-protected nodal lines and quadratic band crossing points are sources of Berry curvature that causes the sign changing anomalous Hall effects [1]. By using an additional 'conducting layer', we were able to obtain the electronic structure of 1 u.c. thick SrRuO3 films. Our results show that 1 uc films are not insulators but remain metallic. Dosing experiments reveal that 1 uc films are correlated Hund metals caused by the high density of states near E_F from the van Hove singularity [2]. We further controlled the strain and octahedron distortion of 1 uc films by using various substates. We demonstrate that the electronic state of 1 uc films can be manipulated from a good metal to a correlated Hund metal, and finally to a Mott insulator [3][4]. I will also briefly touch upon other activities on cuprates[5] and chacogenides [6,7] if time permits.

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Abstract ID: 495

RECENT ADVANCES IN IRON-BASED SUPERCONDUCTING MATERIALS

Yanwei Ma

Institute of Electrical Engineering, Chinese Academy of Sciences, Beijing 100190, CHINA
E-mail: ywma@mail.iee.ac.cn

Iron-based superconductors (IBS) are very promising candidates for high-field magnet applications owing to their ultrahigh upper critical fields and very small anisotropy. In recent years, tremendous progress has been made on the critical current density (J_c) of IBS wires and tapes based on a powder-in-tube technique, e.g., high transport J_c up to 2.2×10^5 A cm^{-2} at 4.2 K and 10 T was achieved in 122 type IBS tapes. Furthermore, the transport J_c of IBS tapes with high-strength composite metal sheath such as Cu/Ag and Stainless steel/Ag was enhanced above 10^5 A cm^{-2} at 4.2 K and 10 T as well. On the other hand, with hot isostatic pressing process, the J_c-performance of IBS round wires was also significantly improved. With the achievement of high-performance multifilamentary IBS long-length tapes, the first IBS single pancake coil and double pancake coil were fabricated and tested at 24 T and 30 T background field, respectively. Two IBS racetrack coils using 100-meter long IBS tapes were successfully made and tested in a superconducting dipole magnet which provided a maximum background field of 10 T at 4.2 K. These results demonstrate the great potential of IBS wires in high-field applications in the future.

Abstract ID: 596

COMPLEXITY AND SPIN-ORBIT COUPLING FAVORING HIGH T_c SUPERCONDUCTIVITY IN NATURAL AND ARTIFICIAL HETEROSTRUCTURES

Antonio Bianconi

RICMASS, Rome International Centre Materials Science Superstripes, Via dei Sabelli 119A, 00185 Rome, ITALY
IC-CNR, Institute of Crystallography Consiglio Nazionale delle Ricerche, Monterotondo, Rome ITALY
E-mail: antonio.bianconi@ricmass.eu

The recent advances in the field of first-principles quantum calculations for material design of high temperature superconductors (HTS) made of artificial electronic heterostructures at 3 nanometers (nm) scale shed finally light on the mechanism of HTS. I will review recent advances in 3 nm electronic technology making now feasible to match theory prediction and device functionality in the field of new quantum devices at high temperature. We present recent achievements on the cooperative interplay of the Rashba spin-orbit coupling (RSOC) joint with phonon mediated pairing at selected k-space spot (e-ph-pairing) to achieve high temperature superconductivity tuning internal electric field in artificial heterostructures [1-4]. We report how it is possible to design the superconducting dome in the artificial heterostructure of quantum units versus either RSOC and e-ph-pairing driven by Fano resonances due to quantum configuration interaction between open and closed pairing channels [2,3]. Our results provide a quantitative tool for material design of very high temperature superconductors [4,5] made of particular superlattices of quantum layers at 3 nm scale.

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Abstract ID: 546

PERPENDICULAR MAGNETIC ANISOTROPY INDUCED BY AN INTERSITE CHARGE TRANSFER

Hiroshi Kageyama

Kyoto University, 615-8581, Kyoto, JAPAN
E-mail: yotoakane@gmail.com

Perovskite oxides ABO_3 continue to be a major subject in materials science because of its chemical and structural diversity1. Of particular interest is the interplay between A and B cations with finite d/f electrons, which, for example, causes inter-site charge transfer (ICT), leading to novel phenomane such as negative thermal expansion and metal-to-insulator transitions. The ICT properties are controlled by cationic substitution, but the mechanism is complicated by three-dimensional (3D) structures. Mixed-anion compounds began to draw attention as game-changing inorganic materials [1]. Since, compared with conventional inorganic compounds such as oxides, mixed-anion compounds may exhibit unique coordination and resultant extended structures, from which fundamentally different chemical and physical property may emerge. In my talk, a new oxyhydride $EuVO_2H$, prepared via anion-exchange reactions of $EuVO_3$ perovskite oxide, will be presented. $EuVO_2H$ with alternating layers of EuH and VO_2 exhibit ICT between the heteroanion layers. While bulk $EuVO_2H$ is a ferromagnetic insulator with T_C = 10 K, application of external pressure or biaxial strain from a substrate to a $EuVO_2H$ film causes ICT to occur from the $Eu^{II}H$ layer to the $V^{III}O_2$ layer. The strained film exhibits a 4-fold increase in T_C and, despite the absence of orbital angular momentum, Eu^{2+} exhibits giant magnetic anisotropy with its easy axis perpendicular to the film, which is favorable for devices such as high-density memory. The present results provide new possibilities for the acquisition of novel functions by alternating layered structures of heteroanions.

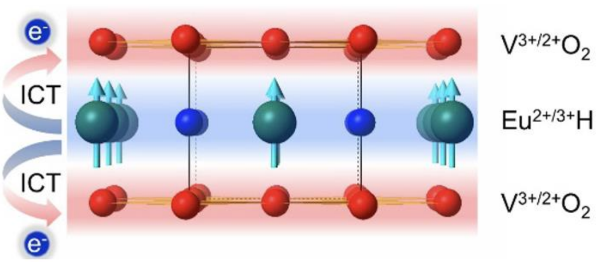

Fig. 1: *Intersite Charge Transfer in $EuVO_2H$.*

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Half-Plenary Session

05.05.2023 FRIDAY - 10.05.2023 WEDNESDAY

Abstract ID: 211

SUPERCONDUCTOR 3D NANOARCHITECTURES: TOPOLOGICAL AND GEOMETRICAL EFFECTS

V. M. Fomin[1,2]

[1] *Institute for Integrative Nanosciences, Leibniz Institute for Solid State and Materials Research (IFW) Dresden, D-01069 Dresden, GERMANY*

[2] *Laboratory of Physics and Engineering of Nanomaterials, Department of Theoretical Physics, Moldova State University, MD-2009 Chişinău, REPUBLIC OF MOLDOVA*

E-mail: v.fomin@ifw-dresden.de

Extending nanostructures into the third dimension has become a vibrant research avenue in condensed-matter physics, because of geometry- and topology-induced phenomena. Advances of high-tech fabrication techniques have allowed for generating geometrically and topologically nontrivial manifolds at the nanoscale, which determine novel electronic, magnetic, optical and transport properties of such objects and unprecedented potentialities for design, functionalization and integration of nanodevices [1]. Recently suggested Möbius-strip microcavities [2] are Berry-phase-programmable optical systems important for topological physics. Prospect directions and challenges in the domain of superconductivity and vortex matter in curved 3D nanoarchitectures and their potential for magnetic field sensing, bolometry, and information technology have been demonstrated [3]. A possibility to efficiently tailor the superconducting properties of 3D nanoarchitectures is opened up by inducing a nontrivial topology of superconducting screening currents. A topological transition between the vortex regime and phase slips under a strong transport current in open superconductor Nb nanotubes with a submicron-scale inhomogeneity of the normal-to-the-surface component of the applied magnetic field leads to a new hysteresis effect [4]. Dynamic topological transitions in open superconductor nanotubes occur under a dc+ac transport current [5], with a transition and co-existence between different regimes of superconducting dynamics (**Fig. 1**) as a key effect.
This work was supported by the COST Action CA21144.

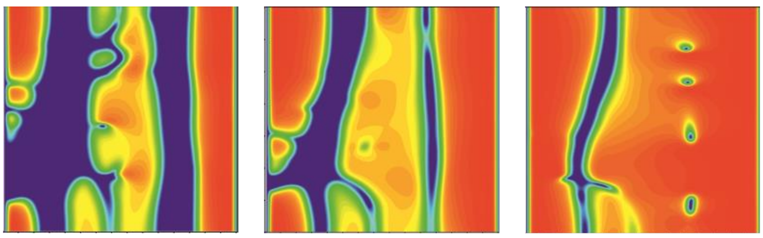

Fig. 1: *Typical dynamics of vortices and co-existence with phase slips in an open Nb nanotube under a dc+ac transport current. The order parameter modulus (from 0: blue to 1: red) for the dc density* $j_0 = 2.1 GAm^{-2}$*, the current modulation depth* $j_1/j_0 = 0.5$*, the ac frequency* $f = 0.6$ *GHz at* $B = 2mT$*. The sizes of panels (height × width) are equal to* $L\times 2\pi R$ *(length × circumference of the tube). (After [4])*

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Abstract ID: 494

CONTROL OF SPIN WAVES BY ONE-DIMENSIONAL MAGNETIC SOLITONS

Victor Laliena[1,2], Javier Campo[3]

1 University of Zaragoza, Dept. of Applied Mathematics, 50018, Zaragoza, SPAIN
2 University of Zaragoza, Institute of Mathematics and Applications (IUMA), 50009, Zaragoza, SPAIN
3 Spanish National Research Council - University of Zaragoza, Aragon Nanoscience and Materials Institute, 50009, Zaragoza, SPAIN

E-mail: laliena@unizar.es

The control of spin waves is one of the biggest challenges in Magnonics: without such control it would be very difficult to design any magnonic device. Some control of the spin waves can be achieved by exploiting the reflection and refraction at artificially made interfaces. However, the use of magnetic solitons to modify the propagation of spin waves has a number of advantages: solitons can be created, destroyed, and moved across a material by applying external stimuli like polarized currents, and they are free from the imperfections that are unavoidable at material interfaces. We discuss the properties of spin waves in the presence of one-dimensional magnetic solitons. Particular attention is paid to the scattering by one isolated magnetic soliton in a monoaxial helimagnet such as $CrNb_3S_6$. We show that the waves scattered by the soliton suffer a lateral shift which has an origin similar to the Goos-Hänchen effect of optics (Fig. 1) [1]. The shift is a fraction of the wavelength, but it can be greatly enhanced, in the frequency window in which the shift is significant and the transmission coefficient very close to one, by using an array of well separated solitons. This lateral shift, which is a consequence of the peculiar form of the spin wave operator, could be very useful to control the spin waves.

We also analyze the important role of the dipolar interaction. It was theoretically known since long time that the DW of an anisotropic ferromagnet is transparent to spin waves and does not induce a lateral shift of the scattered waves. In that theoretical analysis the dipolar interaction was approximated by an effective anisotropy. We show, using a perturbative approach, that the DW does actually reflect the spin waves and causes a lateral shift if the dipolar interaction is properly taken into account [2].

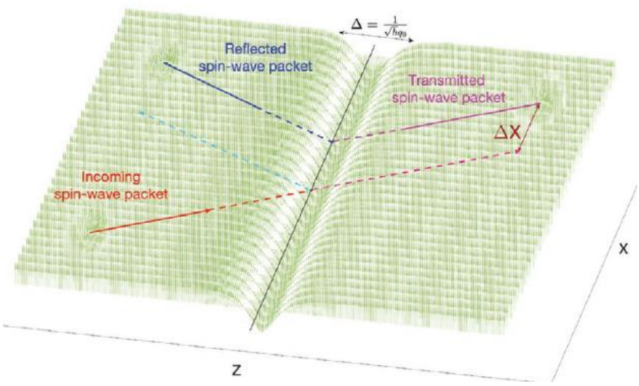

Fig. 1: *Lateral shift of the scattered spin waves.*

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Abstract ID: 182

CHIRALITY AND TOPOLOGY OF SPIN SYSTEM

Katsuya Inoue[1,2,3]

[1]*Chirality Research Center (CResCent), Hiroshima University, Higashihiroshima, Hiroshima JAPAN*
[2]*International Institute for Sustainability with Knotted Chiral Meta Matter (WPI-SKCM²), Hiroshima University, Higashihiroshima, Hiroshima JAPAN*
[3]*Department of Chemistry, Hiroshima University, Higashihiroshima, Hiroshima JAPAN*
E-mail: kxi@hiroshima-u.ac.jp

The concept of chirality, conceived in the wake of the right and left hand pairs, is applicable not only to form pairs but also to movement. Currently, the technical terms handedness for the former and helicity for the latter are used in science. When these two concepts are combined, we can link rotation and linear motion, like a right-handed screw that moves forward when rotated to the right. In chiral magnetic materials, chiral space groups of crystals, which are chirality of form, and spin structures, which are chirality of motion, can be strongly coupled [1]. Chirality is a scale-free concept that is valid from subatomic-scale to cosmic sizes. It is therefore thought to have similar effects at various scales and/or physical properties and even be transferred between different scales and/or physical properties.

As a result of the coupling between the chirality of shape and motion, the magnetic moment become chiral aligned in chiral magnets crystals. It has been found that structures of spins with various topologies are then stabilized [2]. These structures contain many twists and knots, and it is becoming clear that the twist directions and knots are also chiral [3].

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Abstract ID: 110

ULTRA-FAST VORTEX DYNAMICS IN NANOENGINEERED SUPERCONDUCTORS

Oleksandr V. Dobrovolskiy

University of Vienna, Faculty of Physics, 1090 Vienna, AUSTRIA
E-mail: oleksandr.dobrovolskiy@univie.ac.at

The recent great interest in superconductor films with the critical current I_c approaching the depairing current I_d is caused by the close-to-I_d bias regime of superconducting microstrip single-photon detectors (SMSPDs) [1], ultrafast vortex motion at large transport currents [2], and the phenomena of generation of sound [3] and spin [4] waves at vortex velocities of a few km/s. In this context, the issue of high I_c is related to blocking of the penetration of vortices via the strip edges, its control via material and edge-barrier engineering, and knowledge of the effects of various edge defects on the penetration and patterns of Abrikosov vortices.

In my talk, I will review our recent results on the ultra-fast vortex motion in superconductors [5]. Namely, high structural uniformity [6], fast relaxation of heated electrons [7] and perfect edges [8] are required for the ultra-fast vortex motion at velocities exceeding 10 km/s.

I will further discuss vortex patterns upon penetration of vortices from single edge defects and consider the evolution of patterns from *vortex chains* over *vortex jets* to *vortex rivers* with increase of the transport current [9]. Next, an attempt will be made to deduce the maximal vortex velocity v^* from the current-voltage (I-V) curves at zero magnetic field (SMSPD operation condition). This attempt will be hindered by the unknown number of vortices, n_v, and the fact that a small number of fast-moving vortices can induce the same voltage as a large number of slow-moving ones.

To resolve this issue, I will introduce an approach for the quantitative determination of n_v and v^* [10]. Its idea is based on the Aslamazov-Larkin prediction [11] of kinks in the I-V curves of wide and short superconducting constrictions when the number of fluxons crossing the constriction is increased by one. We realize such conditions in wide MoSi thin strips with slits milled by a focused ion beam and reveal quantum effects in a macroscopic system. By observing kinks in the I-V curves with increase of the transport current, we evidence a crossover from a single- to multi-fluxon dynamics and deduce $v^* \simeq 12$km/s. Our experimental observations are augmented with numerical modeling results which reveal a transition from a vortex chain over a vortex jet to a vortex river with increase of n_v and v^*. In all, our findings are essential for the development of 1D and 2D few-fluxon devices and provide a demanded approach for the deduction of maximal vortex velocities at the SMSPD operation conditions.

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Abstract ID: 501

SPIN AND ORBITAL CURRENTS IN DIRAC SEMIMETALS AND TOPOLOGICAL INSULATORS

M. Hayashi

The University of Tokyo, Dept. of Physics, 113-0033, Tokyo, JAPAN
E-mail: hayashi@phys.s.u-tokyo.ac.jp

Generation of spin current is essential for developing magnetic memory technologies based on spin-orbit torque. Recent studies show that unique characteristics of topological insulators, Weyl semimetals and van der Waal heterostructures as an efficient source of spin current. It many cases, it is the large spin Berry curvature associated with the electronic structure of the host material that facilitates generation of spin current.

We have studied the spin Hall effect in topological materials, with particular focus on semimetals that possess Dirac-like electronic bands[1,2]. In a Dirac semimetal, we find the spin Hall conductivity takes a maximum near the Dirac point and decreases with increasing carrier density. The sign of the spin Hall conductivity is the same regardless of the position of the Fermi level. These features can be accounted for quantitatively using a Dirac Hamiltonian model if spin current is defined as a flow of spin magnetic moment. The results demonstrate that the giant spin magnetic moment, with an effective *g*-factor that approaches 100, is responsible for the spin Hall effect. As we have recently established optical means to assess current induced magnetic moments that accumulate at the surface, the size of spin and possible orbital currents that emerge in topological materials will be discussed in the talk.

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Abstract ID: 400

EXPERIMENTALLY ESTABLISHED UNIVERSAL AND NON-UNIVERSAL PROPERTIES THAT DEFINE THE PHYSICS OF CUPRATES

Neven Barišić[1,2]

[1]*Institute of Solid State Physics, TU Wien, Wiedner Hauptstraße 8, 1040 Wien AUSTRIA*
[2]*Department of Physics, University of Zagreb, Bijenička cesta 32, 10000, Zagreb, CROATIA*
E-mail: nbarisic@ifs.hr

Parent compounds of cuprates are charge-transfer insulators with one charge (n_{loc}) localized within a CuO_2 plaquette due to strong correlations. Superconductivity is universally observed in the range of doping between $p\sim$ 0.04 - 0.05 (underdoped) and 0.30 - 0.35 (overdoped) with a maximal value of the superconducting transition temperature (T_c) around $p \sim 0.16$. Above $p \sim$ 0.30 - 0.35, cuprates exhibit only Fermi-liquid behavior. This common pattern implies that the origin of superconductivity stems from universal normal-state behavior, while the wide variation, more than an order of magnitude, in observed maximal T_c's is due to more subtle non-universal effects which tune the superconductivity in particular compounds.

Based on now well-established universal transport [1] and optical conductivity [2,3] properties, we show that the phenomenology of cuprates across the phase diagram is fully captured [4,5] by the charge conservation relation:

$$1 + p = n_{loc} + n_{eff}$$

with the superfluid density that simply corresponds to:

$$\rho_S = n_{eff} \cdot (O_S\, n_{loc})$$

where n_{eff} is the carrier density, which can be directly determined experimentally [1-5], while O_S is a compound-dependent constant [5]. The Fermi-liquid nature of n_{eff} is unambiguously determined by two experimentally confirmed scalings [2,3,6], while it was firmly established that the scattering rate and Fermi-velocity are essentially compound- and doping-independent and thus universal [1-7]. The doping and temperature evolution of n_{loc} reveals a gradual (percolative [8]) delocalization from a value of 1 in the underdoped to 0 in the overdoped regime that is universal for all cuprates [4,5]. As directly obvious from optical spectroscopy, it is n_{eff} that becomes superconductive, while n_{loc} provides the glue [3,5]. We attribute the distinction between low- and high-T_c cuprates to the fine-tuning of the p–d–p fluctuation of the Cu-localized hole (n_{loc}) visiting the neighboring planar–oxygen atoms, which is the reason for the material-dependence embodied in the constant O_S [5].

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Abstract ID: 556

SPIN-ORBIT TORQUE SWITCHING OF MAGNETIC TUNNEL JUNCTIONS FOR MEMORY APPLICATIONS

K. Garello

SPINTEC, Univ. Grenoble Alpes, CEA/CNRS, F-38000 Grenoble, FRANCE

E-mail: kevin.garello@cea.fr

The adoption of the Spin-transfer Torque Magnetic Random Access Memory (STT-MRAM) technology by the main microelectronics industrial actors represents a major achievement of spintronics R&D. Thanks to its unique combination of assets, MRAM can be used for memory applications that other emerging non-volatile memory technologies cannot address, particularly CMOS voltage compatibility, write speed and write endurance. In fact, STT-MRAM is nowadays introduced in chips as replacement of embedded FLASH. Improving speed and power limitations of STT mechanism, Spin-orbit torque (SOT) MRAM has emerged as a credible next-generation MRAM technology targeting replacement of SRAM and offering a better footprint than CMOS-based SRAM. More advanced MRAM family concepts, based on voltage control of anisotropy (VCMA), and interconversion between spin and charge current may open the route towards ultra low power applications.

Across this presentation, I will introduce the different MRAM families and potential benefits for embedded memories [1], after what I will focus on the different challenges to take up SOT-MRAM from material and stack optimization to technology large-scale integration and circuit design [2]. I will describe typical full-scale integration process of perpendicular magnetized SOT-MRAM devices on 300mm wafers, using manufacturable field free methods and CMOS compatible processes. Finally, I will discuss progress challenges in material development, as well as cell and architecture design required to bring SOT-MRAM toward industrial maturity. I will conclude on some opportunities to diverse its application spectra, notably in the field of machine learning.

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Abstract ID: 475

DESIGN OF STRONGLY CORRELATED QUANTUM MATERIALS

Ryan E. Baumbach[1,2]

[1]*National High Magnetic Field Laboratory, Florida State U., 32309, Tallahassee, USA*
[2]*Department of Physics, Florida State U., 32309, Tallahassee, USA*
E-mail: baumbach@magnet.fsu.edu

At the core of research into crystalline inorganic materials is the search for new phenomena that extend our grasp of nature and produce transformative new technologies. During the 20th century, this resulted in dramatic advances that centered on a new quantum understanding of metals, semiconductors, magnetism, superconductivity, and other phenomena. At present, we again find ourselves in the midst of a second quantum revolution where electrons are being trained to do new tricks: e.g., in anomalous correlated electron metals, unconventional superconductors, and materials with topologically protected electronic states. In this talk I will examine the factors that produce these behaviors, and will offer a phenomenological map that we have developed to guide exploration strongly correlated f-electron materials [1-4]. At the same time, I will highlight the diverse synthesis methods are needed to leverage the potential of the entire periodic table. By doing this, I will bring together the diverse elements of the field of New Materials Physics, and thereby describe my perspective on how to develop the next generation of materials for society.

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Oral Sessions

05.05.2023 FRIDAY - 10.05.2023 WEDNESDAY

New Phenomena and Applications in Molecular Magnets I-II

05.05.2023 FRIDAY

Abstract ID: 98

POLARIZED NEUTRON DIFFRACTION: A KEY TOOL TO PROBE SPIN DENSITY AND LOCAL ANISOTROPY IN MOLECULAR BASED MAGNETS

A. Goukassov, I. Kibalin

Laboratoire Léon Brillouin, CEA-CNRS, CE-Saclay, 91191 Gif-sur-Yvette, FRANCE
E-mail: arsen.goukassov@cea.fr

Magnetic anisotropy is an inherent characteristic of magnetic materials describes the response of the magnetization to a magnetic field. Polarized neutron diffraction (PND) is a powerful method for characterizing the local magnetic anisotropy. This technique is based on the susceptibility approach, where measured flipping ratios are used to fit the local magnetic susceptibility tensors for each magnetic site, which allows quantifying the magnetic anisotropy at the atomic level [1]. It became a reference in mapping the magnetic anisotropy at the atomic scale in molecular based magnets [2].

Recently, this approach has been extended to study the magnetic anisotropy in powders [3], which opens large possibilities in the studies of highly interesting powder materials, like frustrated magnets [4], multiferroics, single molecule magnets[5] or nanoscale systems. In the talk, we review the recent studies using PND to analyze the local magnetic anisotropy in molecular magnets. On an example of single-molecule magnet with Co (II) complex we show that the crystallites in a high magnetic field start orient their easy axes along the field, (Fig.1b) [3], thus creating a “magnetically induced preferred orientation”. We show that this effect improves the precision in the determination of the local susceptibility parameters in complex compounds. Newly developed "CrysPy" library applied for the PND data analysis will be also presented [6].

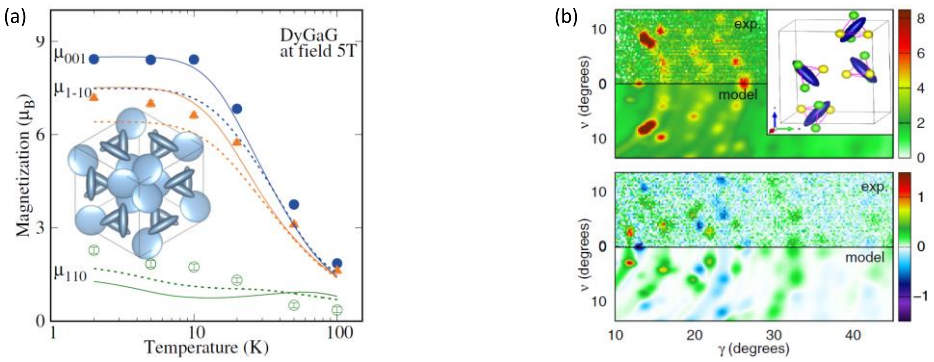

Fig.1: *(a) Magnetization components versus temperature for DyGaG. Insets show magnetization ellipsoids. (b) The measured and calculated flipping sum (top) and difference (bottom) diffraction patterns collected on Co([(CH$_3$)$_2$N]$_3$CS)$_2$Cl$_2$ at 2K, 5T*

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Abstract ID: 199

MODIFICATION OF THE GROUND STATE TOTAL SPIN IN Cr_{10} SINGLE-MOLECULE WHEELS INDUCED BY DEPOSITION ON A METALLIC SUBSTRATE

E. Bartolomé[1], L. Ferrari[2], F. Sedona[2], A. Arauzo[3,4], J. Rubín[3,5], J. Luzón[6], J. Herrero-Albillos[3,5], M. Panighel[7], A. Mugarza[8,9], M. Rancan[10], M. Sambi[2], L. Armelao[2], J. Bartolomé[3,4], F. Bartolomé[3,4]

[1]*Escola Universitària Salesiana de Sarrià (EUSS), Barcelona, SPAIN*
[2]*Dept. di Scienze Chimiche, Università di Padova, Padova, ITALY*
[3]*Instituto de Nanociencia y Materiales de Aragón (Universidad de Zaragoza – CSIC), Zaragoza, SPAIN*
[4]*Dept. de Física de la Materia Condensada, Universidad de Zaragoza, Zaragoza, SPAIN*
[5]*Dept. de Ciencia y Tecnología de Materiales y Fluidos, EINA, Universidad de Zaragoza, Zaragoza, SPAIN*
[6]*Centro Universitario de la Defensa, Zaragoza, SPAIN*
[7]*CNR-IOM, Laboratorio TASC, Basovizza, 34149, Trieste, ITALY*
[8]*Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and Barcelona Institute of Science and Technology, Barcelona, SPAIN*
[9]*ICREA - Institució Catalana de Recerca i Estudis Avançats, 08010 Barcelona, SPAIN*
[10]*Institute of Condensed Matter Chemistry and Technologies for Energy (ICMATE), National Research Council (CNR), c/o Department of Chemical Sciences, University of Padova Padova, ITALY*

E-mail: jrubin@unizar.es

We report the sublimation of monolayers and multilayers of $\{Cr_{10}(OMe)_{20}(O_2CCMe_3)_{10}\}$ wheels, hereafter $\{Cr_{10}\}$, onto Au(111) and Cu(111) single-crystal substrates, and their characterization combining scanning tunneling microscopy (STM) and X-ray magnetic circular dichroism (XMCD). $\{Cr_{10}\}$ in bulk shows axial anisotropy and an intermediate cluster total spin $S = 9$ ground state, stemming from an interaction scheme of two semi-crowns containing four Cr^{3+} ions interacting ferromagnetically, separated by two Cr^{3+} ions antiferromagnetically coupled to their nearest neighbours [1]. The one-monolayer (1ML) samples of $\{Cr_{10}\}$ sublimated on Ag(111) and Cu(111) showed slightly different applied magnetic field dependence of XMCD, revealing that even small distortions produced by accommodation to the substrate influence the wheel's magnetic properties. The field dependence of the magnetization evolves from a smooth curve for the 1ML $\{Cr_{10}\}$ samples to a curve resembling the bulk as the number of layers is increased, as shown in an intermediate 14ML sample. Monte Carlo simulations allow to rationalize the magnetization curves of the 1ML samples in terms of a reduction of the cluster ground-state total spin, as a consequence of variations in the intra-wheel exchange coupling interactions induced by the on-surface deposition.

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Abstract ID: 433

CHIRALITY, MOLECULES AND MAGNETISM

Prasanna S. Ghalsasi[1], Katsuya Inoue[2]

[1]*Department of Chemistry, Faculty of Science, The M. S. University of Baroda, Vadodara, Gujarat, 390 002 INDIA*
[2]*Department of Chemistry, Graduate School of Science, Hiroshima University, Hiroshima, 739- 8526 JAPAN*
E-mail: Prasanna.ghalsasi-chem@msubaroda.ac.in

Chirality is omnipresent from particle physics, molecular chemistry to cosmology.[1] Human, in particular pharmaceutical science, employed chirality to design and develop medicines for treatment of various diseases and disorders. On the other hand, its use in material science is still far from its actual potential [1], mainly because of the absence of proper synthetic methodology. Attempts in this latter aspect will be presented in detail.

Most common strategy for induction of chirality in the molecular magnets is based on inserting chiral moiety in - (a) secondary coordination sphere [2]- as an auxiliary ligand ligating to the magnetic center by the covalent bonding; (b) primary coordination sphere- as a counter cation with ionic bonding. Both these strategies employ halides or pseudo halides such as cyanides, azides for magnetic superexchange. Recently we focused on strategy (b), where chloride mediated Organic-Inorganic Hybrid compounds, A_2CuCl_4, with distorted perovskite type structures were synthesized [3]. Past and present attempts of spontaneous crystallization at solid-liquid and solid-gas interface to observe chiral induction will be discussed [4].

Novel role of molecular level chirality during the formation of magnetic metal oxide structures is envisioned, based on earlier work [5]. Although this concept is analogous to sol-gel mediated synthesis of metal oxides, novelty lies in the application of kinetic method of separating chiral organic salt which in turn induces chirality in concurrently forming Fe_2O_3 [6]. This soft-chemistry method where co-crystallization of chiral organic salt and Fe_2O_3 happens '*isscho-ni*' (Japanese word for together), generates chiral phase in latter. Our results in this direction will be presented.

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Abstract ID: 250

BICOMPONENT ION-PAIR COMPLEXES $[Mn(5\text{-}Hal\text{-}sal_2 323)]_2[ReCl_6]$ (Hal = Cl, Br) EXHIBITING BOTH THERMALLY INDUCED SPIN CROSSOVER AND FIELD-INDUCED SINGLE-ION MAGNETISM

A.V. Kazakova,[1] A.V. Tiunova,[1,2] D.V. Korchagin,[1] G.V. Shilov,[1] E.B. Yagubskii[1]

[1]*Federal research center of Problems of Chemical Physics and Medicinal Chemistry RAS, 142432, Chernogolovka, RUSSIA*
[2]*Lomonosov Moscow State University, 119991 Moscow, RUSSIA*
[3]*National University of Science and Technology "MISiS", 119049 Moscow, RUSSIA*
E-mail: kazakova@icp.ac.ru

The cationic complexes of Mn(III) with the 5-Hal-$sal_2$323 (Hal = Cl, Br) ligands and a paramagnetic doubly charged counterion $[ReCl_6]^{2-}$ have been synthesized: $[Mn(5\text{-}Cl\text{-}sal_2 323)]_2[ReCl_6]$ (**1**) and $[Mn(5\text{-}Br\text{-}sal_2 323)]_2[ReCl_6]$ (**2**). Their crystal structures and magnetic properties have been studied. These isostructural two-component ionic compounds show a thermally induced spin transition at high temperature associated with the cationic subsystem and a field-induced frequency dependent ac magnetic susceptibility at low temperature, associated with the anionic subsystem. The study of the crystal structures of the complexes at 6 temperatures (100, 240, 300, 350, 403, and 423 K) and their *dc* magnetic properties showed that cation Mn1 at 100 K is in the low-spin state with S = 1, and as the temperature rises to 423 K gradually passes into a high-spin state (S = 2), which is accompanied by an increase in the Mn-N bond lengths and a significant distortion of the $Mn1N_4O_2$ octahedral parameters. In contrast to Mn1, cation Mn2 is in the high-spin state over the entire temperature range studied. To probe the possible relaxation behavior of **1** and **2**, associated with the $[Re^{IV}Cl_6]^{2-}$ anion [1], the ac susceptibility was studied in a *dc* field of 3000 Oe at frequencies of 100-10000 Hz and temperatures of 2-3 K. Both the in-phase χ' and out-of-phase χ'' susceptibilities show frequency dependent signals in the temperature range of 2.0 to 2.75 K indicating slow relaxation of magnetization and, therefore, single-ion magnet (SIM) phenomenon. Until now, only one case of the manifestation of single-ion magnetic behavior of the $[Re^{IV}Cl_6]^{2-}$ anion has been known in the literature [1]. The compounds are the first examples of the coexistence of spin crossover and field-induced slow magnetic relaxation in the family of known $[Mn^{III}(sal_2 323)]$ cationic complexes with various counterions.

The work was carried out with the financial support of the Ministry of Education and Science of Russia (grant № 75-15-2020-779) and has been supported by the state assignment of the Ministry of Science and Higher Education of the Russian Federation (No. AAAA-A19-119092390079-8).

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Abstract ID: 299

QUANTUM CRITICALITY AND ANOMALOUS MAGNETIZATION IN A PURELY ORGANIC SPIN LADDER

M. Pardo-Sainz[1,2], T. Ono[2], I. F. Diaz-Ortega[3], T. Kihara[3], H. Nojiri[3], Y. Kono[4], T. Sakakibara[4], H. Yamaguchi[2], Y. Hosokoshi[2], J. Campo[1]

[1]Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC - Universidad de Zaragoza, 50009, Zaragoza, SPAIN
[2]Osaka Metropolitan University, 599-8231, Sakai, JAPAN
[3]Institute for Materials Research, Tohoku University, 980-0812, Sendai, JAPAN
[4]Institute for Solid State Physics, University of Tokyo, 277-0882, Kashiwa, JAPAN
E-mail: miguel.pardo@csic.es

The study of quantum spin systems has attracted much attention for several decades [1]. Recently spin-ladder systems, which are in the crossover region between one and two dimensions, have been at the focus of intensive research towards its understanding, since peculiar phenomena, such as the superconductivity in a hole doped S=1/2 two-leg spin ladder, are expected to appear [2, 3]. However, a major challenge in studying these systems is the difficulty in accessing the spin gap, which is only small enough for experimental measurement in the case of certain organometallic or purely organic magnets [1].

Here we present the compound 4-F-2-NNBIP [= 4-fluoro-2-(1-oxyl-3-oxide-4,4,5,5-tetramethylimidazolin-2-yl) biphenyl], which has been characterized by means of X-ray diffraction, electron paramagnetic resonance (EPR), specific heat, magnetization and susceptibility measurements. The analysis of the experimental data together with numerical calculations show that this system can be well described by a S=1/2 two-leg Heisenberg antiferromagnetic ladder, and we propose the magnetic phase diagram shown in Fig.1. However, a change of slope not characteristic of these systems is observed in the magnetization data at intermediate fields (see left of Fig.1), so its possible origin is discussed.

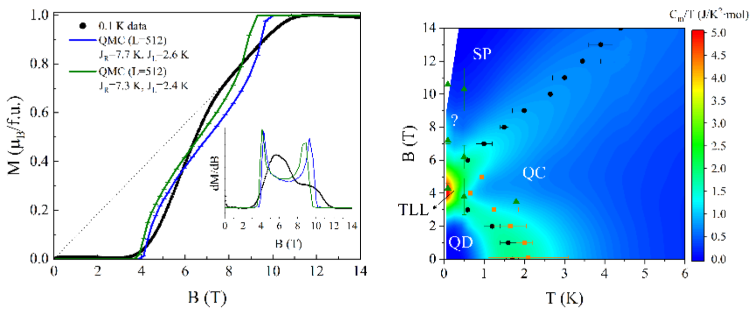

Fig. 1: *Left: magnetization curve (black dots) and its comparison with theoretical curves obtained from QMC calculations. The inset shows the derivative dM/dB. Right: field-temperature phase diagram showing quantum disordered (QD) or spin liquid, quantum critical (QC), Tomonaga-Luttinger liquid (TLL) and spin polarized (SP) phases. The contour plot shows the magnetic specific heat as C_m/T and maxima are indicated by black circles. Orange squares denote the maximum of $d\chi/dT$, while green triangles mark the critical fields obtained from the magnetization data.*

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Abstract ID: 364

STRAIN SWITCHING IN VAN DER WAALS HETEROSTRUCTURES TRIGGERED BY A SPIN-CROSSOVER METAL–ORGANIC FRAMEWORK

S. Mañas-Valero, C. Boix-Constant, E. Coronado

University of Valencia - ICMol, 46980 Paterna, Valencia, SPAIN
E-mail: samuel.manas@uv.es

Van der Waals heterostructures (vdWHs) provide the possibility of engineering new materials with emergent functionalities that are not accessible in another way. These heterostructures are formed by assembling layers of different materials used as building blocks. Beyond inorganic 2D crystals, layered molecular materials remain still rather unexplored, with only few examples regarding their isolation as atomically thin layers.

Here,[1] the family of van der Waals heterostructures is enlarged by introducing a molecular building block able to produce strain: the so-called spin-crossover (SCO). In these metal–organic materials, a spin transition can be induced by applying external stimuli like light, temperature, pressure, or an electric field. In particular, smart vdWHs are prepared in which the electronic and optical properties of the 2D material (graphene and WSe_2) are clearly switched by the strain concomitant to the spin transition. These molecular/inorganic vdWHs represent the deterministic incorporation of bistable molecular layers with other 2D crystals of interest in the emergent fields of straintronics and band engineering in low-dimensional materials.

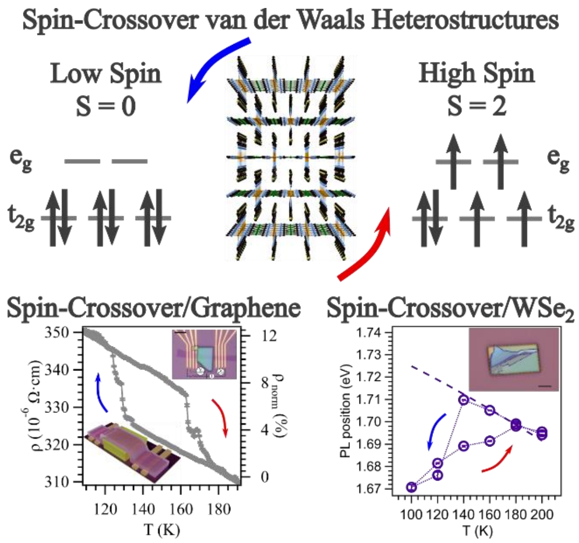

Fig. 1: *Spin-crossover (SCO) transition in the layered molecular metal–organic framework {Fe-(3-Clpyridine)$_2$-[Pt^{II}(CN)$_4$]} and its impact in the properties of van der Waals heterostructures formed by few-layers graphene or monolayer WSe_2.*

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Superconducting Motors and Applications in Electrical Engineering I-II

05.05.2023 FRIDAY

Abstract ID: 150

REALIZATION AND TESTS OF A SYNCHRONOUS GENERATOR WITH HTS ARMATURE WINDINGS

Y. Statra, H. Menana, B. Douine

Group of Research in Electrical Engineering of Nancy (GREEN), University of Lorraine, F-54000 Nancy, FRANCE
E-mail: hocine.menana@univ-lorraine.fr

High temperature superconductors (HTS) have been successfully used as inductors in synchronous machines [1]. However, their use in the armature windings is avoided in order to prevent the AC losses and the inherent cryogenic costs. The aim of this work is to show the possibility to develop synchronous machines with armature windings made of HTS. The construction and the preliminary tests of an axial field HTS synchronous generator prototype are presented. The realized HTS machine is composed of a 3-phase stator with three pancake coils made of BSCCO tape HTS windings, and a rotor composed of four NdFeB permanent magnets (Fig.1).

Several tests have been conducted at liquid nitrogen temperature. The measurements have been comforted by modeling results obtained by a 3D finite element model of the studied machine. Investigations on AC loss and their measurement for HTS coils mounted on iron part are also carried out, by using the method described in [2].

The preliminary tests on the prototype, in both modeling and measurements, are very promising [3].

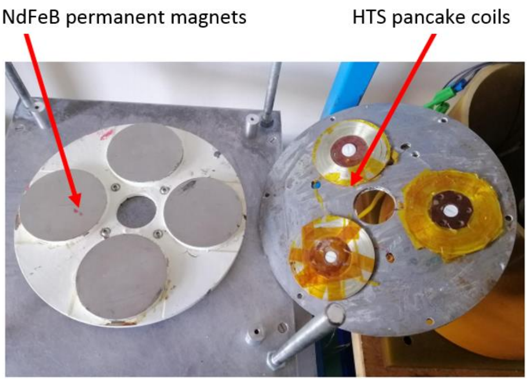

Fig. 1: *The stator and rotor of the realized HTS synchronous machine prototype.*

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Abstract ID: 262

ELECTROMAGNETIC DESIGN OF ULTRA-HIGH SPEED SUPERCONDUCTING MOTORS APPLIED FOR ELECTRIC PUMPS IN LIQUID-PROPELLANT ROCKETS

Y. Terao[1], S. Fuchino[1], Y. Mawatari[2], Y. Yoshida[2], A. Matsumoto[3], M. Sugano[4], S. Awaji[5]

[1]*The University of Tokyo, 277-0882, Kashiwa-city, JAPAN*
[2]*National Institute of Advanced Industrial Science and Technology, 305-8560, Tsukuba-city, JAPAN*
[3]*National Institute for Materials Science, 305-0047, Tsukuba-city, JAPAN*
[4]*High Energy Accelerator Research Organization, 305-0801, Tsukuba-city, JAPAN*
[5]*Tohoku University, 980-8577, Sendai-city, JAPAN*
E-mail: yterao8934@g.ecc.u-tokyo.ac.jp

Electric pumps for liquid propellant rocket engines can improve controllability of thrust and velocity as well as simplifying piping configurations [1,2]. However, the output power density of motors for the electric pump systems should be higher than that of state-of-the-art motors. We propose new superconducting (SC) motors consist of permanent magnet rotor and MgB_2 SC armature windings (Fig. 1). The SC motors are to be applied to liquid hydrogen feeding pumps, in Fig. 2, of 100 kW at 50,000 rpm applied for 30 kN class liquid-propellant rockets. In this presentation, finite element analysis is conducted for electromagnetic design of the SC motors and some motor characteristics in relation with the MgB_2 SC wire features are to be discussed.

Acknowledgement

This research is supported by TIA collaborative research program, "Kakehashi" in 2022. And we would like to thank Dr. Hideki Tanaka in Hitachi Co. Inc. for many helpful comments and discussions about MgB_2 SC wires for the SC motor designs and AC loss estimations.

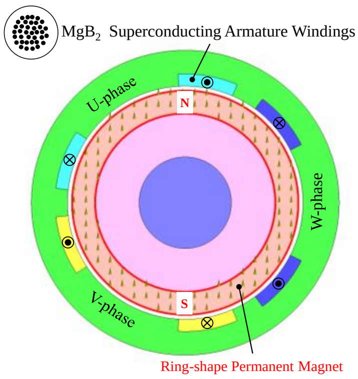

Fig. 1: *A Superconducting motor using permanent magnet and MgB_2 armature windings.*

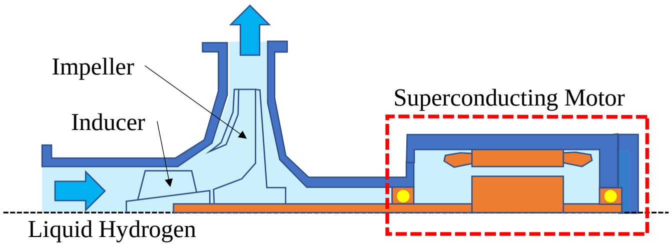

Fig. 2: *Arrangement of liquid hydrogen pump using a superconducting motor.*

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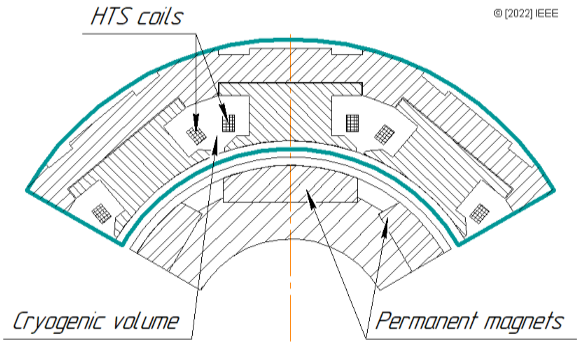
Abstract ID: 378

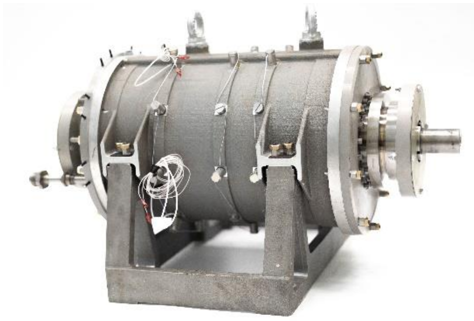
TEST RESULTS OF 90 kW HTS GENERATOR FOR SMALL-SCALE DEMONSTRATOR OF GENERATING SYSTEM

N. Ivanov, S. Zhuravlev, M. Zdorova, A. Shirokov, S. Zanegin, V. Merkushov, A. Suhanov

Moscow Aviation Institute, 125993, Moscow, RUSSIA
E-mail: n.s.ivanov88@gmail.com

Several projects of HTS electrical machines were introduced in the recent years [1,2]. This paper represents the results of calculation, modeling and testing of a 90 kW 6000 rpm synchronous machine with HTS armature winding. The considered machine consists of permanent magnet rotor and 3-phase stator HTS winding which contains 9 double pancake racetrack coils. All of the HTS coils for armature winding were produced and tested [1]. Due to the design features of the coils, additional modeling has been carried out to determine the degradation of the critical current and identify the manufacturing quality criteria of the coils. According to experimental results, their critical current matches the calculated value and ranges from -6% to +3% of the average value, so repeatability has been achieved. Finally, machine was assembled and tested. Cooling time, critical currents of stator phases, no-load and on-load tests were produced.





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Abstract ID: 274

THE DESIGN OF AN EXPERIMENTAL PROTOTYPE OF A FULLY SUPERCONDUCTING ELECTRIC MACHINE WITH HTS-2G STATIONARY WINDINGS

R. Ilyasov, D. Dezhin, G. Kuznetsov

Moscow aviation institute, Dept. Electric power, electromechanical and biotechnical systems, 125993, Moscow, RUSSIA
E-mail: ilyasovri@mai.ru

The design of an experimental prototype of a fully superconducting electric machine with HTS-2G stationary windings has been developed. Combined excitation is carried out jointly by permanent magnets on the rotor and axial excitation windings on the stator (fig.1). Stationary windings on the stator are placed in individual cryostats, which eliminates the need for sliding seals and current collectors. The prototype has a power of 100 kW at a speed of 6000 rpm, with the possibility of boosting the speed to 12000 rpm and increasing the rated power to 200 kW. To ensure operability at 15% power in the event of an emergency absence of a cryoagent, the prototype has an independent backup set of armature and axial excitation copper windings. This made it possible at the first stage to carry out tests without installing superconducting windings. The prototype is made in the form of a two-package scheme, which makes it possible to shift the phases of various packages by an arbitrary geometric angle. The windings of the packages can be connected in 3 phases, in 6 phases, in two sets of three phases with a shift of 30 electrical degrees, in order to reduce the amplitude of ripples when working on a rectifier.

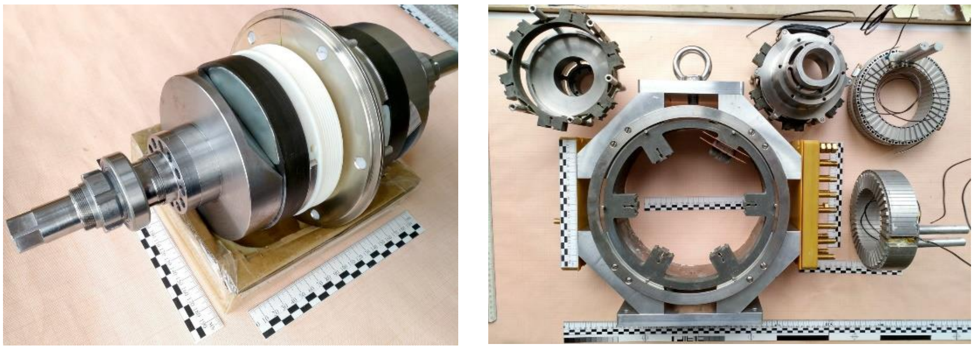

Fig. 1: *The Rotor and Stators parts.*

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Abstract ID: 280

OPTIMUM DRIVE CONDITION FOR HIGH TEMPERATURE SUPERCONDUCTING INDUCTION/ SYNCHRONOUS MOTOR AND PWM FULL-BRIDGE INVERTER SYSTEM

T. Nakamura, M. Yamamoto

Kyoto University, Dept. of Electrical Engineering, 6158510, Kyoto, JAPAN
E-mail: nakamura.taketsune.2a@kyoto-u.ac.jp

We are researching and developing a High Temperature Superconducting Induction/ Synchronous Motor (HTS-ISM) [1] system aiming at practical use for transportation equipment (ships, automobiles, aircraft). In the above development, it is important to study the system including not only the motor body but also the inverter. In this study, we analytically investigate the optimum driving conditions for a rotating system that combines an HTS-ISM and a pulse width modulation (PWM) full-bridge inverter.

The characteristics of the HTS-ISM are modeled by coupling the nonlinear voltage equations and the equation of motion. In the PWM inverter, an Insulated Gate Bipolar Transistor (IGBT) is introduced as a semiconductor element, and its switching loss, on-state loss, and on-state resistance of the freewheel diode are considered in the circuit modeling. Fig. 1 shows the analysis results of starting characteristics of a 50 kW class HTS-ISM [2]. In the figure, control is applied so that the steady rotation speed is reached in 10 s. As shown in the inset figure, when a PWM voltage waveform with a carrier frequency of 5 kHz is applied, slip value increases due to the appearance of the finite flux-flow resistance, compared to when an ideal sinusoidal voltage is applied. In other words, the dissipation inside the HTS-ISM is large when PWM driving. In other words, it is shown that the characteristic evaluation combined with the inverter characteristics is essential because the loss inside the HTS-ISM increases when PWM driving. In order to reduce the loss on the motor side, the carrier frequency of the inverter should be increased. However, a high carrier frequency causes a problem that the switching loss of the inverter increases. In this presentation, we plan to discuss the optimum driving frequency and configuration of the system from the above point of view.

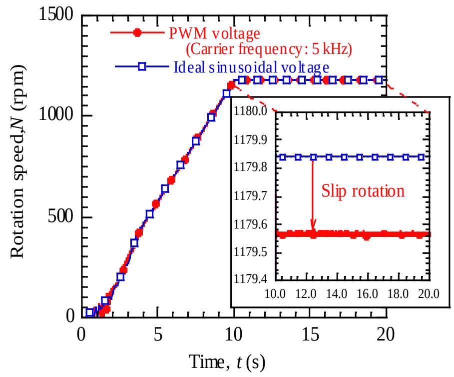

Fig. 1: *Analysis results of starting characteristics of 50 kW class HTS-ISM [2].*

Acknowledgements

We would like to thank Mr. Tomoharu Karashima and Mr. Masaya Okuno for their helpful discussions when they were students at Kyoto University. This work was supported by JSPS KAKENHI under Grants no. 22H01471.

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Superconducting, Magnetic, Topological Arsenides and Tellurides I-II

05.05.2023 FRIDAY

Abstract ID: 291

SYNTHESIS OF IRON-BASED SUPERCONDUCTORS BY MECHANICAL ALLOYING

V.A. Vlasenko, A.S. Medvedev, K.S. Pervakov

V.L. Ginzburg Centre for High-Temperature Superconductivity and Quantum Materials, P.N. Lebedev Physical Institute of the Russian Academy of Sciences (LPI RAS), 53, Leninsky Ave., 119991 Moscow, RUSSIA
E-mail: pervakovks@lebedev.ru

Here we report on successfully synthesized electron-doped ($BaFe_{2-x}Ni_xAs_2$) and hole-doped ($Ba_{1-x}(Na/K)_xFe_2As_2$, $Sr_{1-x}Na_xFe_2As_2$) bulk superconductors by high-energy mechanical alloying (MA) technique [1-3]. In this work we used a Fritsch Pulverisette 7 Premium Line planetary ball mill with tungsten carbide milling garnet. The volume ratio in all cases for milling balls, grinding material and free space was about 1:1:1. The starting reagents were high purity elemental Ba, Sr, Na, K, Ni and precursor FeAs synthesized beforehand. The bulk compounds were prepared in several steps: reagents were taken in a stoichiometric ratio, placed into the milling jar together with milling balls and placed into the planetary ball mill. The milling process was carried out in several (up to 36) cycles at 800 rpm for 5 min, followed by standing for 3 min for milling garnet cooling. In order to control the MA process, after each 15 min of grinding, the tungsten carbide milling jar was opened inside an argon box, and the mixture was characterized by X-ray diffraction (XRD).

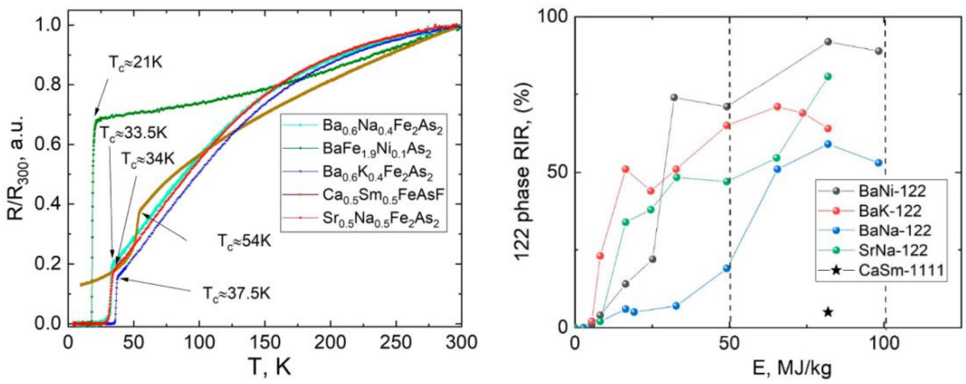

Fig. 1: *Resistivity measurements (left panel) and phase volume fraction (right panel) [3]*

The MA process results in homogeneous amorphous phases of $BaFe_2As_2$ and $SrFe_2As_2$. It was found that the optimum time for high-energy milling in all cases is about 1.5–2 h, and the maximum amount of amorphous phase could be obtained when energy of 50–100 MJ/kg was absorbed by the powder (Fig.1). After a short-term heat treatment, we obtained nearly optimum doped superconducting bulk samples. Therefore, MA is a potential scalable method to produce bulk superconducting material.

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Abstract ID: 295

DEFECTS INFLUENCE ON SUPERCONDUCTING PROPERTIES IN $EuRbFe_4As_4$ COMPOUND

V.A. Vlasenko, A. Yu. Degtyarenko, A.V. Sadakov, O.A. Sobolevskiy, A.S. Usoltsev, K.S. Pervakov

V.L. Ginzburg Centre for High-Temperature Superconductivity and Quantum Materials, P.N. Lebedev Physical Institute of the Russian Academy of Sciences (LPI RAS), 53, Leninsky Ave., 119991 Moscow, RUSSIA

E-mail: vlasenkovlad@gmail.com

We have studied in detail $EuRbFe_4As_4$ single crystals with $T_c \approx$ 36-37K synthesized by the "self-flux" method [1] by various magnetic methods and by high-resolution transmission electron microscopy (HRTEM).

In order to take a deeper look at the interplay between superconductivity and helicoid magnetic subsystem [1] we performed measurements of the lower critical field (H_{c1}) in the H||c geometry. Measurements were done by MPMS SQUID magnetometer in the temperature range from 7K to 35K. It was found, that the H_{c1} behavior exhibits a rather sharp feature at $T_m \approx 15K$. Which in conjunction with the energy gap data [2] leads us to believe a superfluid density changes at $T_m \approx 15K$ while superconducting energy gap remains still and does not exhibit any features. This changes in the superfluid density may have the correlation with the vortex structure and pinning in the $EuRbFe_4As_4$ magnetic superconductors [3,4].

The systematic AC susceptibility and magnetic moment M(H,T) measurements show that the activation energy $U_0(H)$ follows a $\approx H^{-0.5}$ dependence in magnetic fields above 0.1T which points to the prevalence of the planar defects along the ab plane. Using high-resolution transmission electron microscopy, we observed an atomic structure of as-grown Eu-1144 system single crystals. The HRTEM investigation shows that crystals have two-dimensional intrinsic nanoscale inclusions with a volume fraction of ~5.6%, which act as 2D pinning centers. Thus, we establish the correlation between the structure defects and SC properties [5]. However, the $J_c \sim \Delta M(H)$ did not vastly change above or below Eu^{2+} magnetic ordering at 15 K. Therefore, the afore mentioned H_{c1} feature may be caused by rearrangement of the Abrikosov vortex structure during the magnetic transition.

This research was funded by the RSF 21-12-00394. The work was performed using equipment of the Lebedev Physical Institute's Shared Facility Center.

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Abstract ID: 388

CRYSTAL GROWTH, MAGNETOTRANSPORT PROPERTIES, AND TUNNELING SPECTROSCOPY OF ALKALI METAL BASED Na(Fe,Co)As PNICTIDES

T.E. Kuzmicheva[1], S.A. Kuzmichev[2,1], L.A. Morgun[1], A.I. Boltalin[3], A.I. Shilov[1,3], I.V. Zhuvagin[4], V.M. Mikhailov[1], I.A. Nikitchenkov[2], E.O. Rakhmanov[3], I.V. Morozov[3]

[1]V.L. Ginzburg Centre for High-Temperature Superconductivity and Quantum Materials P.N. Lebedev Physical Institute of the Russian Academy of Sciences (LPI RAS), 53, Leninsky Ave., 119991 Moscow, RUSSIA
[2]Faculty of Physics, Moscow State University, 1, Leninskiye Gory 119234, Moscow RUSSIA
[3]Department of Chemistry, Moscow State University, 1, Leninskiye Gory 119234, Moscow RUSSIA
[4]National Research University Higher School of Economics, Moscow 101000, RUSSIA
E-mail: kuzmichevate@lebedev.ru

Layered NaFeAs relates to the 111 family of Fe-based superconductors (SC). It has nontrivial phase doping diagram: showing a low $T_c \approx 10$ K in the stoichiometric state and a coexistence of bulky separated SC and antiferromagnetic phases, its SC properties could be optimized by (Fe,Co) doping up to $T_c \approx 10$ K for (4–5)% Co concentration [1,2]. Due to alkali metal, the SC properties of NaFeAs rapidly degrade even in presence trace amounts of oxygen or water vapor. This feature strongly complicates any studies of the 111 family pnictides, and results to a lack of experimental data on NaFeAs available to date.

Using a "self-flux" technique, we have grown large $NaFe_{1-x}Co_xAs$ single crystals of various composition with x = 0.02-0.05 and $T_c \approx 18$–22 K, respectively. For all the experiments, the sample mounting was made in a dry argon atmosphere. Magnetotransport probes showed almost linear shifting of the resistive SC transition in the fields up to 16 T. We determined the slope $dH_{c2}/dT \approx -2.4$ T/K, and estimate the upper critical field $H_{c2}(0) \approx 34$ T using a single-band model.

At 4.2 K, using a planar "break-junction" technique [3] we formed tunneling junctions of SC–constriction–SC (ScS) type. Above T_c we reproducibly observed a residual nonlinearity of the d(V)/dV spectra of ScS junctions that cannot be described by a junction overheating, and does not depend on the junction area and resistance. Such normal-state features could originate from the electron density of states (DOS) features in the vicinity if the Fermi level, or its renormalization by a resonant electron-phonon interaction.

Below T_c we for the first time observed an incoherent multiple Andreev reflection effect (IMARE). We detected a multiple-gap superconductivity and estimated the magnitudes of the large and the small SC gaps. The characteristic ratios $2\Delta_L(0)/k_BT_c \approx 5.3 \pm 1.0$ and $2\Delta_S(0)/k_BT_c \approx 1.3 \pm 0.3$ are almost similar for the underdoped and optimally doped compound. Both SC gaps turn to zero at the same T_c, whereas the directly measured temperature dependences of the SC gaps $\Delta_L(T)$ and $\Delta_S(T)$ are typical for a moderate interband interaction in the momentum space.

The work was performed using equipment of the Lebedev Physical Institute's Shared Facility Center. This research was funded by the RSF project number 22-72-10082.

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Abstract ID: 504

MAGNETISM AND BAND STRUCTURE OF $EuCd_2As_2$

A. Akrap

Department of Physics, University of Fribourg, Fribourg, SWITZERLAND
E-mail: ana.akrap@unifr.ch

Nowadays we know of many gapless electronic phases with conical bands, such as graphene, Dirac semimetals, and Weyl semimetals. Their low-energy excitations resemble truly relativistic particles. To see those excitations, we have to capture the physics at a milli-electron-volt scale. In our experiments, we access electronic structures at these low energies by combining Landau level spectroscopy, zero-field infrared spectroscopy, and effective Hamiltonian models.

$EuCd_2As_2$ has emerged as a topological material where magnetism may produce strong effects. This compound has been understood as a candidate Weyl semimetal, based mostly on ab initio calculations, transport and photoemission measurements. I will present our recent results on samples in which we control the carrier concentration through chemical synthesis. We find magneto-optical evidence of a sizeable band gap, remarkably sensitive to the local Eu magnetism. Our results contradict the current consensus on the ground state of this compound, bringing into question its topological nature.

Abstract ID: 87

OPTICAL FINGERPRINTS OF THE ELECTRONIC BAND RECONSTRUCTION IN VAN DER WAALS MAGNETIC MATERIALS

L. Degiorgi

Laboratorium für Festkörperphysik, ETH - Zürich, 8093 Zürich, SWITZERLAND
E-mail: degiorgi@phys.ethz.ch

We report a broadband study of the charge dynamics in the van der Waals magnetic materials 2H-M_xTaS$_2$ (M = Mn and Co), which span the onset of both long-range antiferromagnetic (AFM) and ferromagnetic (FM) order, depending on the intercalation M and its concentration x. We discover a spectral weight (SW) shift from high to low energy scales for FM compositions, while reversely SW is removed from low towards high spectral energies for AFM compounds (Fig. 1). This maps the related reconstruction of the electronic band structure along the crossover from the FM to AFM order, which restores an occupation balance in the density of states between spin majority and minority bands of the intercalated 3d elements [1]. Our spectroscopic findings seem to be consistent with dedicated first-principles calculations upon tuning element-intercalation, pressure and/or magnetic field on similar intercalated materials.

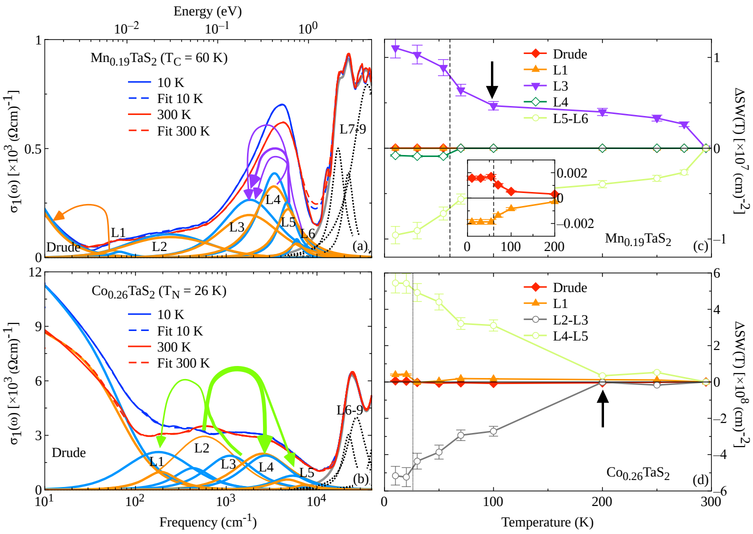

Fig. 1: *(a-b) In-plane real part ($\sigma_1(\omega)$) of the optical conductivity at 10 and 300 K together with their respective total Drude-Lorentz fit (thick dashed line) and (c-d) T dependence of the SW relative variation with respect to 300 K for selected fit components (see legend in panels (a-b)) of 2H-M_xTaS$_2$ (M = Mn and Co): (a,c) x = 0.19 (FM) Mn-concentration and (b,d) x = 0.26 (AFM) Co-concentration. Panels (a-b) explicitly show all fit components: the total Drude and Lorentz (Li, i = 1 to 9) HOs. The coloured shaded areas emphasise SW encountered by each component (reddish and blueish colors refer to 300 and 10 K, respectively, while the grey shaded area corresponds to SW being T-independent). The rounded arrows in panels (a-b) highlight the direction in energy of the SW reshuffling upon lowering T, which is stronger with thicker arrow. The inset in panel (c) is a blow-up of the SW relative variation for the Drude term and HO L1. The vertical dashed and dotted lines in panels (c-d) mark T_C and T_N, respectively.*

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Abstract ID: 108

A PUZZLE OF NEGATIVE MAGNETORESISTANCE IN LAYERED AFM TOPOLOGICAL SEMIMETAL $EuSn_2As_2$

K.S. Pervakov[1], A.V. Sadakov[1], O.A. Sobolevskiy[1], V.A. Vlasenko[1], V.P. Martovitsky[1], E.I. Maltsev[1,2], P.D. Grigoriev[3], N.S. Pavlov[4], I.A. Nekrasov[4], O.E. Tereshenko[5], V.M. Pudalov[1]

[1]*V.L. Ginzburg Research Center, P.N. Lebedev Physical Institute RAS, Moscow, RUSSIA*
[2]*IFW, Dresden, GERMANY*
[3]*L.D. Landau Institute of Theoretical Physics RAS, Chernogolovka, RUSSIA*
[4]*Institute for Electrophysics, Ural Branch RAS, Ekaterinburg, RUSSIA*
[5]*Institute for Semiconductor Physics, RAS, Novosibirsk, RUSSIA*
E-mail: pudalov@lebedev.ru

Materials with topological electronic band structure and magnetic order have recently become a focus of theoretical and experimental interest in condensed matter community. These materials suggest a platform for studying topological quantum phenomena, such as the quantum anomalous Hall effect, axion insulator states, and chiral Majorana fermions. One of the promising stoichiometric materials is the topological semimetal $EuSn_2As_2$, in which Eu-spins are coupled ferromagnetically within layer, and at 24K order antiferromagnetically between adjacent layers along the c-axis. This layered topologically non-trivial semimetal with AFM-type ordering is known to exhibit a generic negative parabolic magnetoresistance $R \propto R_0 - aB^2$ that tightly correlates with magnetization changes in external field *M(B):* it terminates sharply at the field-induced spin-flip transition. This effect was observed earlier in several experimental studies [1-3] where the resistance varied by $\delta R/R_0$ ~ 6-8% with magnetic field. Despite this effect is well documented experimentally, its theoretical explanation is lacking up to date. To describe the observed magnetoresistance we propose a theoretical mechanism that does not involve potential structural or magnetic defects in the crystal and is intrinsic to the layered AFM materials with spin-orbit band splitting in the vicinity of the Fermi energy. The theoretical interpretation is supported by our precise ARPES measurements and by DFT band structure calculations. We believe, the proposed mechanism of magnetoresistance is applicable to a wide class of the layered AFM- ordered semimetals.

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Abstract ID: 319

DIRECT OBSERVATION OF SPIN EXCITON IN SUPERCONDUCTING OXYPNICTIDES BY ANDREEV SPECTROSCOPY

T.E. Kuzmicheva[1], S.A. Kuzmichev[2,1], M.M. Korshunov[3]

[1] V.L. Ginzburg Centre for High-Temperature Superconductivity and Quantum Materials P.N. Lebedev Physical Institute of the RAS, 53, Leninsky Ave., 119991 Moscow, RUSSIA
[2] Faculty of Physics, Moscow State University, 1, Leninskiye Gory, 119234, Moscow RUSSIA
[3] L.V. Kirensky Institute of Physics, Siberian Branch RAS, 60, Akademgorodok, 660036, Krasnoyarsk, RUSSIA
E-mail: kuzmichevate@lebedev.ru

We have studied superconducting (SC) oxypnictides Gd(O,F)FeAs and (Sm,Th)OFeAs (1111 family) of almost optimal composition and $T_c \approx 50$ K. In the Fermi surface, hole barrels near the Γ point and electron barrels near the M point are coupled by a nesting vector **Q**, at which the imaginary part of the dynamic spin susceptibility Im[χ(**Q**,w)] shows a spin-resonance peak at position $\omega_R(0) < [\Delta_L(0) + \Delta_S(0)]$ [1]. In order to study the SC energy parameters we used incoherent multiple Andreev reflection effect (IMARE) spectroscopy of SC–thin normal metal–SC (SnS) nanojunctions. SnS junctions were formed by a planar "break-junction" technique [2]. IMARE causes an excess current at I(V) curve of SnS junction at any bias voltage *eV*, zero-bias conductance peak, and a subharmonic gap structure (SGS) in the dI(V)/dV-spectrum at bias voltages $V_n(T) = 2\Delta(T)/n$, n = 1, 2, …. The positions of the latter directly relate with the SC gap magnitude at any temperature until T_c. We reproducibly observed two distinct SGS's and directly determined two SC gaps in the 1111 compounds, with characteristic ratios $2\Delta_L(0)/k_BT_c \approx 5.2$, and $2\Delta_S(0)/k_BT_c \approx 1.5$ [3].

Beyond to the parent SGS of the large SC gap, the dI(V)/dV spectra of SnS junctions showed a satellite fine structure below T_c caused by an emission of bosons (existing in the SC state only) with characteristic energy ε_0 by electrons during IMARE [4–6]. The positions of the fine structure satisfied the formula $V_n(T) = [2\Delta(T) + k\varepsilon_0(T)]/n$, k = 1, 2, … In the spectra of the most qualitative junctions we observed a multiple bosonic resonance with $k \leq 4$ [5]. For Gd(O,F)FeAs and (Sm,Th)OFeAs with $T_c \approx 50$ K the boson energy $\varepsilon_0 \approx 10$–13 meV. Under doping variation, ε_0 was scaled with T_c together with $\Delta_L(0)$ and $\Delta_S(0)$ [6]. At $T << T_c$, ε_0 does not exceed the indirect SC gap $\Delta_L(0) + \Delta_S(0)$. We directly measured the temperature dependence of the boson energy. $\varepsilon_0(T)$ weakly decreases with temperature and does not resemble the $[\Delta_L(0) + \Delta_S(0)]$ temperature trend [6]. In the framework of 5-orbital $s^{\pm}$-model, we calculated the Im[χ(**Q**,w)] dependences using the experimental $\Delta_{L,S}(T)$ IMARE data. We showed the temperature behavior $\omega_R(0)$ agrees well with the experimental $\varepsilon_0(T)$ [6]. Therefore, the observed bosonic mode could be a spin exciton, which indicates an important role of spin fluctuations in the Cooper pairing in the SC oxypnictides.

The work was performed using equipment of the Lebedev Physical Institute's Shared Facility Center.

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Abstract ID: 379

SnAs-BASED TOPOLOGICAL AND SUPERCONDUCTING MATERIALS AND HETEROSTRUCTURES

K.S. Pervakov[1], V.A. Vlasenko[1], E.I. Maltsev[1, 2], V.M. Pudalov[1]

[1] *V.L. Ginzburg Centre for High-Temperature Superconductivity and Quantum Materials, P.N. Lebedev Physical Institute of the Russian Academy of Sciences (LPI RAS), 53, Leninsky Ave., 119991 Moscow, RUSSIA*
[2] *Leibniz Institute for Solid State and Materials Research (IFW Dresden), 20, Helmholtzstrasse, 01069 Dresden, GERMANY*
E-mail: pervakovks@lebedev.ru

The topological superconductivity may be realized in artificial structures and at interfaces. Currently, a number of approaches have been proposed for the engineering of new topological superconductors and for detection of Majorana fermions [1]. One of them is based on the proximity effect between a conventional s-type superconductor and a material with strong Rashba spin-orbit splitting (eg InAs) [2-5]. The second approach is also based on the effect of proximity between an s-wave superconductor (SC) and a ferromagnetic (FM) atoms chain [6-8]. Yet another approach utilizes the proximity effect of the s-wave superconductor and topological insulator (TI) [2, 9]. The materials based on SnAs layers ASn_2As_2 (A = Na, K, Sr, Eu, Li) are promising for creation of such topologically nontrivial structures comprising materials of the same elemental composition but of various functional classes that include TI ($SrSn_2As_2$), TI with AFM ordering ($EuSn_2As_2$), and SCs (SnAs [10], Sn_4As_3 [11], $NaSn_2As_2$ [12]). Recent research has shown that the $NaSn_2As_2$ compound is the s-wave superconductor with critical temperature T_c about 1.3-1.6 K, and that T_c increases to 2 K by doping on Sn sites with Na. Moreover, the $(Na/Sr/Eu)Sn_2As_2$ compounds have the same crystal structure (R-3m), and can be readily exfoliated due to weak van der Waals bonding between neighboring layers as reported for $NaSn_2As_2$ and $EuSn_2As_2$ [13-15]. The layered structure is inherent in other members of this family, which makes it possible to fabricate van der Waals structures from exfoliated flakes. Of great interest are the interfaces between the s-type superconductor ($NaSn_2As_2$) and the topological insulator ($SrSn_2As_2$), or between $NaSn_2As_2$ and magnetic TI ($EuSn_2As_2$). An interesting issue is the charge transport mechanism in SnAs layers confined between the magnetically ordered layers of Eu in $EuSn_2As_2$. Another question of interests in this family is the $Na_{1-x}Sr_xSn_2As_2$ compound – how the superconducting phase turns into the topological insulator upon varying x: does it occur via a direct quantum phase transition SC-TI, or through an intermediate topologically trivial phase?

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Superconductivity and Magnetism in 3D Nanoarchitectures I-II

05.05.2023 FRIDAY

Abstract ID: 187

SIMULATION OF DIRECT-WRITE FABRICATION WITH FOCUSED ELECTRON BEAMS FOR 3D NANO-ARCHITECTURES

A. Kuprava, M. Huth

Goethe University, Dept. of Physics, 60438, Frankfurt/Main, GERMANY
E-mail: Michael.huth@physik.uni-frankfurt.de

Three-dimensional (3D) magnetic nanostructures enable the magnetization to orientate itself into three dimensions mediated by additional degrees of freedom and hence allowing complex spin configurations which can lead to novel magnetic phenomena. Such exciting tailored and designed structures can open the door for addressing fundamental questions and potential novel applications in magnetism. The exploration of this field has just begun with improvements in fabrication and characterization methods. A growing number of examples have already been demonstrated, such as complex 3D tetrapod arrays [1], arrays of multi-axial nanocubes and nanotrees [2], as well as more complex structures [3]; see [4] for a recent review. In this contribution focus will be on recent advances in 3D nanofabrication by direct-writing using focused electron beam induced deposition (FEBID) [5]. FEBID is a unique and highly flexible direct-write nanofabrication approach. It is based on the electron-induced dissociation of a previously adsorbed precursor gas in the focus of an electron beam typically provided by a scanning electron microscope. After a brief introduction to the methodology controlling the growth of nano-scale 3D structures starting from a CAD model – including modelling of the growth process – very recent results on applications of FEBID in nano-magnetism are presented. A novel FEBID/CVD approach suitable for the fabrication of hollow, multi-segment or multilayer magnetic 3D structures is presented for the first time [6].

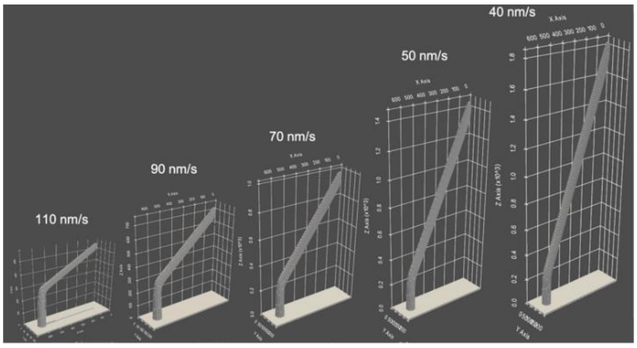

Fig. 1: *Result of simulated growth of reference structure with different lateral beam velocities.*

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Abstract ID: 197

TUNING DOMAIN WALL BEHAVIOUR IN THREE DIMENSIONAL NANOSTRUCTURES

Claire Donnelly

Max Planck Institute for Chemical Physics of Solids, Dresden, GERMANY
E-mail: cd691@cam.ac.uk

Three dimensional magnetic systems promise significant opportunities for applications, for example providing higher density devices and new functionalities associated with complex topology and the introduction of chirality and torsion [1,2].

Advanced nanofabrication allows us fine control over the three-dimensional geometry of magnetic nanostructures [3], providing a route to tune the magnetic properties of a system. In particular, the introduction of curvature, chirality and torsion can tune the structure and behaviour of 3D spin textures such as domain walls. Here, we make use of focused electron beam induced deposition to fabricate highly coupled, three dimensional helical magnetic nanoarchitectures. With 3D X-ray magnetic imaging, we determine that due to the three dimensional geometry new domain wall states form, which leads to the formation of topological textures in the magnetic induction [4]. Moreover, by tuning parameters such as the thickness or curvature, added control over the energy landscape of the domain wall can be achieved, leading to effects such as domain wall automation [5].

With these new experimental capabilities, the experimental investigation of three dimensional magnetic nanoarchitectures is established, opening the door to the discovery of new geometrical effects, and the possibility for future technological devices.

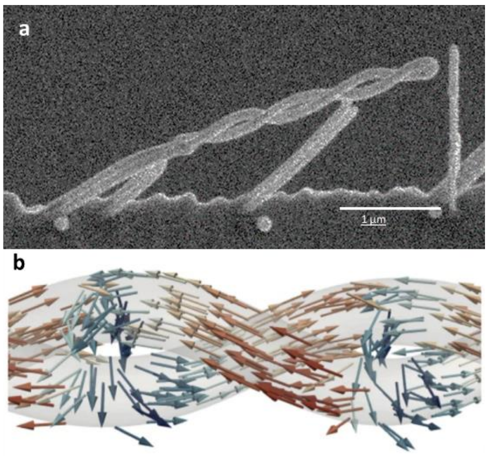

Fig. 1: *Design of the three dimensional geometry provides control over the magnetic textures. In a double helix cobalt nanostructure, fabricated with focused electron beam induced deposition, highly coupled "locked domain walls" form, representing a bound state that leads to the formation of textures in the surrounding magnetic induction. Reproduced from [4].*

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Abstract ID: 508

NANO-ENGINEERED HIGH-TEMPERATURE SUPERCONDUCTORS AND HYBRID SYSTEMS FOR ENERGY-EFFICIENT FUNCTIONAL DEVICES

A. Palau[1], J. Alcalà[1], A. Barrera[1], A. Fernández-Rodríguez[1], T. Günkel[1], LL. Balcells[1], N. Mestres[1], A. Sanchez[2], Marinkovic[3], E. Fourneau[3], A.V. Silhanek[3]

[1]Institut de Ciència de Materials de Barcelona, ICMAB-CSIC, Bellaterra, 08193, SPAIN
[2]Departament de Fisica, Universitat Autonoma de Barcelona, Bellaterra, 08193, SPAIN
[3]Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, Université de Liège, B-4000 Liège, BELGIUM

E-mail: palau@icmab.es

High-temperature superconductors (HTS), combined with other functional materials offer unique opportunities to tune their physical properties with multiple external inputs, thus providing the basis for realizing energy-efficient electronic devices for sustainable Information and Communication Technologies (s-ICT). In spite of great technological advancements in the recent years, functional devices based on HTS are still in the early stage with respect to those based on conventional low-temperature superconductors. An important drawback is their complexity and high sensitivity on doping which imposes extreme demands on the micro-, nano-fabrication. In this talk, I will introduce different types of micro-, nano-structures and hybrid systems based on HTS films, specially designed to obtain novel functional properties which can be tuned with temperature, magnetic or electrical fields, or geometry constrains [1-3]. On one hand, field-induced oxygen vacancy modulations provide a viable mechanism to reversibly tune the superconducting parameter (Fig. 1 (a)) opening comprehensive prospects for gate-modulated electronic quantum devices - superconducting transistors, reversible patterning of weak-links or other nanostructures to create vortex pinning landscapes on demand (Fig. 1 (b)) [1]. On the other hand, the combination of HTS with other functional materials in hybrid systems can be exploited to create and manipulate non-trivial spin textures though loss-less supercurrents (Fig. 1 (c)) [3] or magnetic-superconductor metasurfaces for unprecedented control of magnetic fields.

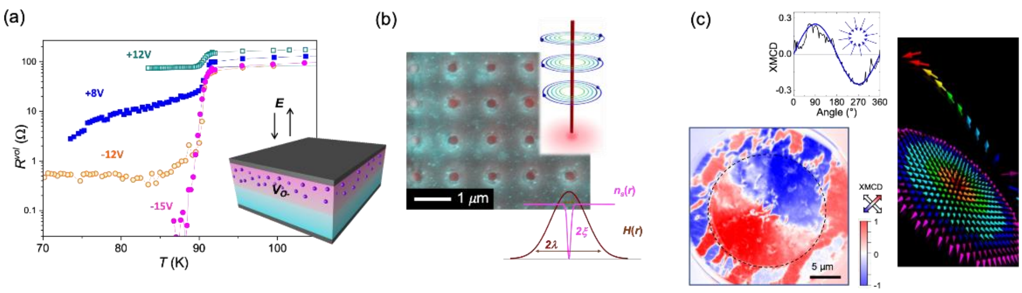

Fig. 1: *(a) Reversible oxygen doping modulation through field induced oxygen diffusion. (b) Nanoscale spatial modulation of the superconducting parameter. (c) Singular magnetic domains such as monopolar-like configurations obtained in hybrid superconductor-ferromagnetic systems.*

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Abstract ID: 88

GEOMETRICALLY CURVED, SKIN-CONFORMAL AND SELF-HEALABLE MAGNETOELECTRONICS

D. Makarov

Helmholtz-Zentrum Dresden-Rossendorf e.V., 01328 Dresden, GERMANY
E-mail: d.makarov@hzdr.de

Extending 2D structures into 3D space has become a general trend in multiple disciplines, including electronics, photonics, plasmonics, superconductivity and magnetism [1-3]. This approach provides means to modify conventional or to launch novel functionalities by tailoring curvature and 3D shape of magnetic thin films and nanowires [3]. In this talk, we will address fundamentals of curvature-induced effects and discuss experimental realisations of geometrically curved low-dimensional architectures and their characterization, which among others resulted in the experimental confirmation of the exchange-driven chiral effects [4]. Geometrically curved magnetic thin films are interesting not only fundamentally. They are the key component of mechanically flexible magnetic field sensors. We will briefly outline activities on shapeable magnetoelectronics [5,6], which includes flexible, stretchable and printable magnetic field sensors for the realisation of human-machine interfaces [7,8], interactive electronics for virtual [9] and augmented [10] reality applications and soft robotics [11] to mention just a few. Very recently, self-healable magnetic field sensors for interactive printed electronics were reported [12]. The presence of the geometrical curvature in a magnetic thin film influences pinning of magnetic domain walls and in this respect it affects the sensitivity of mechanically flexible magnetic field sensors. This is an intimate link between the fundamental topic of curvilinear magnetism and application-oriented activities on shapeable magnetoelectronics. This link will be discussed in the presentation as well.

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Abstract ID: 89

NANO- AND FLEXOMAGNETISM OF MAGNETOELECTRIC Cr_2O_3 ANTIFERROMAGNETS

D. Makarov

Helmholtz-Zentrum Dresden-Rossendorf e.V., 01328 Dresden, GERMANY
E-mail: d.makarov@hzdr.de

Antiferromagnetic insulators are a prospective material science platform for magnonics, spin superfluidity, THz spintronics and non-volatile data storage. Due to linear magnetoelectric effect at room temperature, Cr_2O_3 is a convenient playground to test fundamental predictions and new device ideas. In this presentation, we will cover our activities on physics and applications of Cr_2O_3. In particular, we provide insight into the nanoscale mechanics of antiferromagnetic domain walls in single crystals of Cr_2O_3 [1]. Furthermore, we will discuss the family of flexomagnetic effects in Cr_2O_3 thin films [2]. It is demonstrated that in addition to the conventional magnetic moment induced by the strain gradient, there is another flexomagnetic effect which impacts the magnetic phase transition resulting in the distribution of the Néel temperature along the film thickness. The details on the study of the defect nanostructure in Cr_2O_3 thin films [3,4] and bulks [5] and their impact on magnetism and magnetoelectricity of Cr_2O_3 will be discussed as well. We identified spin Hall magnetoresistance as a possible mechanism to explain all-electric readout of the magnetic state of Cr_2O_3 interfaced with a heavy metal like Pt [6,7]. The possibility to read-out the antiferromagnetic order parameter of magnetoelectric Cr_2O_3 all-electrically enabled realisation of antiferromagnetic magnetoelectric random access memory (AF-MERAM) [8].

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Abstract ID: 266

LOCAL AND NONLOCAL EFFECTS OF GEOMETRY IN CURVILINEAR MAGNETIC NANOARCHITECTURES

O. V. Pylypovskyi[1,2]

[1]Helmholtz-Zentrum Dresden-Rossendorf, 01328, Dresden, GERMANY
[2]Kyiv Academic University, 03142, Kyiv, UKRAINE
E-mail: o.pylypovskyi@hzdr.de

Interplay between the geometry and behavior of magnetic textures in statics and dynamics has been traditionally considered regarding planar confined samples and their boundaries (vortices in nanodisks, interaction of skyrmions and domain walls with notches etc.). Recent developments of experimental techniques on fabrication of freestanding 3D nanostructures gave a possibility to access and validate theoretical predictions of behavior of magnetic textures, related to the intrinsic geometric properties of extended films and complex sample topologies [1].

Properties of energy functionals in both, ferro- and antiferromagnetic samples reflect geometric symmetries in curvature-driven Dzyaloshinskii-Moriya interaction and anisotropies, which are proportional to the first and second powers of the curvatures, respectively [1]. Magnetostatics is also sensitive to the breaks of the geometric symmetries. In thin films, it is possible to tease out an interplay between the out-of-surface magnetization component and mean curvature of the film [2]. Furthermore, for such non-local textures as vortices hosted by asymmetric Py caps, it enables complex magnetochiral effects pronounced in twisting of the vortex string in a helix and coupling of this helix chirality with the vorticity of the whole texture [3].

Antiferromagnetic curvilinear nanoarchitectures provide more intrinsic material symmetries. In spin chains, the dipolar interaction provides the hard-axis shape anisotropy, with the anisotropy axis along the tangential direction to the chain. This makes the geometry-driven helimagnetic phase transition to be possible for any finite curvature and torsion of the chain [4]. The locally broken spatial translation symmetry of antiferromagnetic dimers in bipartite chains leads to the micromagnetic energy term of the non-chiral longitudinal Dzyaloshinskii energy symmetry and enables local weak ferromagnetic response related to the spatial inhomogeneity of the Neel vector [5]. The geometry-driven easy axis of anisotropy is present even if the material anisotropy is of the hard-axis type, which enables spin-flop transition governed by the chain shape. In a particular case of the ring with the hard-tangential anisotropy and uniform ground state, the helimagnetic phase transition appears in spin-flop phase and the intermediate canted phase for the case of strong Dzyaloshinskii-Moriya interaction [6].

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Topological Quantum Matter I-II

05.05.2023 FRIDAY

Abstract ID: 131

THE EFFECT OF LASER LIGHT ON COOPER-PAIR INSULATOR

A. Yu. Mironov[1,2]

[1] *A.V. Rzhanov Institute of Semiconductor Physics, 630090 Novosibirsk, RUSSIA*
[2] *Terra Quantum AG, 9400 Rorschach, SWITZERLAND*
E-mail: mironov@isp.nsc.ru

We present the results of the study of low-temperature current response to laser light applied to a superinsulating NbTiN film. In experiments we use laser with wavelength 457, 514 and 850 nm. No dependence of induced current from wavelength was observed. We found that, after the appearance of the light firstly destroy superinsulating state: in experiments we observed decreasing of threshold voltage with increasing of light power before dilution refrigerator in region 0 – 50 nW. At power higher than 50 nW nonzero of the induced current occurs. With increasing of light power induced current increases, then reach maxima and quickly decreases at power higher then 2-4 mW. Simultaneously current-voltage characteristics change behavior from insulating to metallic. With increasing of temperatures value of induced currant is decreasing to zero. As a result of these observations, we conclude that there is a direct relationship between the appearance of the light-induced current and Cooper pairs in the insulating state, which are destroying by light.

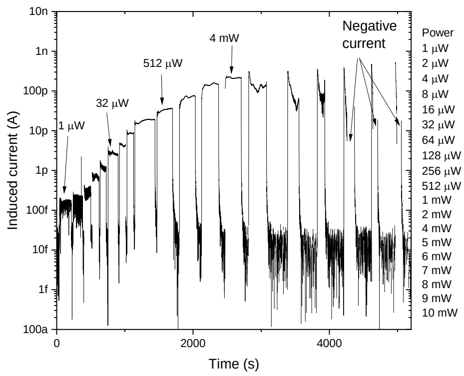

Fig. 1: *Typical experimental figure of current induced by laser light at temperatures sufficient for the existence of cooper-pair insulator.*

This work was supported by the RSF # 18-72-10056 and Terra Quantum AG.

Abstract ID: 193

INFINITE SYMMETRY, FAILURE OF LOCALIZATION AND THE PHASES OF 2D GAPPED QUANTUM MATTER

Carlo A. Trugenberger

SwissScientific Technologies, rue due Rhone 59, CH-1204 Geneva, SWITZERLAND
E-mail: ca.trugenberger@bluewin.ch

Dynamical symmetry is a powerful principle to classify classical configuration spaces or quantum Hilbert spaces without detailed knowledge of a Hamiltonian. Paramount examples include the SU(3) flavour symmetry of the strong interactions or the conformal symmetry of 2D statistical mechanics.

Gapped many-body quantum states are incompressible (below threshold temperatures and energies). Uniform gapped states have thus the dynamical symmetry of quantum volume-preserving diffeomorphsims. In 2D, this reduces to quantum area-preserving diffeomorphisms, an infinite-dimensional symmetry whose representation theory has been, nonetheless completely worked out [1]. Quantum states of such uniform gapped systems, therefore are highest-weight states of the symmetry algebra. These are characterized by an infinite number of constraints, encoding the fact that these states are so rigid that they behave as a single quantum state. This is the reason why, when interactions open a gap, Anderson localization fails, even in low dimensions: there are no more bulk degrees of freedom that can be localized. The familiar topological protection is a special case of this larger class of states protected by infinite symmetry.

Using this dynamical symmetry algebra one can classify all possible 2D uniform gapped quantum states. These are given by particularly robust quantum states, called minimal models, for which there is a finite number of representations, closed under composition (bootstrap) [2]. When parity and time reversal are broken, one obtains, e.g., the whole measured hierarchy of quantum Hall states [2]. In the P- and T-invariant cases, one obtains, e.g., superconductors, topological Mott insulators (also called Bose metals in the bosonic case) and superinsulators [3], with all their towers of possible excitations. As an example, I will discuss the SU(N) flavour symmetry of purely electric mesons in the superinsulating phase [4].

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Abstract ID: 204

TOPOLOGICAL GAUGE THEORIES OF JOSEPHSON JUNCTION ARRAYS

Maria Cristina Diamantini

Nips Laboratory, INFN and Dipartimento di Fisica e Geologia, University of Perugia
Via Pascoli, I-06100,Perugia, ITALY
E-mail: cristina.diamantini@pg.infn.it

I will show that Josephson junctions arrays are described by a topological gauge theory [1]. As an immediate consequence, they have three quantum phases at low temperatures, the familiar superconducting phase, but also a dual superinsulating phase [1] and an intermediate (bosonic) topological insulator phase, which is often called anomalous, or Bose metal phase [1]. In this phase the resistance saturates at low temperatures because of transport by edge excitations. In the superinsulating phase, the resistance diverges at a finite temperature, due to magnetic monopole instantons [2,3]. I will further show that all superconductors behave as Josephson junction arrays in the ultrathin, planar limit because of strong infrared divergences [4].

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Abstract ID: 365

SPECTRAL RESOLUTION OF AN ULTRAFAST MICROWAVE SPECTRUM ANALYZER BASED ON A SWEEP-TUNED SPIN-TORQUE NANO-OSCILLATOR

S. Louis, A.N. Slavin

Oakland University, Dept. of Physics, 48309, Rochester, Michigan, USA
E-mail: slavin@oakland.edu

Modern applications in radar and communication technologies often use frequency-agile signals, the spectral analysis of which requires sub-μs temporal resolution. Such a speed of the spectral analysis can be achieved with a sweep-tuned spectrum analyzer only if the local oscillator of the analyzer has a nano-scale size, and very low time constants, so that its frequency can be swept on the time scale of the targeted temporal resolution. It was predicted in [1, 2] that such an ultrafast analysis can be performed using spin-torque nano-oscillators (STNO) both in microwave (MHz to GHz) [1] and THz [2] frequency ranges.

Recent experimental studies [3, 4] performed on the vortex-magnetic-state [3] and uniform-magnetic-state [4] STNOs, rapidly sweep-tuned by a bias voltage, fully confirmed these theoretical predictions, and proved that ultrafast time-resolved spectral analysis of frequency-agile microwave signals is possible. The critical reduction in the time of the spectral analysis comes from the naturally small (1−100 ns) temporal constants of the nano-sized STNOs. The advantage of an ultrafast frequency-tunability of STNOs, that have a large (>100 MHz) relaxation frequency f_p of amplitude fluctuations, is exploited to realize ultrafast wide-band time-resolved spectral analysis at nanosecond time scale with a frequency resolution limited only by the sweeping frequency through the "bandwidth" theorem (see Fig.1)

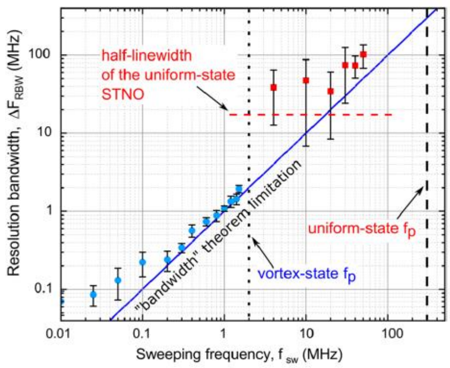

Fig.1: *Resolution bandwidth of a sweep-tuned spectrum analyzer as a function of the sweeping*

The demonstration of the time-resolved (T~50 ns) spectral analysis in the GHz frequency range (frequency interval of 1.0 GHz around a central frequency of 9.1 GHz with a scanning speed of 50 MHz/ns) was performed on an STNO comprised of a perpendicular polarizer and a perpendicularly and uniformly magnetized "free" magnetic layer [4]. It was shown in [4] that such a uniform-state STNO-based spectrum analyzer can efficiently perform spectral analysis of frequency-agile signals with rapidly varying frequency components, and that a relatively wide (~10 MHz) generation linewidth of the STNO does not significantly affect the frequency resolution of the spectral analysis, which is determined by the speed of the frequency sweeping.

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Abstract ID: 381

INTERTYPE SUPERCONDUCTIVITY IN FERROMAGNETIC SUPERCONDUCTORS

A. Vagov[1,2], T.T. Saraiva[1], A.A. Shanenko[1], A.S. Vasenko[1], J. Albino Aguiar[2], V.S. Stolyarov[3], D. Roditchev[4]

[1]*Centre of Quantum Metamaterials, HSE University, Moscow, 101000, RUSSIA*
[2]*Departamento de Física, Universidade Federal de Pernambuco, 50670-901 Recife, PE, BRAZIL*
[3]*Moscow Institute of Physics and Technology, 141700 Dolgoprudny, RUSSIA*
[4]*LPEM, UMR-8213, ESPCI Paris, PSL Research University, CNRS, Sorbonne Université, Paris 75005, FRANCE*

E-mail: ashanenko@hse.ru

Coexistence and interplay of two order parameters in ferromagnetic superconductors give rise to highly non-trivial physical effects. One of those is a temperature controlled change of the superconductivity type [1]. In the present work we demonstrate that at this change the system enters the regime of the intertype (IT) superconductivity. It is characterized by the appearance of the intermediate mixed state (IMS) with exotic spatial flux configurations - vortex clusters, chains, giant vortices and vortex liquid droplets - that are found in neither type-I nor type-II bulk superconductors. The IT regime was known to take place in a limited class of low-κ materials [2], where the Ginzburg-Landau parameter κ is close to its critical value κ_0 = 0.71. Our study demonstrates that the IT regime is achieved in ferromagnetic superconductors, practically irrespective of their microscopic parameters and κ-value, by simply varying the temperature. The only condition is that the Curie temperature should be smaller than the superconducting critical temperature T_c and the system is in type II in the vicinity of T_c, as in recent iron pnictides $EuFe_2(As_{1-x}P_x)_2$ [3].

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Abstract ID: 435

ULTRAFAST DYNAMICS OF TOPOLOGICAL SEMIMETALS: FROM WEYL NODE ANNIHILATION TO TOPOLOGICAL PHASE TRANSITION

Jimin Zhao[1,2,3]

[1] *Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, CHINA*
[2] *School of Physical Sciences, Univ. of Chinese Academy of Sciences, Beijing 100049, CHINA*
[3] *Songshan Lake Materials Laboratory, Dongguan, Guangdong 523808, CHINA*
E-mail: jmzhao@iphy.ac.cn

We recently carried out ultrafast spectroscopy investigations on topological semimetals, including Weyl semimetal $Co_3Sn_2S_2$, Weyl semimetal TaAs, Dirac semimetal Cd_3As_2, as well as nodal line topological material LaBi. Significantly, we discovered a very rare experimental evidence of the Weyl Node Annihilation in magnetic Weyl semimetal $Co_3Sn_2S_2$, unveiled by spin-polarized ultrafast dynamics [1]. For the first time, spin polarized gap and topology-driven photon bottleneck effect were also detected [1]. We also identified topological phase transitions through the quasiparticle ultrafast dynamics [1] and coherent phonon dynamics [2]. We observed the coherent phonon beating in Cd_3As_2, which originates from the helix vacancy-induced phonon (HVP) modes [2], whose dynamics exhibits an indication of the topological phase transition. We obtain the electron-phonon coupling (EPC) strength of TaAs from its excited state ultrafast dynamics [3], and we generate and detect coherent phonons in Cd_3As_2 and LaBi [2,4,5].

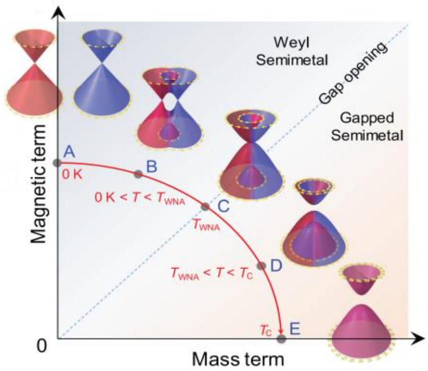

Fig. 1: *Gap evolution with temperature in the topological phase diagram [1].*

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WEYL KONDO SEMIMETALS AND THEIR RELATION TO OTHER TOPOLOGICAL STATES

Gaku Eguchi

Institute of Solid State Physics, TU Wien AUSTRIA
E-mail: eguchi@ifp.tuwien.ac.at

The past decade has seen a wealth of investigations on materials that are considered as topological semimetals and insulators. Their electronic structures harbor band crossings that are enabled by certain symmetries. The relevant bulk or surface excitations are Dirac or Weyl quasiparticles as opposed to Schrödinger quasiparticles in `normal' (topologically trivial) solids. In the best studied regime of noninteracting or weakly interacting topological materials, key characterization tools are ARPES and quantum oscillation experiments together with density functional theory. In the recently evidenced strong correlation regime, by contrast, these tools fail and new ones have been put forward such as specific heat and the spontaneous Hall effect in materials with preserved time reversal symmetry [1-3]. In this presentation I will report on the details of the thermodynamic and transport signatures of $Ce_3Bi_4Pd_3$, and compare them with results on other topological semimetals and insulators [4,5].

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Vortex Matter, Dynamics and Pinning I-II

05.05.2023 FRIDAY

Abstract ID:85

THE ROLE OF THE PINNING CROSSOVER IN THE NON-MONOTONIC MAGNETIC BEHAVIORS OF TYPE-II SUPERCONDUCTORS

M. Polichetti[1,2], A. Galluzzi[1,2], K. Buchkov[3,4], V. Tomov[3], E. Nazarova[3], A. Leo[1,2], G. Grimaldi[2], S. Pace[1,2]

[1]University of Salerno, Dept. of Physics, 84084, Fisciano (SALERNO), ITALY
[2]CNR-SPIN Salerno, Dept. of Physics, 84084, Fisciano (SALERNO), ITALY
[3]Bulgarian Academy of Sciences, Inst. of Solid State Physics, 1784, Sofia, BULGARIA
[4]Bulgarian Academy of Sciences, Inst. of Optical Materials and Technologies, 1113, Sofia, BULGARIA
E-mail: mpolichetti@unisa.it

The appearance of a Second Magnetization Peak (SMP) in the M(H) hysteresis loop, associated to a non-monotonic modulation of the critical current density $J_c(H)$ as function of the applied magnetic field, is often reported in concomitance with another non-monotonic behavior of the magnetic relaxation rate S in type-II superconductors. In these cases, in fact, the S(H) curve shows the presence of a plateau, with a minimum that appears also in the temperature dependence of the relaxation rate S(T). This concomitance has been shown to exist independently of the class of the analyzed superconductor, and some characteristics suggest a sort of universal correlation between these non-monotonic behaviors. The reduction of the J_c in the superconductors is associated to the growth of S and related to the decrease in the efficiency of pinning centers. For these reasons, the analysis of the mechanisms beneath the temperature and field dependences of the magnetic relaxation rate can be useful for the improvement of the electrical transport characteristics of the superconductors. Our analysis will focus on the correlation that has been found between the onset of the SMP and the minimum in S, which happen at two different, and apparently not related, characteristic fields. The study started from the magnetic behavior of a $FeSe_{0.5}Te_{0.5}$ crystal which shows a SMP phenomenon, and the results have been shown to be valid also for other superconducting materials.

Abstract ID: 112

VORTEX PINNING BY PARTICLE IRRADIATION INDUCED DEFECTS

D. Torsello[1,2], M. Fracasso[1,2], R. Gerbaldo[1,2], G. Ghigo[1,2], L. Gozzelino[1,2], F. Ledda[1,2], S. Sparacio[1,2], F. Laviano[1,2]

[1]*Department of Applied Science and Technology, Politecnico di Torino, Torino 10129, ITALY*
[2]*Istituto Nazionale di Fisica Nucleare, Sezione di Torino, Torino 10125, ITALY*
E-mail: daniele.torsello@polito.it

Particle irradiaton has been proved to be an efficient tool to introduce controlled pinning center distributions in any class of superconductors, allowing both the optimization of the pinning landscape and the investigation of vortex dynamics and pinning models.

However, defects play an additional role, also acting as scattering centers for carriers, reducing the critical temperature [1] and greatly affecting the order parameter and the intrinsic anisotropy of the superconductor [2]. By controlling the distribution and morphology of defects through a suitable choice of the type, energy and fluence of the striking particles, one can explore different pinning regimes and minimize the unwanted critical temperature suppression [3].

In this talk, we will review the types of defects that can be introduced using particle irradiation, and give examples of how superconducting properties are modified when the pinning landscape is optimized in this way in conventional, cuprates and iron-based superconductors. We will discuss pinning engineering ranging from the introduction of isotropic pinning sites provided by light particle irradiation to strong anisotropic pinning centers obtained with swift heavy ions, and combinations of the above.

The analysis of the pinning properties was carried out employing electric transport, ac-susceptometry, microwave and magneto-optical imaging techniques [4]. Monte Carlo and Molecular Dynamics simulations guided the choice of the particles, energies and fluences for the experiments, but can also be used to predict the morphology and density of defects created in specific radiation harsh environments [5], hinting an understanding of how the superconducting and pinning properties might be affected.

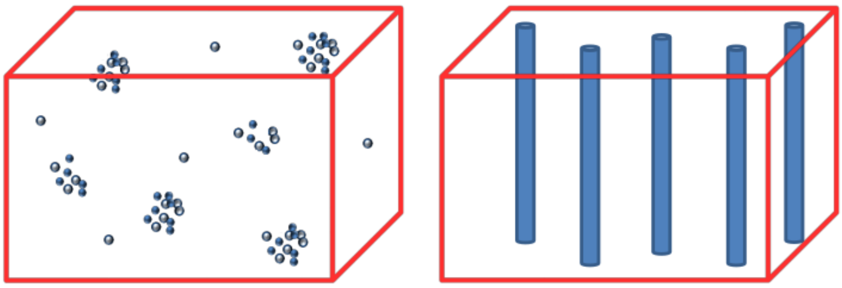

Fig. 1: *Sketch of defect distributions from light particle irradiation (left) and swift heavy ions (right).*

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Abstract ID: 127

VORTEX PINNING AT HIGH FREQUENCIES IN SUPERCONDUCTORS: A COMPARATIVE STUDY

N. Pompeo[1,2], A. Alimenti[1], T. Torokhtii[1], P. Vidal García[1,2], E. Silva[1,2]

[1]*Dept. of I.E.M. Engineering, Università Roma Tre, 00146 Roma, ITALY*
[2]*INFN Sezione di Roma Tre, Roma, ITALY*
E-mail: nicola.pompeo@uniroma3.it

New high frequency (hf) perspective applications of superconductors, operating in high dc magnetic fields (up to 16 T), are emerging. The haloscopes and the beam screen coatings for large circular particles accelerators (e.g. CERN-FCC and IHEP-SPPC) are exemplary cases [1]. While in general superconductors attain very low surface impedance values in the Meissner state, those type II superconductors driven in the mixed state by a static magnetic field experience additional dissipation due to vortex motion. In the mixed phase, the surface impedance depends mostly on the vortex dynamics [2], with the interplay between flux flow dissipation, vortex pinning effects and thermal creep. Depending on the specific material, its pinning landscape and its operation regime (temperature T, frequency and magnitude and orientation of the field B, ν), these mechanisms impact differently in shaping the hf response.

We present a comparative study performed on several low-T_c and high-T_c superconductors: Nb_3Sn, NbTi, MgB_2, $FeSe_{0.5}Te_{0.5}$, $YBa_2Cu_3O_{7-d}$, as thin films, bulks, coated conductors. Measurements are performed in magnetic fields up to 12 T exploiting a technique based on dual tone (8-27 GHz) dielectric resonators, which allows to obtain the pinning frequency, the flux-flow resistivity ρ_{ff}, the pinning constant k_p, the thermal creep factor χ. Polycrystalline Nb_3Sn [3] samples exhibit a distinct weakening of the pinning constant by increasing B, correlated with the quality of the grain boundaries. NbTi films on insulating substrates show a similarly decreasing $k_p(B)$, of absolute value up to 4 times smaller than in Nb_3Sn. By contrast, $YBa_2Cu_3O_{7-d}$ samples [4], with or without the addition of artificial pins, consistently exhibit a very large and B-independent k_p up to 12 T, irrespective whether in the shape of coated conductor or thin films (both deposited by Chemical Solution Deposition or Pulsed Laser Ablation – PLD), pointing to single vortex pinning regime as opposed to the collective one observed in low-T_c superconductors. The defects nature affects the magnitude of $k_p(B)$, which attains the largest values in the PLD films. In $FeSe_{0.5}Te_{0.5}$ thin films [5] k_p shows smaller values than $YBa_2Cu_3O_{7-d}$ and decreases appreciably when the field grows above 3-5 T, exhibiting a noticeable crossover from single to collective pinning regimes. Finally, MgB_2 polycrystals were considered [6]: their vortex dynamics is well described within a single-component approach, whereas their multiband nature manifests itself through the flux-flow resistivity field dependence. Further considerations are provided concerning creep effects and flux flow resistivity.

This work was partially supported by: MIUR-PRIN Project "HIBiSCUS" (Grant 201785KWLE); MoU-FCC Add. FCC-GOV-CC-0218 (KE5084/ATS); INFN project "SAMARA". We sincerely thank collaborations and fruitful discussions with V. Braccini, G. Celentano, S. Calatroni, R. Flükiger, C. Pira, S. Posen, T. Puig, M. Putti, T. Spina.

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Abstract ID: 92

VORTEX DYNAMICS AND PINNING IN $CaKFe_4As_4$ SINGLE CRYSTALS FROM DC MAGNETIC RELAXATION AND AC SUSCEPTIBILITY STUDIES

Adrian Crisan

National Institute of Materials Physics, 405A Atomistilor Str., 077125 Magurele, ROMANIA
E-mail: acrisan652@gmail.com

We have investigated the vortex dynamics and pinning potential of high-quality single crystals of superconducting material $CaKFe_4As_4$ having high critical current density and very high upper critical field using both magnetization relaxation measurements and frequency-dependent AC susceptibility. Preliminary studies of the superconducting transition and of the isothermal magnetization loops confirmed the high quality of the samples, while temperature dependence of the AC susceptibility in high magnetic fields show absolutely no dependence on the cooling conditions, hence, no magnetic history. From magnetization relaxation measurements were extracted the values of the normalized pinning potential U^*, which reveals a clear crossover between elastic creep and plastic creep. The extremely high values of U^*, up to 1200 K around the temperature of 20 K lead to a nearly zero value of the probability of thermally-activated flux jumps at temperatures of interest for high-field applications. The values of the creep exponents in the two creep regimes resulted from the analysis of the magnetization relaxation data are in complete agreement with theoretical models. Pinning potentials were also estimated, near the critical temperature, from AC susceptibility measurements, their values being close to those resulted (at the same temperature and DC field) from the magnetization relaxation data. Using the on-set of the third harmonic AC susceptibility response we have determined the melting line of the vortex system in the temperature-field phase diagram and estimated the anisotropy factor.

Abstract ID: 130

DETERMINATION OF THE VORTEX MASS IN HIGH-TEMPERATURE SUPERCONDUCTORS USING THz CIRCULARLY POLARIZED LIGHT

C. Kadlec[1], R. Tesař[1], M. Šindler[1], J. Koláček[1], L. Skrbek[2], P. Lipavský[2]

[1]*Institute of Physics, Czech Academy of Sciences, 182 21, Prague, CZECH REPUBLIC*
[2]*Faculty of Mathematics and Physics, Charles University, 121 16, Prague, CZECH REPUBLIC*
E-mail: kadlecch@fzu.cz

The determination of the mass of Abrikosov vortices in superconductors is a long standing issue. Whereas the theoretical approximations spand over 8 orders of magnitude, only two experimental evaluations had been previously performed, one using an electro-acoustic method [1], the second one magneto-optical imaging [2]. Here we propose an approach based on far-infrared magnetic circular dichroism [3].

Our method is inspired by the standard determination of cyclotron mass of charge carriers in semiconductors in magnetic field through measuring the cyclotron resonance. In the case of vortices, we probe their interaction with circularly polarized far-infrared light under external magnetic field of up to 11 T. It differs for the clockwise and anti-clockwise polarized light cases, resulting in the so-called circular dichroism, which manifests itself as a difference in the transmittance of the light through the superconducting sample. We propose a model to relate the ratio of transmittances of opposite helicity to the mass of the vortices.

We have chosen to concentrate on YBaCuO, the most common high-temperature superconductor. It has been prepared in the form of a 107 nm-thick film of with CuO_2 planes parallel to the surface deposited on a (100) lanthanum aluminate substrate by pulsed laser deposition. The sample parameters have been determined by usual techniques or taken from the literature. Additional film properties in the far-infrared range have been established in a separate experiment using standard time-domain THz spectroscopy. With such inputs, we show that the theory of the vortex mass developed by Kopnin and coworkers [4] matches our experimental data *without any additional fitting parameter.*

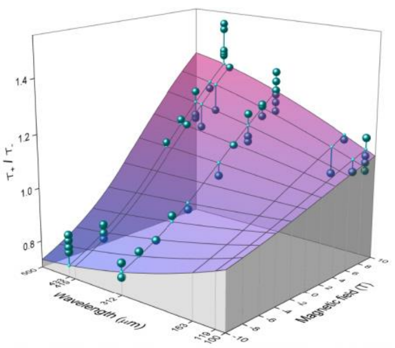

Fig. 1: *Transmittance ratio: experiments (spheres) compare to theory (surface)*

At THz frequencies, where the circular dichroism is observed, both diagonal and off-diagonal masses are complex at finite frequencies, which reflects a delay between a change of the vortex velocity and a change of the total momentum of quasiparticles in its core. They become real in the low-frequency limit. The off-diagonal mass describes a property common in anisotropic systems that the velocity of an excitation is not parallel with its momentum.

For YBaCuO at 45 K, in the zero-frequency limit, the diagonal mass of Abrikosov vortices amounts to 2.2 x 10^8 electron masses per centimeter, while the off-diagonal one reaches 4.9 x 10^8 electron masses per centimeter.

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Abstract ID: 406

TUNABLE FLUX QUANTUM OF VORTICES IN TYPE-I AND TYPE-II SUPERCONDUCTORS

Junyi Ge[1], An-Lei Zhang[1], Vladimir Gladilin[2], Joris von de Vondel[3], Victor Moshchalkov[3]

[1]*Mateirals Genome Institute, Shanghai University, 200444 Shanghai, CHINA*
[2]*TQC, Universitiet Antwerpen, Universiteitsplein 1, B-2610 Antwerpen, BELGIUM*
[3]*Quantum Solid-State Physics, Department of Physics and Astronomy, KU Leuven, Celestijnenlaan 200D, B-3001 Leuven, BELGIUM*
E-mail: junyi_ge@t.shu.edu.cn

Superconductivity is a macroscopic quantum state. The singularity of the order parameter along any closed path inside the superconductor requires that the enclosed magnetic flux must be quantized. This leads to the formation of vortex with integer flux quantum of h/2e. In the intermediate state of type-I superconductors, magnetic flux penetrates in the form of giant vortices. Here we will show that the vorticity can be tuned by changing the temperature, and single vortices penetration is expected close to Tc. For type-II superconductors with the lateral size comparable or even smaller than the penetration depth, the magnetic flux of a vortex can be non-quantized. In this presentation, I will introduce the flux quantization in type-I and type-II superconductors, together with an efficient way to tune the magnetic flux of vortices by using superconducting stripes.

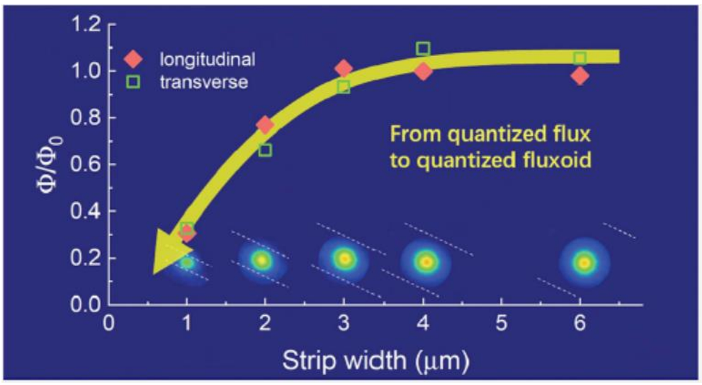

Fig. 1: *Noninteger flux quantum of vortices in superconducting stripes.*

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Abstract ID: 434

VORTEX PATTERN TRANSITION IN SUPERCONDUCTING STRIPS: FROM 1D TO 2D LATTICE

Tian He[1], Jia-Ying Zhang[1], Jing-Yu He[1], An-Lei Zhang[1], Vladimir Gladilin[2], Victor V. Moshchalkov[3], Jun-Yi Ge[1]

[1]Materials Genome Institute, Shanghai University, 200444 Shanghai, CHINA
[2]TQC-Theory of Quantum and Complex Systems, Universiteit Antwerpen, Universiteitsplein 1, B-2610 Antwerpen, BELGIUM
[3]Quantum Solid-State Physics, Department of Physics and Astronomy, KU Leuven, Celestijnenlaan 200D, B-3001 Leuven, BELGIUM

E-mail: junyi_ge@t.shu.edu.cn & hetian0928@shu.edu.cn

Both electrical and magnetic properties of superconductors are determined by the vortex matter as well as its dynamics. The systematic understanding of the distribution and interaction of vortices in superconducting strips is important for the application of superconducting devices. Here, by using low-temperature scanning Hall probe microscope, we performed direct visualization of the vortex pattern in different widths of superconducting strips. A vortex lattice transition from 1D to 2D is observed. For 1D lattice, the fully vortex expulsion magnetic field has to be taken into account, and the vortex lattice is mainly determined by the relatively strong confinement effect compared with the vortex-vortex interaction. At relatively high magnetic fields, the v-v interaction becomes dominant, and 2D vortex lattice is formed. The results of numerical simulation well repeat our experiments. A phase diagram of vortex patterns of narrow superconducting strips with magnetic field is established. The present work illustrates how the vortex pattern evolves in narrow superconducting strips, and can provide a new clue to design high-performance superconducting sensors for superconducting electronics applications.

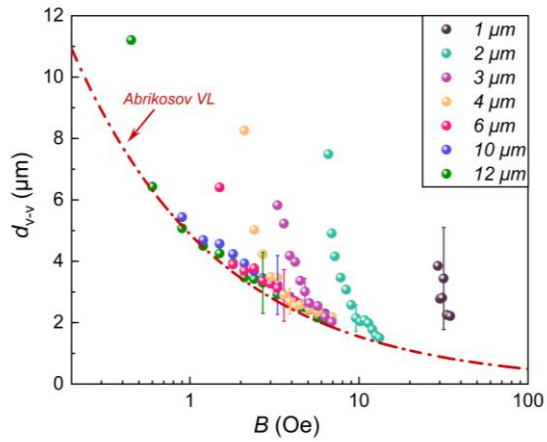

Fig. 1: *Averaged vortex-vortex distance as a function of the applied magnetic field in superconducting stripes with different widths. The error bars are the standard deviation. The dash-dotted line shows the expected v-v distance of an Abrikosov vortex lattice.*

Advances In Thin Films, Multi-Layers and Patterned Nanostructures I-II

06.05.2023 SATURDAY

Abstract ID: 221

LATERALLY PATTERNED EMBEDDED MAGNETIC NANOSTRUCTURES IN $Fe_{60}Al_{40}$

A. Semisalova[1], T. Strusch[1], R. Meckenstock[1], R. Bali[2], K. Potzger[2], K. Lenz[2], J. Lindner[2], M. Farle[1]

[1]*Faculty of Physics and CENIDE, University of Duisburg-Essen, 47057, Duisburg, GERMANY*
[2]*Institute of Ion Beam Physics and Materials Research, HZDR, 01328, Dresden, GERMANY*
E-mail: anna.semisalova@uni-due.de

Correlation between the ordered/disordered chemical structure and magnetism in several B2 alloys (e.g. $Fe_{60}Al_{40}$, $Fe_{50}Rh_{50}$) has inspired significant efforts of researchers working in nanomagnetism, spintronics and materials science [1-4]. These binary alloys allow a delicate tuning of magnetic properties in magnetic bilayers and laterally patterned magnetic nanostructures using chemical disordering via ion bombardment. The magnetization of $Fe_{60}Al_{40}$ is highly sensitive to the transition from the B2-ordered structure to the A2 (bcc, or disordered one) [4-6]. The paramagnetic $Fe_{60}Al_{40}$ alloy can be turned at room temperature into a ferromagnet with a saturation magnetization of up to 800 kA/m when the chemical disorder is introduced by ion irradiation with Ne ions [1]. Formation of antisite defects induces ferromagnetism associated with the increase in Fe–Fe nearest neighbors in an A2 structure and a lattice expansion. Focused ion beam irradiation can be used to produce individual embedded sub-50 nm nanomagnets in a paramagnetic surrounding [7]. Broad beam irradiation trough lithographically produced masks allows for magnetic patterning of periodical disorder-induced nanostructures embedded in non-ferromagnetic structurally ordered $Fe_{60}Al_{40}$ matrix, which opens a way to the design of *magnetic landscapes*. In this talk, the results of our recent studies of magnetization dynamics and ferromagnetic resonance in thin films and striped patterned textures in $Fe_{60}Al_{40}$ will be given. We investigate the dual role of $Fe_{60}Al_{40}$ as a spin source and a spin sink depending on its chemical order in spin pumping experiments [8] and analyze lateral spin pumping effects in nanostructured films.

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Abstract ID: 317

FLEXOMAGNETIC EFFECTS IN ANTIFERROMAGNETIC EPITAXIAL Cr_2O_3 THIN FILMS

P. Makushko[1], T. Kosub[1], O.V. Pylypovskyi[1,2], N. Hedrich[3], J. Li[1], A. Pashkin[1], S. Avdoshenko[4], R. Hübner[1], F. Ganss[1], D. Wolf[5], A. Lubk[5,6], M.O. Liedke[7], M. Butterling[7], A. Wagner[7], K. Wagner[3], B.J. Shields[3], P. Lehmann[3], I. Veremchuk[1], J Fassbender[1], P. Maletinsky[3], D. Makarov[1]

[1]*Helmholtz-Zentrum Dresden-Rossendorf e.V., Institute of Ion Beam Physics and Materials Research, 01328, Dresden, GERMANY*
[2]*Kyiv Academic University, 03142, Kyiv, UKRAINE*
[3]*Department of Physics, University of Basel, 4056, Basel, SWITZERLAND*
[4]*Institute for Solid State Research, Leibniz Institute for Solid State and Materials Research Dresden, 01069, Dresden, GERMANY*
[5]*Leibniz Institute for Solid State and Materials Research, IFW Dresden, Helmholtzstr. 20, 01069, Dresden, GERMANY*
[6]*Institute of Solid State and Materials Physics, TU Dresden, 01069, Dresden, GERMANY*
[7]*Helmholtz-Zentrum Dresden-Rossendorf e.V., Institute of Radiation Physics, 01328, Dresden, GERMANY*
E-mail: p.makushko@hzdr.de

Thin films of antiferromagnetic insulators (Cr_2O_3, Fe_2O_3, NiO etc.) are a prospective material platform for magnonics, spin superfluidity, THz spintronics, and non-volatile data storage. A standard micromagnetic approach for the description of thin film system commonly relies on the effective parameters, assumed to be homogeneously distributed within a material. The family of magnetomechanical effects includes piezo- and flexomagnetic responses, which determine the modification of the magnetic order parameters due to homogeneous or inhomogeneous strain, respectively. Accounting for the strain-gradient-driven magnetomechanical coupling promises technological advantages: the cross-coupling between elastic, magnetic and electric subsystems opens additional degrees of freedom in the control of the respective order parameters [1]-[3].

In this work, we discover the presence of flexomagnetic effects in epitaxial antiferromagnetic Cr_2O_3 thin films [4]. We demonstrate that a gradient of mechanical strain affect the order-disorder magnetic phase transition resulting in the distribution of the Néel temperature along the thickness of Cr_2O_3 thin film. The inhomogeneous reduction of the antiferromagnetic order parameter induces a flexomagnetic coefficient of about 15 μB nm^{-2}. The antiferromagnetic ordering in the strained films can persist up to 100 °C, rendering Cr_2O_3 as a prospective material for industrial spintronic applications. Strain gradient in Cr_2O_3 thin films enables fundamental research on magnetomechanics and thermodynamics of antiferromagnetic solitons, spin waves and artificial spin ice systems in magnetic materials with continuously graded parameters.

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Abstract ID: 476

THIN FILM SUPERCONDUCTING MAGNETIC FIELD CONCENTRATOR OF PLANAR DESIGN

L.P. Ichkitidze[1,2], A.Yu. Lysenko[2], M.S. Savelev[1,2], S.V. Selishchev[2]

[1]*Institute of Biomedical Systems, National Research University of Electronic Technology, 124498 Zelenograd, Moscow, RUSSIA*
[2]*Institute for Regenerative Medicine, Sechenov First Moscow State Medical University (Sechenov University), 119991 Moscow, RUSSIA*
E-mail: ichkitidze@bms.zone

Most magnetic field sensors (MFS) have a high resolution, i.e. low threshold sensitivity ≤1 nT, achieved through the use of superconducting film magnetic field concentrators (MFCs). They are used in MFS, in which various structures can serve as magnetosensitive elements (MSE), such as Josephson junctions, Hall sensors, sensors based on spintronic effects, etc. In this work, we study the planar structure of a superconducting film concentrator (see Figure 1), in which the MFC and MSE are in the same plane and do not intersect with each other. A sketch of the proposed structure is shown in Figure 1, and the following parameters are indicated on it: 1-MFC receiving rings (outer radius r_L=2 mm, ring width w_L=0.8 mm); 2 – substrate; 3 – active bands (AB) wide of the concentrator w_s=30 μm; 4 – MSE with width w_0=10 μm; 5 – the width of the gap between the AP and the MSE varied within w_a=0.2-5 μm; (0,0) – AB coordinate system; (x_0,y_0) – coordinates of the MSE center; w_p=20 nm – cut width; $2l_i$ is the distance between the cuts. All elements deposited on the substrate have the same thickness. In figure *c*, *d* and *e*: parallel sections in the AB are located uniformly in width, unevenly far from the MSE and near the MSE, respectively.

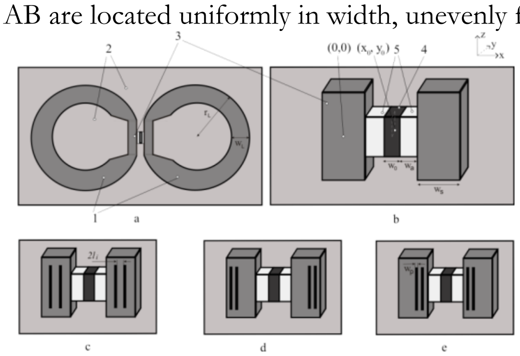

Fig. 1: *Sketch of planar film superconducting magnetic field concentrator.*

The concentration factor F of the magnetic field was determined as the ratio of the average value of the magnetic field at the MSE to the value of the external recorded field. It has been established that for a MFC containing AB without incisions (Figure 1, b), the parameter F takes values ~ from 100 to 200. The location of the incisions on the AB significantly changes F, in particular, its value is 20% more in Figure 1, *e* than in case *b*.

It should be noted that the parameter F takes on higher values when the MFC is made of a film of low-temperature superconducting material, relative to the case when the concentrator is made of a film of high-temperature superconducting material.

The results obtained will improve the efficiency of existing magnetic field sensors in the form of a reduction in the size of the receiving antenna, which will make it possible to detect smaller magnetic objects, including magnetic nanoparticles in the biological medium.

This work is supported by the Ministry of Science and Higher Education of the Russian Federation (project No. 075-03-2020-216 of December 27, 2019). Research at Sechenov University in terms of computer calculation of the magnetic field concentrator was funded by the Ministry of Science and Higher Education of the Russian Federation under grant agreement No. 075-15-2021-596.

Abstract ID: 529

ADJUSTMENT OF THE CORRECT COERCIVITY VALUES OF EXCHANGE-BIASED FILMS BY THE STONER-WOHLFARTH MODEL

M.V. Bakhmetiev[1,2], A.D. Talantsev[1], R.B. Morgunov[1,2]

1Federal Research Center of Problems of Chemical Physics and Medicinal Chemistry, Russian Academy of Sciences, 142432, Chernogolovka, RUSSIA
2Russian Quantum Center, Skolkovo innovation city, 121205, Moscow, RUSSIA
E-mail: bakhmetiev.maxim@gmail.com

Conventionally, in SQUID magnetometers, the sample is mounted in a plastic tube of 5 mm diameter [1, 2]. For unification of the experimental conditions in serial measurements, the thin films are fabricated on square substrates of 5 × 5 mm² size and the sample is installed into the plastic tube in a way, that the substrate boundaries are parallel to the sample tube axis. In these conditions the sample borders should be parallel to the magnetic field. However, there is a slight misalignment between the substrate boundary and the easy axis of the thin film resulting in tilted angle of magnetic field in respect to the anisotropy axes direction in the film. This, in turn, leads to incorrect coercivity values when measuring exchange-biased thin films such as NiFe/Cu/IrMn (green points in Fig. 1a and 1b).

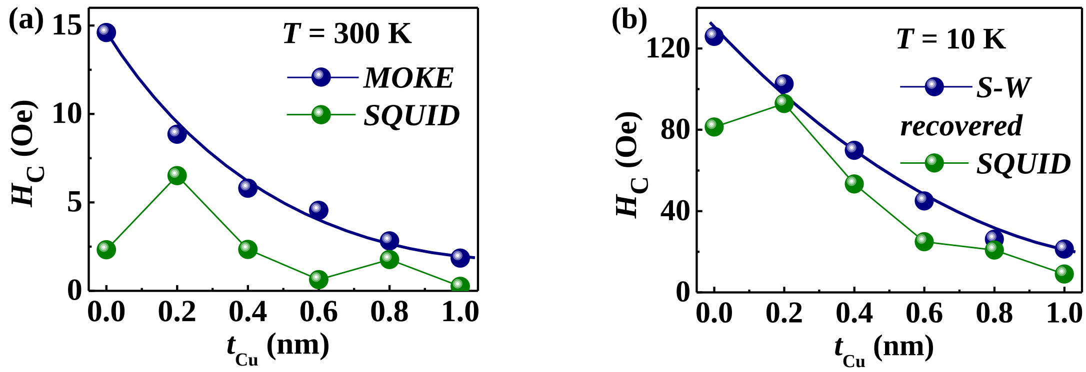

Fig. 1: *Application of the angle recovery protocol to serial measurement of coercivity in NiFe/Cu/IrMn structures with a variable exchange bias. (a) A reference dataset for the SQUID and MOKE (easy axis) coercivity values, measured at T = 300 K. (b) The dependences of* H_C *on* t_{Cu} *recorded with SQUID magnetometer and recovered with the Stoner-Wohlfarth model at T = 10 K.*

The inevitable uncertainty in the orientation of the easy axis is no longer a factor that introduces errors in the measurement of the coercivity. A technique is proposed for reconstructing the true coercivity values using the Stoner-Wohlfarth model for a set of exchange-biased thin films (blue points in Fig. 1b), which makes it possible to reduce experimental errors caused by spontaneous displacements of the easy axis of magnetic anisotropy relative to the direction of the magnetic field in a SQUID-magnetometer in the temperature range from 2 to 300 K.

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Abstract ID: 165

MAGNETO-OPTICS, REVISITED

R. Schaefer[1,2]

[1] *Leibniz Institute for Solid State and Materials Research (IFW) Dresden, Helmholtzstrasse 20, D-01069 Dresden, GERMANY*
[2] *Institute for Materials Science, Technische Universität Dresden, D-01062 Dresden, GERMANY*
E-mail: r.schaefer@ifw-dresden.de

In conventional magneto-optical microscopy and magnetometry a magnetic sample is illuminated with plane-polarised light and a magnetic domain contrast or magneto-optical signal, respectively, is generated by an analyser making use of the Kerr rotation. In this presentation we review numerous magneto-optical effects, which have not been considered or overlooked in the past. They lead to magnetisation-dependent *intensity modulations* of the reflected light that can be detected in *analyser-free* magneto-optical setups. Some of the discussed effects extend the spectrum of magneto-optical measurements in visible light by experimental possibilities, which were known so far only for X-rays spectroscopy.

By focusing on wide-field magneto-optical microscopy the following effects will be discussed: (i) The transverse Kerr effect can be applied for in-plane magnetised material, demonstrated for an FeSi sheet. (ii) Illuminating the same sample with circularly polarised light leads to a domain contrast with a different symmetry as the conventional Kerr contrast. (iii) Circular polarisation can also be used for perpendicularly magnetised material, demonstrated for a garnet film and an ultrathin CoFeB film. (iv) Plane-polarised light at a specific angle can be employed for both, in-plane and perpendicular media. (v) Perpendicular light incidence leads to a domain contrast on in-plane materials that is quadratic in the magnetisation and to a domain boundary contrast. (vi) Domain contrast can even be obtained without polariser. In cases (ii) and (iii), the contrast is generated by MCD (Magnetic Circular Dichroism, i.e. by the differential absorption of left and right circularly polarised light, induced by magnetization components along the direction of light propagation) while MLD (Magnetic Linear Dichroism, i.e. by the differential absorption of linearly polarised light, induced by magnetisation components transverse to the propagation direction) is responsible for the contrast in case (v). The domain boundary contrast is due to the magneto-optical gradient effect in metallic samples. A domain boundary contrast can also arise due to interference of phase-shifted magneto-optical amplitudes.

All reported effects and contrasts can be applied directly for domain imaging. In any case they need to be considered also in conventional magneto-optical Kerr microscopy and MOKE magnetometry as they can be superimposed on any regular Kerr signal.

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Abstract ID: 369

NMR SPIN ECHO OF DOMAIN WALL PINNING IN MAGNETS IN COMBINATION WITH AN ADDITIONAL MAGNETIC VIDEO-PULSE

T.A. Gavasheli[1], G.I. Mamniashvili[2], T.O. Gegechkori[2]

[1]*Ivane Javakhishvili Tbilisi State University, 0179, Tbilisi, GEORGIA*
[2]*Ivane Javakhishvili Tbilisi State University Andronikashvili Institute of Physics, 0186, Tbilisi, GEORGIA*
E-mail: tsismari_gavasheli@yahoo.com

NMR spin echo at application of an additional magnetic video-pulse is a convenient method to study the domain wall pinning in magnetic materials [1]. We present a short review of recent results obtained in this direction. Domain wall (DW) pinning force is the critical amplitude of a magnetic video-pulse (MVP) below which the DW is fixed.

For its assessment, two alternative NMR methods were chosen. In the first case, the pinning of DW was measured by the action of MVP applied between two radio-frequency pulses formed by them on a two-pulse echo signal, and in the second one, the pinning was measured at the combined action of MVP and radiofrequency (RF) pulses on the nuclear spin system in DW during the process of formation a single-pulse echo, by means of generation of the so-called magnetic echo signal [1]. The comparative study of the DW pinning was made by these two methods in magnets (lithium-zinc ferrite and cobalt micropowder) [2].

Acknowledgment

This work was supported by Shota Rustaveli National Science Foundation of Georgia (Grant # STEM-22-1339).

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Abstract ID: 544

FREQUENCY AND HUMIDITY DEPENDENT ELECTRICAL PROPERTIES OF ORGANIC SEMICONDUCTOR BASED SENSORS

Muneeb ur Rahman

Department of Physics, Islamia College Peshawar, Peshawar 25000, KP, PAKISTAN

E-mail: muneeb@icp.edu.pk

The imidazole derivative 2-(4, 5-Diphenyl-1H-Imidazole-2-yl)phenol was deposited between the Ag-electrodes via drop-casting method to fabricate the humidity sensor. The rectangular-shaped flakes of various shapes and sizes along with voids, pores, and pore-channels have been observed in surface morphology of the deposited material. The H_2O molecules interacted with N and NH site in the central ring of the compound and functional group OH at ortho-position. The calculated dielectric constant of the material was 1.4 which is bit lower than our previous published value of 1.6. Capacitive and resistive behavior of the device was checked at two different frequencies (1kHz and 10 kHz) for different humidity levels. In the humidity range of 45-95%RH the sensor's capacitance was increased from 10.1 pF to 378 pF, and from 7.43 pF to 16.48 pF at applied frequencies of 1 kHz and 10 kHz, respectively. The response and recovery time of the sensor was 34 sec and 6 sec, respectively. The goodness of fit, R^2 value was 0.99 which is close to unity for physisorbed layers. The sensor showed low hysteresis and has good sensitivity in comparison to the reported devices based on other materials.

Abstract ID: 560

TUNNELING HALL EFFECT: THEORY AND EXPERIMENT

E. Karashtin[1,2], N. Gusev[1,2], I. Pashen'kin[1], M. Sapozhnikov[1,2], A. Fraerman[1]

[1]*Institute for Physics of Microstructures RAS, GSP-105, 603950, Nizhny Novgorod, RUSSIA*
[2]*University of Nizhny Novgorod, 23 Prospekt Gagarina, 603950, Nizhny Novgorod, RUSSIA*
E-mail: eugenk@ipmras.ru

Tunneling (anomalous) Hall effect consists in appearance of the Hall voltage if an electric current flows through a magnetic tunnel junction (MTJ) due to the spin-orbit interaction in an insulating barrier. The mechanism of tunneling Hall effect may either be skew scattering or side jump. The former is caused by asymmetry of tunneling probability of the conductance electrons through the barrier with respect to their momentum along its surface. It was theoretically considered in several papers [1-3]. The latter is caused by the anomalous electron velocity inside the barrier caused by the spin-orbit coupling (SOC). SOC may either exist due to a non-centrosymmetric barrier [3] or due to an electric field induced by the voltage applied to the MTJ. The Hall current inside the barrier caused by such SOC was calculated in [4]. The experiments aimed at spectroscopy were carried out in [5].

We provide a consequent theory that takes into account all mechanisms of tunneling Hall effect. A simple model is used in which a delta-shape barrier possesses a Rashba SOC. We show that there is an additional side-jump mechanism caused by the asymmetry of the electron coefficient of reflection from the barrier with respect to the electron momentum along the insulator surface. We show that the quadratic in the applied voltage V_{bias} Hall effect appears in such system. We carry out an experiment in which tunneling Hall effect is measured in an MTJ with a ferromagnet (CoFeB) and a heavy metal (Pt, Ta) layer separated by a 1.5nm thick MgO insulator (Fig. 1a). The quadratic in V_{bias} Hall effect is observed. It is much stronger than the linear one for a thin (1 nm) Pt (Fig. 1b) and is almost independent of the nonmagnetic material (Pt or Ta). This effect decreases as the Pt layer is made thicker which manifests its surface nature. It almost vanishes for a 10 nm Pt layer.

This work was supported by the Russian Science Foundation (Grant #21-12-00271).

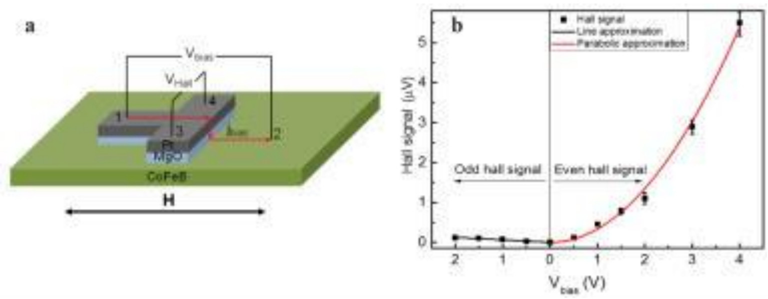

Fig. 1: *a) Sample and geometry of measurement. b)Even and odd tunneling Hall signal for Pt(1nm).*

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Chiral Magnetism: Solitons and Skyrmions I

06.05.2023 SATURDAY

Abstract ID: 251

DYNAMICAL SWITCHING, CREATION, AND MANIPULATION OF TOPOLOGICAL MAGNETISM IN SPIN-CHARGE COUPLED MAGNETS

Masahito Mochizuki

Department of Applied Physics, Waseda University, JAPAN
E-mail: masa_mochizuki@waseda.jp

Dynamical switching, creation, and manipulation of topological magnetism, e.g., skyrmions, merons, hedgehogs and Z_2 vortices, by application of electromagneic waves (i.e., light and microwave) are subject of intensive study in recent research of condensed-matter physics. In this talk, we discuss our recent theoretical studies on dynamical phenomena and dynamical manipulation of such topological magnetic texcures in spin-charge coupled magnets via light or microwave irradiation.

We start with the Kondo-lattice model which describes metallic magnets with localized spins coupled to itinerant electrons via exchange interactions called Kondo coupling. The localized spins are mutually coupled through effective interactions mediated by the conduction electrons. These effective interactions result in emergence of rich magnetically ordered phases including various types of skyrmion crystals as superpositions of multiple magnetic helices. Taking this model, we theoretically demonstrate the microwave-induced skyrmion creations [1], the microwave-induced switching of magnetic topology[2], and the photoinduced 120-degree spin order with topological Z_2 vortices[3].

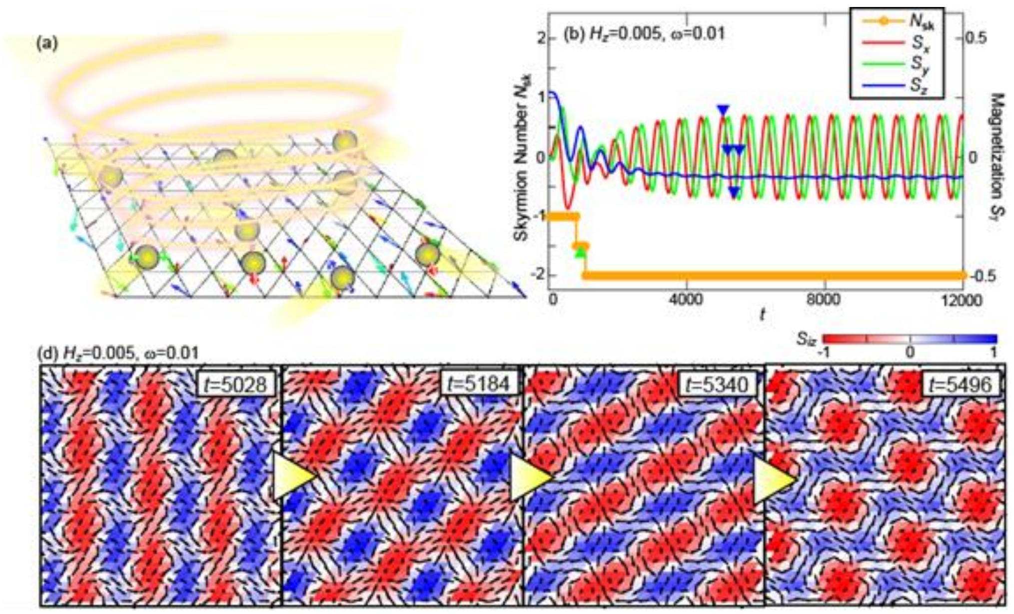

Fig. 1 *(a) Schematics of the Kondo-lattice magnet irradiated with electromagnetic waves. (b), (c) Simulated results of the microwave-induced magnetic topology switching.*

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THE 8th INTERNATIONAL CONFERENCE on SUPERCONDUCTIVITY and MAGNETISM

ICSM2023, Ölüdeniz-Fethiye, TÜRKİYE, May 04-11 2023

Abstract ID: 412

MICROWAVE-ASSISTED SYNTHESIS OF FERRITES FROM HYDROTALCITES AND THEIR APPLICATION FOR CERAMIC INDUCTION PLATES

Abderrahim Lahlahi Attalhaoui, G.C. Jaime, Samuel Porcar, Diego Fraga, Juan B. Carda, Robinson Cadena

Department of Inorganic and Organic Chemistry, Universitat Jaume I, Avenida Vicent Sos Baynat, s/n, 12071 Castellón de la Plana, SPAIN

E-mail: alahlahi@uji.es

Ferrites are iron compounds with magnetic properties and are widely used in technological applications such as sensors, information storage devices and catalysts [1]. The synthesis of ferrites from hydrotalcites using microwaves has been the subject of study in this work due to the advantages offered by this method compared to traditional synthesis processes.

Hydrotalcite in its origin is a compound of aluminate and magnesium carbonate that is presented in the form of thin layers. It has been demonstrated that the decomposition of Ni-Zn-Fe hydrotalcites yields ferrites that significantly improve the magnetic and structural properties of the particles. In addition, the use of microwaves allows a faster and more efficient synthesis compared to traditional high-temperature heating processes. Particles with smaller diameters and higher purity are produced compared to traditional processes [2].

Ceramic method **Hydrotalcite decomposition**

Fig. 1: *SEM micrograph of ferrites synthesized by ceramic route and by decomposition of hydrotalcites.*

Regarding the application of these nanoparticles, in the present project, a modified ceramic support is developed. This ceramic material is suitable for electromagnetic induction plates that are traditionally made of glass-ceramic material. Materials for this type of applications are mainly characterized by their high resistance to thermal shock and by their high magnetic permeability coefficients that reduce the shielding of the magnetic field [3].

In order to develop this ceramic plate, with the magnetic, thermal and mechanical properties required by this type of heating technology, a porcelain stoneware composition has been doped with synthesized particles of mixed Ni-Zn ferrites with low coercivity coefficients [4].

By magnetizing the porcelain, eddy currents are established which heat the whole mass of the support by Joule effect. This implies a reduction of the thermal gradient inside the piece as opposed to a diamagnetic composition [5].

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Abstract ID: 440

NEW INCOMMENSURATE MAGNETIC PHASES IN THE MULTIFERROIC COMPOUND $MnCr_2O_4$

M. Pardo-Sainz[1,2], A. Toshima[3], G. André[4], J. Basbús[5], G. J. Cuello[6], T. Honda[7], T. Otomo[7], K. Inoue[3], Y. Kousaka[2,3], J. Campo[1]

[1]*Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC - Universidad de Zaragoza, 50009, Zaragoza, SPAIN*
[2]*Osaka Metropolitan University, 599-8231, Sakai, JAPAN*
[3]*Chirality Research Center, Hiroshima University, 739-8526, Higashihiroshima, JAPAN*
[4]*Laboratoire Léon Brillouin, 91191, Saclay, FRANCE*
[5]*Centro Atómico Bariloche, R8402AGP, S. C. de Bariloche, ARGENTINE*
[6]*Institut Laue-Langevin, 38042, Grenoble, FRANCE*
[7]*Institute of Materials Structure Science, 305-0801, Tsukuba, JAPAN*
E-mail: miguel.pardo@csic.es

Nowadays, chromium-based normal spinel oxides ACr_2O_4 are one of the most studied materials in the condensed matter community due to the interplay between its magnetic, electric and structural properties [1,2]. In particular, for $MnCr_2O_4$, the ground state magnetic structure is still controversial because the magnetic structures reported by different groups and investigated by independent techniques are inconsistent [1-3].

The magnetic structure of this compound was reinvestigated by magnetization, specific heat and neutron diffraction experiments at different temperatures. The results revealed that a new magnetic phase, not previously reported, is developed below 18 K. The magnetic phases present in this sample were: ferrimagnetic order below T_C = 45 K; conical spin order with propagation vector K_{S1} = (0.62(1), 0.62(1), 0) below T_{S1} = 20 K; and conical spin order with propagation vector K_{S2} =(0.660(3), 0.600(1), 0.200(1)) below T_{S2} = 18 K.

Using the super-space group formalism, the symmetry of the nuclear and magnetic structures is determined (see figure 1). Through simple theoretical calculations, we derive the directions along which the electric polarization lies for each magnetic phase.

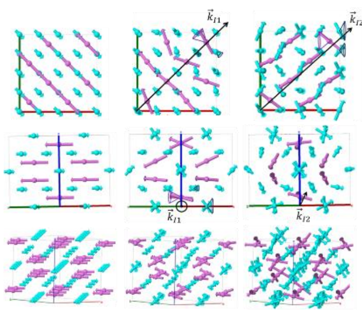

Fig. 1: *Scheme of the magnetic structures for each of the 2 different phases.*

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Flux Pinning in Coated Conductors

06.05.2023 SATURDAY

Abstract ID: 505

STEERED FLUX DYNAMICS IN LASER NANOSTRUCTURED SUPERCONDUCTING THIN FILMS

A. Badía-Majós[1,2], E. Martínez[2], L.A. Angurel[2,3], G.F. de la Fuente[2], E. Fourneau[4], S. Marinkovic[4], A.V. Silhanek[4]

[1] *Department of Condensed Matter Physics, University of Zaragoza, SPAIN*
[2] *Aragón Nanoscience and Materials Institute (INMA), CSIC-Universidad de Zaragoza, SPAIN*
[3] *Department of Material Science, University of Zaragoza, SPAIN*
[4] *Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, Université de Liège, BELGIUM*
E-mail: anabadia@unizar.es

Superconducting Nb thin films with thicknesses of 100nm and 200nm have been nanostructured by means of a femtosecond UV laser. Interference-like patterns of induced structures with lateral modulation of ≈ 200nm are obtained for optimized laser scanning conditions. Untreated and laser-patterned samples have been characterized by Surface and Transmission Electron Microscopy with elemental analysis, Atomic Force Microscopy, Magneto-Optical-Imaging, SQUID magnetometry, and transport measurements.

The superconducting properties reveal anisotropic behavior in accordance with the observed topography. The surface ripples define channels for anisotropic current flow and flux penetration as deduced from the MOI observations and transport measurements. The magnetic characterization of the samples displays crossover characteristics in the critical current density $\mathbf{J}_c(\mathbf{B},T)$: (i) the enhancement of the critical current density along the channels is roughly given by a factor of 2, (ii) laser treated samples show higher values of magnetization at low fields and higher temperatures, (iii) at low temperatures, laser treated samples are more prone to the appearance of flux avalanches, and (iv) as expected, avalanches initiate at regions of higher $\mathbf{J}_c$ but eventually, they proceed along the ripple defined flux channels.

Our results are interpreted in terms of the phenomenological theory for flux penetration in type-II superconductors, i.e.: the Maxwell equations for the fields $\mathbf{B}$, $\mathbf{E}$, $\mathbf{J}$ and the material law $\mathbf{E}(\mathbf{J})$ that incorporates the sample-dependent critical current density $\mathbf{J}_c(\mathbf{B},T)$.

Abstract ID: 514

STRUCTURE AND FLUX PINNING OF $EuBaCuO_{7-\delta}$-$BaHfO_3$ NANO-COMPOSITE FILMS DEPOSITED BY ULTRA-FAST PULSE LASER DEPOSITION TECHNIQUE

Yue Zhao[1], Yue Wu[1], Guangyu Jiang[1], Pan Lib[2], Hongli Su[3]

[1]School of Electronic Information and Electrical Engineering, Shanghai Jiao Tong University, 200240 Shanghai, PEOPLE'S REPUBLIC OF CHINA
[2]School of Materials Science and Engineering, Shanghai Jiao Tong University, 200240 Shanghai, PEOPLE'S REPUBLIC OF CHINA
[3]College of Materials Science and Engineering, Beijing University of Technology, 100022 Beijing, PEOPLE'S REPUBLIC OF CHINA
E-mail: yuezhao@sjtu.edu.cn

2G superconducting tapes based on Rare earth-barium-copper oxides are one of the key candidate materials for high-field magnet applications. An advanced pulse laser deposition system was developed to fabricate long-length high performance 2G HTS in our group. Due to the local overheating and quench process during the dynamic deposition, the transient liquid presents and assists the orientation growth of superconducting layer, which leads to the growth rate up to 100 nm/s. In this talk, $EuBa_2Cu_3O_{7-\delta}$ (EuBCO) films with different $BaHfO_3$ (BHO) dopant content was deposited to understand the structure and flux pinning behaviors. Structure characterizations reveal the BHO morphologies transform form nanoparticles to nanocolumns with dopant content during ultra-fast deposition. A self-assembly mechanism related to the high flux element during transient-liquid assisted epitaxial growth was proposed. In addition, a distinct lamellar structure of BHO in EuBCO matrix was found in all these three films, which is related to the change of growth conditions during the reel-to-reel process. The vortex behavior at low temperature and high field was investigated in details. The correlation between the high-field flux pinning and the microstructure was established. This study provides the clues to further design the pinning structure of the film during the ultra-fast PLD process.

Abstract ID: 522

HIGH J_C AND STRONG FLUX-PINNING IN LONG-LENGTH HTS WIRES AT SUPEROx

Pavel Degtyarenko

SuperOx, Moscow, RUSSIA
S-Innovations, Moscow, RUSSIA
E-mail: degtyarenkopn@gmail.com

In the recent years, the demand from private companies developing high magnetic field compact fusion has boosted the production of 2G HTS wire as an enabling material more than ten-fold. SuperOx has become a leader in 2G HTS wire production offering high-performing, robust product based on YBCO.

Strong flux pinning at low temperature in high magnetic field in SuperOx HTS wire is due to Y_2O_3 nanoparticles randomly distributed in the YBCO matrix. The epitaxial Y_2O_3 nanoparticles are semi-coherent to the YBCO matrix and give rise to abundant point-like defects such as misfit dislocations, nano-strain and, possibly, local oxygen non-stoichiometry, which are believed to be the actual pinning centers for the magnetic flux vortices.

The use of Y_2O_3, which is chemically *in*trinsic to YBCO, for enhanced pinning is in contrast to the artificial pinning center (APC) approach to introduce to REBCO chemically *ex*trinsic nanoparticles such as $BaZrO_3$ (BZO). In addition to the chemical complexity, the APC approach also adds nano-structural complexity, because the BZO nanoparticles tend to self-assemble into nano-columns preferentially aligned along the YBCO *c*-axis direction. As a result, 2G HTS wire with APC poses a significant challenge in manufacturing requiring extremely strict process control and narrowing down optimal processing parameter space, since even slight deviations of composition and/or growth conditions may result in drastic changes of the HTS layer nano-structure, hence in the wire superconducting performance.

The chemically and nano-structurally simple YBCO with random Y_2O_3 nanoparticles has proven to be amenable to robust, large volume manufacturing thus securing SuperOx leadership. In the talk we will give examples of actual production wire performance exceeding very high specs from fusion, in particular, for engineering current density at 20 K in 20 T magnetic field of over 750 A/mm^2. Upon the successful completion of the recent production scale-up, the present capacity of SuperOx is over 700 km of 12 mm wide 2G HTS wire per year.

Abstract ID: 592

HTS TAPE FOR FUSION MAGNETS

B. Moeckly

Commonwealth Fusion Systems, 117 Hospital Road, Devens, MA 01434 USA
E-mail: brian@cfs.energy

A thriving industry based on production of high-temperature superconducting (HTS) tape has been a dream for over two decades. Commercialization of applications utilizing HTS tape has been hampered due to the limited quantities of available tape and its high price. There has hence been little to no demand for the tape and no significant market. That situation has now changed with the recent growth of the fusion industry, and high-field fusion companies are purchasing very high volumes of HTS tape. Following our successful demonstration of a large-bore, 20-Tesla, all-HTS magnet in September 2021, we have begun construction of an energy-breakeven fusion device called SPARC that will be commissioned in 2025. A fusion pilot plant called ARC will follow, with the aim of putting fusion power on the grid in the early 2030s. In this talk I will explain why high-field HTS magnets are a game changer for fusion energy and will describe the types of HTS magnets required for tokamak operation. I will also discuss the electromechanical requirements of HTS tape for fusion magnets, and I will provide projections of future tape needs for this application.

High Tc Superconductors and Related Compounds I-II

06.05.2023 SATURDAY

Abstract ID: 170

HIGH-T$_c$ SUPERCONDUCTIVITY: THE ENDGAME AND BEYOND

T. Valla

Donostia International Physics Center, 20018 Donostia-San Sebastian, SPAIN
E-mail: tonica.valla@dipc.org

Cuprate high-T$_c$ superconductors (HTSC) may hold the promise of lossless transport of electrical power, a net positive fusion power generation and quantum computing devices, but after more than 35 years of the discovery and intense research, the mechanism of HTSC in cuprates remains unresolved. Moreover, most of the current studies are focused on phenomena in the underdoped materials that are largely unrelated to the most important unanswered question: what is the mechanism of superconductivity in cuprates? Here, I will present capabilities of angle-resolved photoemission spectroscopy (ARPES) and show that this technique is perfectly suited to provide a smoking gun evidence for the pairing mechanism in cuprates [1,2]. I will present the ARPES studies of a prototypical cuprate, $Bi_2Sr_2CaCu_2O_{8+d,}$ in a wide range of doping, covering not only the superconducting dome, but also its endpoint on the overdoped side and the non-superconducting metallic phase [3]. In the strongly overdoped regime, where superconductivity is the only remaining order, free of complications that usually pollute the underdoped regime, we detect anomaly in the state's dispersion that monotonically weakens with increasing doping and completely disappears precisely where superconductivity disappears – a tell-tale sign of its involvement in the pairing interaction (Fig. 1). Our study indicates that the resolution of high Tc problem might finally be in sight by providing a direct connection of the detected anomaly with superconductivity [4].

I will also discuss the problems and potential solutions in using the cuprates as a platform for topological superconductivity [5].

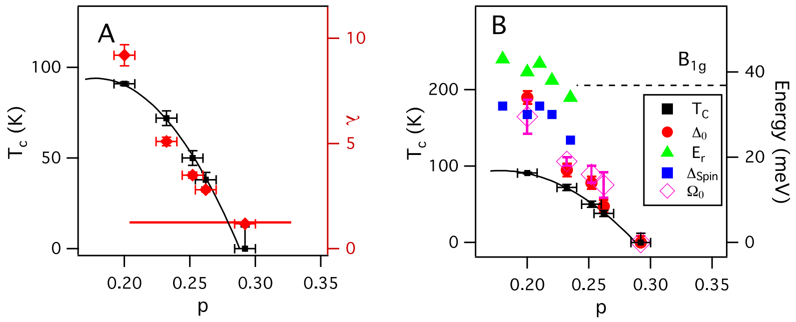

Fig. 1 *A) Electron-boson coupling constant and B) energies of some bosonic candidates that might be involved in the coupling to antinodal quasiparticles observed in* $Bi_2Sr_2CaCu_2O_{8+d}$.

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ROLES OF THE TWO ELECTRONIC SUBSYSTEMS IN HIGH-T_C CUPRATES – AN OPTICAL SPECTROSCOPY PERSPECTIVE

C.M.N. Kumar[1,2,5], Ana Akrap[3], Chris C. Homes[4], Edoardo Martino[5], Benjamin Klebel-Knobloch[6], Wojciech Tabis[6,7], Osor S. Barišić[2], Denis K. Sunko[8], Neven Barišić[6,8]

[1]*Institute of Nuclear Physics Polish Academy of Sciences, Radzikowskiego 152, 31-342 Kraków, POLAND*
[2]*Institute of Physics, Bijenička cesta 46, HR-10000, Zagreb, CROATIA*
[3]*Department of Physics, University of Fribourg, SWITZERLAND*
[4]*Condensed Matter Physics and Materials Science Department and National Synchrotron Light Source II, Brookhaven National Laboratory, USA*
[5]*Institute of Physics, École polytechnique fédérale de Lausanne (EPFL), SWITZERLAND*
[6]*Institute of Solid State Physics, TU Wien, AUSTRIA*
[7]*AGH University of Science and Technology, POLAND*
[8]*Department of Physics, Faculty of Science, University of Zagreb, CROATIA*
E-mail: cmnkumar@ifj.edu.pl

Understanding the physical properties of unconventional superconductors and other correlated materials presents a significant challenge due to their complex behavior with regard to doping, frequency, and temperature. This has frequently led to non-Fermi-liquid (non-FL) interpretations. Optical conductivity is a major challenge in this context. Despite the complexity, transport properties revealed the FL nature of the itinerant charges. We have used this to our advantage and calculated, directly from transport, without any fitting, the low-frequency part of the optical spectra of two well-known cuprate materials, underdoped $HgBa_2CuO_{4+\delta}$ and optimally-doped $Bi_2Sr_2CaCu_2O_{8+\delta}$. Calculated and experimental curves perfectly match. After subtraction of the FL contribution, a non-FL component emerges in the mid-infrared range (MIR). As argued, based on the evolution of its MIR spectral weight with temperature, frequency, and doping, this contribution can unambiguously be ascribed to the localized charge. In contrast to the gapped response in cuprates, a dissipative response was identified in pnictides and ruthenates. Such an unbiased FL/non-FL separation is extended across the cuprate phase diagram, which captures all the key features of the normal and the superconducting state, which includes the pseudogap and superfluid density.

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EVIDENCE FOR STRONG-COUPLING SUPERCONDUCTIVITY IN ALKALI-FULLERIDE FILMS

J.S. Zhou[1,2], Y.L. Chen[3], C.L. Song[1,2], L.X. Yang[1,2]

[1]*State Key Laboratory of Low Dimensional Quantum Physics, Department of Physics, Tsinghua University, Beijing 100084, CHINA*
[2]*Frontier Science Center for Quantum Information, Beijing 100084, CHINA*
[3]*Department of Physics, Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU, UK*
E-mail: lxyang@tsinghua.edu.cn

There has been a long-standing debate about the mechanism of the unusual superconductivity in alkali-intercalated fulleride superconductors. In this work, using high-resolution angle-resolved photoemission spectroscopy, we systematically investigate the electronic structures of superconducting K_3C_{60} thin films. We observe a dispersive energy band crossing the Fermi level with the occupied bandwidth of about 130 meV. The measured band structure shows prominent quasiparticle kinks and a replica band involving high-energy Jahn-Teller active $H_g(8)$ phonon mode, reflecting strong electron-phonon coupling in the system. The electron-phonon coupling constant is estimated to be about 1.2, which dominates the quasiparticle mass renormalization. Moreover, we observe an isotropic nodeless superconducting gap beyond the mean-field estimation ($2\Delta/k_BT_c \approx 5$). Both the large electron-phonon coupling constant and large reduced superconducting gap suggest a strong-coupling superconductivity in K_3C_{60}, while the electronic correlation effect is suggested by the observation of a waterfall-like band dispersion and the small bandwidth compared with the effective Coulomb interaction. Our results not only directly visualize the crucial band structure of superconducting fulleride but also provide important insights into the mechanism of the unusual superconductivity.

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Abstract ID: 163

MAGNETIC FIELD – ASSISTED CHARGE STRIPES

D. Radić[1], B. Keran[1], P. Grozić, A.M. Kadigrobov[1,2]

[1]*University of Zagreb, Faculty of Science, Department of Physics, 10000 Zagreb, CROATIA*
[2]*Theoretische Physik III, Ruhr-Universitaet Bochum, D-44801 Bochum, GERMANY*
E-mail: dradic@phy.hr

Numerous experiments in recent years indicate often presence of charge ordering such as charge stripes - charge density wave (CDW) in layered 2D materials among which we single out the most well-known example, the high-Tc superconducting cuprates. External magnetic field leads to enhancement of existing ordering, i.e. stabilization of long-ranged CDW. We show that topological reconstruction of the Fermi surface (FS), appearing as a consequence of spontaneously created periodic modulation of band electrons – CDW, of such wave vector to bring closed fermion pockets to very slight overlap, opens a pseudo-gap and lowers the total energy of electron condensate. The chain of closed electron pockets is transformed into an open FS. Such CDW appears as a rather peculiar quantum phase transition, with nonstandard dependence of condensate energy on order parameter, if electron-phonon coupling λ exceeds the critical value $\lambda_c \approx 0.61$. It appears in the opposite regime with respect to the standard CDW mechanism related to the FS nesting. Furthermore, applying the external magnetic field here further supports the mechanism of spontaneous FS reconstruction to open orbits, thus relaxing the average increase of energy due to Landau quantization of initial closed obits. Taking also into account electron over-gap tunneling assisted by magnetic field (magnetic breakdown), we find that subtle balance of counted effects leads to the overall strengthening of the spontaneous CDW ordering, lowering the required critical coupling constant (see Fig. 1).

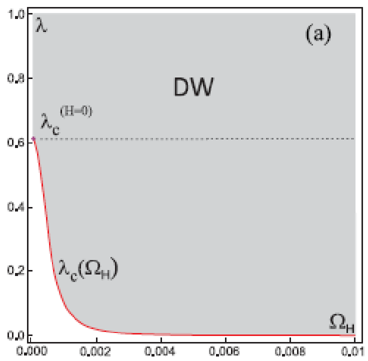

Fig. 1: *Phase diagram in coupling (λ) – magnetic field (Ω_H in units of the Fermi energy) space. $\lambda_c^{(H=0)}$ (dashed line) is the zero-field critical coupling below which the CDW is not present (phase transition into unordered state). $\lambda_c(\Omega_H)$ is the critical line below which the CDW (DW - gray shading) is exponentially suppressed (white area). Magnetic field apparently aids the DW ordering and extends it in the part of phase diagram where it was not present in the zero field, i.e. the required critical coupling to establish the DW ordered state is significantly smaller.*

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Abstract ID: 228

ANOMALOUS MAGNETIC EXCITATIONS IN THE HALF-FILLED Tl-BASED CUPRATE

I. Biało[1,2], K. Tanaka[1,3], Q. Wang[1], K. von Arx[1,4], J. Küspert[1], C. Lin[1], W. Pudełko[5], N.C. Plumb[5], Y. Sassa[4], N. Brookes[5], D. Betto[5], M. Ishikado[7], H. Eisaki[8], J. Chang[1]

[1]*Physik-Institut, Universität Zürich, Winterthurerstrasse 190, CH-8057 Zürich, SWITZERLAND*
[2]*AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, 30-059 Kraków, POLAND*
[3]*Department of Physics and Engineering Physics, University of Saskatchewan, Saskatoon, Saskatchewan, S7N 5E2, CANADA*
[4]*Department of Physics, Chalmers University of Technology, SE-412 96 Göteborg, SWEDEN*
[5]*Swiss Light Source, Paul Scherrer Institut, CH-5232 Villigen PSI, SWITZERLAND*
[6]*European Synchrotron Radiation Facility, 71 Avenue des Martyrs, 38043 Grenoble, FRANCE*
[7]*Comprehensive Research Organization for Science and Society (CROSS), Tokai, Ibaraki 319-1106, JAPAN*
[8]*Electronics and Photonics Research Institute, National Institute of Advanced Industrial Science and Technology, Ibaraki 305-8568, JAPAN*

E-mail: izabela.bialo@uzh.ch

The physics of two-dimensional square lattice at half-filling is well described by the Hubbard model with the antiferromagnetic ground state represented by an effective Heisenberg Hamiltonian. However, when the system is moved from the strong-coupling limit to the region of intermediate interactions (e.g., by introducing doping), quantum fluctuations may appear [1]. During the years, it was difficult to experimentally value the importance and strength of quantum fluctuations. However, increasing resolution of synchrotron techniques, as well as improved crystal growth technology, enable one to observe their experimental manifestations in more detail [2-4].

The presence of quantum fluctuations should, in principle, affect the magnon dispersion. Here, we present the first high-resolution resonant inelastic x-ray scattering (RIXS) studies of a Tl-based system that hosts long-lived magnon excitations. We identify a double layer, highly tetragonal Mott insulating cuprate, $Tl_2Ba_5CuO_x$, that provides us with a model system to study the anomalous magnetic excitations around $(\pi,0)$ point. Using the model of a square lattice Heisenberg antiferromagnet with ring exchange and finite interlayer coupling [5], we show that the single magnon dispersion derived from our RIXS studies cannot be effectively described without including renormalization coefficients of exchange parameters. This renormalization can be assigned to the presence of strong quantum fluctuations that are considered to be involved in the pairing mechanism in cuprate superconductors.

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Abstract ID: 426

ULTRAFAST DYNAMICS IN $(Li_{0.84}Fe_{0.16})OHFe_{0.98}Se$ AND SINGLE-LAYER $FeSe/SrTiO_3$: CORRELATION BETWEEN T_c AND THE EPC STRENGTH

Jimin Zhao[1,2,3]

[1] *Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China*
[2] *School of Physical Sciences, Univ. of Chinese Academy of Sciences, Beijing 100049, China*
[3] *Songshan Lake Materials Laboratory, Dongguan, Guangdong 523808, China*
E-mail: jmzhao@iphy.ac.cn

We have demonstrated an ultrafast dynamics evidence of the high-T_c superconductivity in the interface superconductor single-layer FeSe on $SrTiO_3$ substrate, with unambiguous observation of the SC gap $\Delta(T)$ and important acquisition of the electron-phonon coupling (EPC) strength λ [2]. Furthermore, we have also probed the quasiparticle dynamics and coherent phonon oscillation in the intercalated novel superconductor $(Li_{0.84}Fe_{0.16})OHFe_{0.98}Se$ [1]. Significantly, the EPC strength is experimentally obtained and compared among the single-layer $FeSe/SrTiO_3$, bulk FeSe, KFe_2Se_2, $(Li_{0.84}Fe_{0.16})OHFe_{0.98}Se$, $Fe_{1.01}Se_{0.2}Te_{0.8}$, $Fe_{1.05}Se_{0.2}Te_{0.8}$, and many other iron-based superconductors reported by colleagues. We find that the EPC strength has a universal positive correlation with the SC T_c among almost all types of iron-based superconductors, thus bridging the bulk and monolayer system, as well as FeAs- and FeSe-based superconductors [1].

Our results demonstrate that ultrafast spectroscopy is a promising venue for investigating interface superconductors, which is non-contact, single-layer sensitive, gap-perceptive, and most significantly capable of detecting the EPC strength directly. Our investigations demonstrate that EPC plays an important role in the iron-based superconductivity.

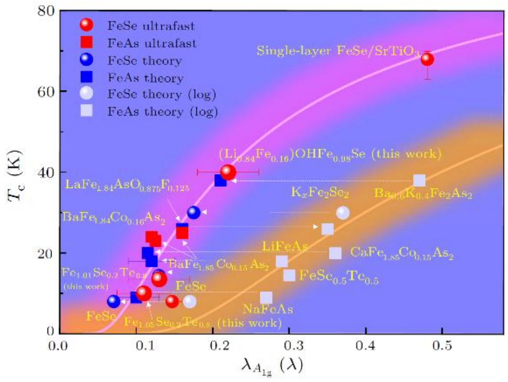

Fig. 1: *Universal positive correlation between the EPC strength $\lambda_{A_{1g}}$ (λ) and SC T_c in iron-based superconductors [1].*

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Magnetic Recording, Sensors and Microwave Devices

06.05.2023 SATURDAY

Abstract ID: 374

STRESS TENSOR DISTRIBUTION MONITORING & REHABILITATION IN STEELS

Spyridon Angelopoulos[1], Polyxeni Vourna[1], Aphrodite Ktena[2], Peter Svec[3], Evangelos Hristoforou[1]

[1]Laboratory of Electronic Sensors, National Technical University of Athens, Athens, GREECE
[2]National Kopodistrian University of Athens, Athens, GREECE
[3]Slovak Academy of Sciences, Bratislava, SLOVAKIA
E-mail: hristoforou@ece.ntua.gr

We have developed a method and the corresponding instruments, able to provide surface and bulk residual stress, as well as plastic deformation distribution monitoring in ferromagnetic steels and their welds. The method is based on the correlation of the classic reference methods of stress tensor distribution determination and monitoring on the surface and the bulk of steels, namely X-ray Bragg-Brentano diffraction (XRD-BB) and neutron diffraction (ND) respectively, with the corresponding surface or bulk magnetic permeability and magnetostriction, resulting in reference magnetic stress calibration curves (MASC) for each different type of steel. Normalization of all different MASCs with respect to the corresponding yield point and maximum permeability respectively resulted in a universal law of dependence of stresses on magnetic properties concerning residual stresses, thus facilitating in determining the MASC of an unknown type of steel, only by a stress-strain characterization together with in-situ magnetic permeability measurement. The mentioned uncertainty and speed of measurement for surface and bulk stress measurements have been verified for 17 out of the 42 different types of steels, involved in the most interesting steel applications. The stress monitoring methods are also accompanied by a localized stress rehabilitation, using localized induction heating probes. The system is accompanied by the proper software code, advancing the stress monitoring and rehabilitation method into an automated stress testing & rehabilitation system, meeting the needs for the modern & advanced steel production and manufacturing.

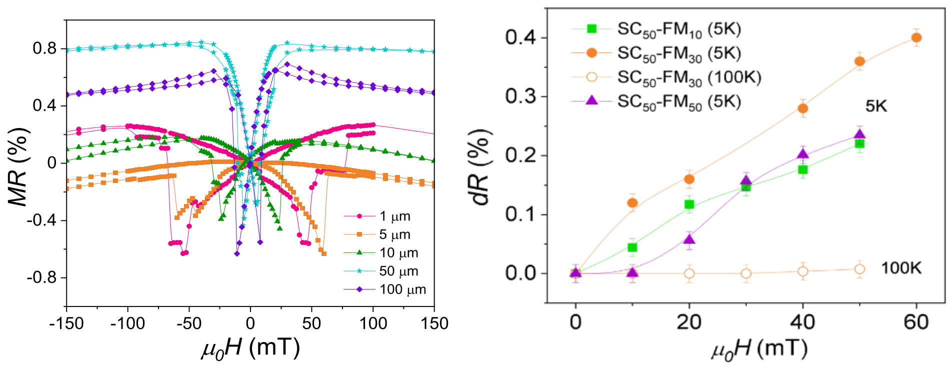
Abstract ID: 480

TUNABLE NON-TRIVIAL MAGNETIC STATES IN PERMALLOY MAGNETIC STRIPS AND SUPERCONDUCTING-FERROMAGNETIC HYBRID SYSTEMS

A. Barrera[1], E. Fourneau[2], J. Alcalà[1] , A. Sanchez[3], A. Silhanek[2], Ll. Balcells[1], N. Mestres[1], A. Palau[1]

[1]*Insitut de Ciencia de Materials de Barcelona, CSIC, Bellaterra 08193, SPAIN*
[2]*Université de Liège, B-4000 Sart Tilman, BELGIUM*
[3]*Universitat Autonoma de Barcelona, Bellaterra 08193, SPAIN*
E-mail: abarrera@icmab.es

Control of magnetization reversal processes and complex spin textures is a key issue for the implementation of magnetic materials in technological applications. The modulation of shape magnetic anisotropy in nanowire structures with a high aspect ratio is an efficient way to tune sharp in-plane magnetic switching. However, control of fast magnetization reversal processes induced by perpendicular magnetic fields is much more challenging. Here, tunable sharp magnetoresistance changes, triggered by out-of-plane magnetic fields, are demonstrated in thin permalloy strips grown on single crystal substrates. Micromagnetic simulations are used to evaluate the resistance changes of the strips at different applied field values and directions and correlate them with the magnetic domain distribution. The experimentally observed sharp magnetic switching, tailored by the shape anisotropy of the strips, is properly accounted for by numerical simulations when considering a substrate-induced uniaxial magnetic anisotropy. These results are promising for the design of magnetic sensors and other advanced magnetoresistive devices working with perpendicular magnetic fields by using simple structures. Additionally, the combination of superconducting $YBa_2Cu_3O_{7-x}$ structures with ferromagnetic materials in hybrid devices, allow us to manipulate magnetic textures, through loss-less superconducting stray fields or transport super-currents. Multiple volatile and non-volatile magnetic states with different magnetoresistance signal can be stabilized at remanence and modified by applying small magnetic fields or currents (Figure 1 (b)) [2].



(a) **(b)**

Fig. 1: a*) Sharp magnetoresistance jumps obtained in permalloy strips of different widths***. b)** *Remanent magnetoresistance ratio as a function of the applied magnetic field obtained in hybrid systems.*

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Abstract ID: 525

COMPARISON OF Fe-B BASED METALLIC GLASSES AFTER LONG-TERM ROOM TEMPERATURE AGEING

I. Janotova[1], P. Svec[1], D. Janickovic[1], Leonardo Viana Dias[1], I. Skorvanek[2], P. Svec Sr[1]

[1]Institute of Physics, Slovak Academy of Sciences, 84511 Bratislava, SLOVAKIA
[2]Institute of Experimental Physics, Slovak Academy of Sciences, 04001 Kosice, SLOVAKIA
E-mail: fyzisvec@savba.sk

Rapidly quenched amorphous Fe-B based system belongs to one of the most and longest studied amorphous alloy system which appeared since the report of discovery of Au-Si metallic glass in 1960 [1]. Research on preparation, stability and transformation to crystalline state in amorphous Fe-B ranges from 1970's, e. g. [2] till recent period. While most of the studies and developments were performed on ternary and more component alloys, Fe-B still remains a model system from which most of the nanocrystalline magnetic materials were developed by suitable alloying, e. g. Finemet, Nanoperm and several others. In all these systems both the stability of amorphous state as well as the transformation to stable crystalline state are of scientific and technical interest. Transformation kinetics and especially differences in second-stage transformation reaction in long-term room-temperature aged rapidly quenched hypoeutectic Fe-B metallic glasses were investigated on amorphous Fe86B14 ribbons prepared by planar flow casting. Three sets of amorphous ribbons in different stage of ageing were considered: (1) ribbon prepared in 1995, (2) ribbon produced in 2005 and (3) freshly prepared ribbon.

Preliminary analysis of the three sets of samples by differential scanning calorimetry and electrical resistivity measurements as a function of temperature in linear heating regime indicated minimal changes in the kinetics of first-stage of crystallization and no detectable differences in the crystaline structure embedded in the remaining amorphous matrix. The second crystallization stage which involves the amorphous remains, however, exhibited significant differences in the kinetics of the process for the three sample sets. Details of these differences were further investigated by kinetic and diffraction methods and by STEM/EDS techniques analogous to those used in [3]. Changes in the stability of the amorphous remains due to prolonged room-temperature ageing were correlated with local ordering of the original amorphous matrix and with the mass transport mechanisms controlling nucleation and growth processes upon devitrification.

Acknowledgement

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Magnetism of Nanoparticles, Nano-wires and Nanostructures

06.05.2023 SATURDAY

Abstract ID: 257

SYNTHESIS, CHARACTERIZATION, MAGNETIC AND EVALUATION OF THE ANTIBACTERIAL POTENTIAL OF (ZINC, COBALT, MAGNESIUM) FERRITE, CHROMITE AND ALUMINATE NANOPARTICLES

Mahmoud Khalil[1], Israa Hajjar[2], Maryam Al Bitar[2], Rayan Zahr[1], Sarah Zahr[1], Ramadan Awad[2]

[1]*Department of Biological Sciences, Faculty of Science, Beirut Arab University, Beirut, LEBANON*
[2]*Department of Physics, Faculty of Science, Beirut Arab University, Beirut, LEBANON*
E-mail: m.khalil@bau.edu.lb

(Zinc, cobalt, magnesium) ferrite, chromite and aluminate nanoparticles ($(Zn_{0.33}Co_{0.33}Mg_{0.33})\ M_2O_4$; M = Fe, Cr and Al) were prepared via the co-precipitation method. The prepared nanoparticles (NPs) (denoted by F-NPs for ferrite, C-NPs for chromite, and A-NPs for aluminate) have been characterized by the X-ray powder diffraction (XRD), Transmission electron microscope (TEM), Energy dispersive x-ray (EDX), Fourier transform infrared spectroscopy (FTIR), UV–vis spectroscopy, X-ray photoelectron spectroscopy (XPS), and Vibrating sample magnetometer (VSM). XRD patterns revealed cubic structure of the prepared NPs with the detection of secondary phases; Cr_2O_3 in C-NPs and MgO in A-NPs. TEM investigations showed a quasi-spherical shape for F-NPs, two morphologies distributed between cubic and quasi-spherical for C-NPs and nearly spherical shape for A-NPs. EDX analysis assured the presence of the chemical constituents in all NPs. Vibrational modes of the NPs have been investigated by FTIR analysis. The direct bandgap and Urbach energy values were calculated and displayed an inverse relation due to the structural disorder in the NPs. XPS analysis was used to investigate the composition as well as the valence state of the elements constituting the NPs. Furthermore, the M-H hysteresis curves displayed a ferromagnetic behavior for F-NPs and C-NPs, while a superparamagnetic nature was evident for sample A-NPs. The antibacterial activity of the synthesized NPs was assessed against four bacterial strains; two gram-positive (*Staphylococcus aureus* and *Enterococcus faecium*) and two gram-negative (*Stenotrophomonas maltophilia and Escherichia coli)* bacteria. The methods used to evaluate the antibacterial activity included broth micro-dilution method to determine the minimum inhibitory concentration (MIC), the minimum bactericidal concentration (MBC), and time-kill test. The A-NPs exhibited a potent antibacterial activity against almost all targeted bacteria compared to F- and C-NPs. These findings point to the importance of the biological applications of these NPs and the possibility of investigating other biomedical applications.

Abstract ID: 275

MAGNETIC ANISOTROPY AND EXCHANGE FIELDS IN Co NANOPARTICLES ON COPPER SURFACE AND GRAPHENE SHEETS

S.L. Prischepa[1,2], A.L. Danilyuk[1], N.G. Kovalchuk[1], E.S. Nazarenko[1]

[1]*Belarusian State University of Informatics and Radioelectronics, 220013, Minsk, BELARUS*
[2]*National Research Nuclear University MEPhI, 115409, Moscow, RUSSIA*
E-mail: prischepa@bsuir.by

We report the magnetic properties of a new type of composite consisting of Co nanoparticles electrochemically deposited on graphene (Gr) sheets. Graphene was grown by the atmospheric pressure chemical vapor deposition as described elsewhere [1]. Samples are characterized by scanning and transmission electron microscopy, Raman and X-ray photoelectron spectroscopy. It was obtained that the average size of Co nanoparticles and the distance between them were about 100 nm. Nanopartciles represent the core-shell structure in which the shell is CoO and the core is metallic Co. The electrochemical deposition did not affect the crystallinity of graphene [2]. Reference samples consisting of Co nanoparticles deposited on the Cu foil, were also fabricated and investigated. The magnetization M versus the magnetic field H was measured by Vibrating Sample Magnetometer (VSM) in the temperature range from 4 up to 300 K. The magnetic field was always applied parallel to the sample surface. The $M(H)$ curves were analyzed within the law of the approach to magnetic saturation (LAS).

Analysis of $M(H)$ hysteresis loops revealed that, with the temperature increase, the saturation magnetic field decreases, the steepness in the region of approximation to the saturation magnetization becomes higher, providing a faster saturation signal. Estimations of coercive force, blocking temperature, exchange constant, and Bloch constant are performed. For the Co/Cu and Co/Gr/Cu systems, hysteresis loop shift associated with the presence of an exchange bias caused by the influence of the antiferromagnetic CoO shell have been observed. The effect of the exchange bias is most significantly manifested in Co/Cu at a temperature of 4-50 K, when the shift of the hysteresis loop reaches a value of 0.30-0.40 kOe. At the same time, the coercive force at 4 K is less than its magnitude at 50 and 100 K. With an increase in temperature to 300 K, the effect of exchange bias disappears.

In the framework of the random anisotropy model (RAM), the anisotropy and exchange fields are calculated. Using the saturation magnetization approximation for 2D systems [3,4], correlation functions characterizing the distribution of magnetic anisotropy axes in arrays of Co nanoparticles were determined. The regularities of the influence of temperature on the correlation functions are established. It is shown that the low temperature region (T=4 K) is characterized by the presence of oscillatory correlation functions that do not decay in amplitude with a distance, which can be explained by an increase in the correlation of the anisotropy axes due to magnetostatic interaction and exchange bias. It is found that the amplitude of the correlation function increases smoothly with distance for the Co/Cu system, and for cobalt on graphene its behavior is determined by the exchange field.

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Abstract ID: 283

MAGNETIC AND ELECTRONIC PROPERTIES OF SIZE AND SHAPE CONTROLLED $CoFe_2O_4$ NANOPARTICLES FOR BIOMEDICAL APPLICATIONS

A. Szatmari[1], R. Bortnic[1], L. Barbu-Tudoran[2], F. Nekvapil[1], R. Stiufiuc[3], C. Iacovita[3], I.Gr. Deac[1], E. Burzo[1], R. Dudric[1], R. Tetean[1]

[1]*Faculty of Physics, "Babes-Bolyai" University, Kogalniceanu 1, 400084 Cluj-Napoca, ROMANIA*
[2]*Electron Microscopy Center "Prof. C. Craciun", Faculty of Biology & Geology, "Babes-Bolyai" University, 5-7 Clinicilor St., 400006 Cluj-Napoca, ROMANIA*
[3]*Department of Pharmaceutical Physics-Biophysics, Faculty of Pharmacy, Iuliu Hatieganu University of Medicine and Pharmacy, 6 Pasteur St., 400349 Cluj-Napoca, ROMANIA*
E-mail: romulus.tetean@ubbcluj.ro

The crystalline magnetic $CoFe_2O_4$ nanoparticles were prepared through the hydrothermal chemical route. The synthesis was carried in a PPL lined hydrothermal autoclave at a temperature of 230 ^{o}C for 23 h. cobalt (II) and iron (III) acetylacetonates were used as precursors and the solvent used were ethylene glycol or triethylene glycol. With the addition of polyvinylpyrrolidone (PVP) of different average molecular weight we have managed to control the morphology and size of the final nanoparticles. PVP with average molecular weight in between 10 and 360 kg/mol were added to the solution before the hydrothermal treatment. On the other hand, $Co_{1-x}Zn_xFe_2O_4$ nanoparticles ($0 \leq x \leq 1$) have been synthesized via a green, sucrose and pectin based, sol-gel combustion method. Transmission electron microscopy images show different tendencies growth depending of the length of the PVP polymer added. It was revealed that by using this PVP we can tune the morphology of the particles to spherical, cubical and rhomboidal. The prepared compounds are single phase. XRD measurements show that all samples crystallize in the cubic *Fd-3m* space group. The average crystallites sizes determined using Debye-Scherrer formula were found to be between 11 nm and 18 nm depending on the PVP molecular weight for pure samples and between 30 nm and 40 nm in the case of doped samples. EDS analysis on Zn doped samples confirmed the presence of cobalt, zinc, iron, and oxygen without contamination. Raman spectra show clearly that Zn ions are preferentially located in tetrahedral sites for low Zn concentrations. Due to their high crystallinity, the nanoparticles show high values of the magnetization, which increases with the Zn content for $x<0.5$. Magnetic measurements performed in an applied magnetic field between -2 T and 2 T, show small hysteresis loops at room temperature in concordance with the particle size. Small coercive fields, H_C, were found for all prepared samples. The H_C were 300 Oe respectively 50 Oe for the samples obtained with PVP molecular weight of 250 kg/mol and without polymer.The magnetic properties are discussed based on Raman results. The magnetic data support a core–shell model, where the core is ferrimagnetically ordered, and the shell shows a spin glass type behavior. The reduced magnetizations of spin glass components follow an $m_g = (1 - bH^{-1/2})$ field dependence. The b values are strongly correlated with the intensities of exchange interactions. Co ferrite doped with 30% of Zn produced the largest SAR values, which increase linearly from 148 to 840 W/gMNPs as the H is increased from 20 to 60 kA/m.

Abstract ID: 310

MAGNETIC PROPERTIES OF THE Ni AND Co-DOPED $MnFe_2O_4$ /SiO_2 NANOCOMPOSITES

T. Dippong[1], R. Tetean[2], I.G. Deac[2]

[1] *Department of Chemistry and Biology, Technical University of Cluj-Napoca, North University Center of Baia-Mare, 430122, ROMANIA*
[2] *Facultatea de Fizica, Universitatea Babes-Bolyai, 400084, Cluj-Napoca, ROMANIA*
E-mail: iosif.deac@phys.ubbcluj.ro

We report on the influence of Ni^{2+} and Co^{2+} ions doping on the magnetic properties of the $MnFe_2O_4/SiO_2$ nanocompozites, obtained by various inovative routes. Saturation magnetization (M_S), remanent magnetization (M_R), squareness (S), coercivity (H_C), magnetic moment per formula unit (n_B) and anisotropy constant (K) were determined since they are key parameters for a magnetic material to be used in various applications. X-ray diffraction (XRD) indicated the presence of nanocrystalline mixed cubic spinel ferrites in the presence of several secondary phases. The crystallite sizes varie with the increase of the annealing temperature and with Ni and Co content. The shape of the hysteresis loops revealed the dependence of magnetic behavior on the structural properties. The saturation magnetization and coercivity increase with the degree of crystallinity, crystallite size and annealing temperature for the both Ni and Co containing systems. The coercive field behaves differently for different heat treatment temperatures, increasing for 800 C and decreasing for 1200 C with increasing Mn content.

The Ni-rich nanocomposites show superparamagnetic-like behavior, while the Mn-rich nanocomposites have paramagnetic behavior. For the Ni containing samples, the main magnetic parameters M_S, M_R, n_B and K increase, while H_c decreases with increasing Ni content. NCs annealed at 1200 ^oC have increased Ms (16.0-45.8 emu/g), M_R (4.5-16.8 emu/g), and K (2.876-5.430 erg/dm^3). The H_c (265-175 Oe), decreases with increasing Ni content at 1200 ^oC [1]. The different behavior of these samples from the un-coated $Mn(Ni;Co)Fe_2O_4$ particles came from the SiO_2 matrix and from the preparation routes [2].

For the Co doping samples, for 800 ^oC heat treatment temperature, M_S increase from 19.4 emu/g to 38.2 emu/g and K from 0.365 to $1.32 \cdot 10^{-3}$ erg/cm^{-1} while for 1200 ^oC M_S decreases from 32.6 emu/g at 18.3 emu/g. When Mn is replaced by Co the behavior is ferromagnetic-like for both low and high Co ions concentration. The magnetic properties were discussed in the frame of the collinear two-sublattices Néel's theory and of the non-collinear Yafet-Kittel model considering the presence of hematite and some other parasitic phases [1,2].

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Abstract ID: 566

PHYTOSYNTHESIS AND CHARACTERISATION OF A NEW IRON DOPED MAGNETIC NANO-BIOADSORBANT

Y.E. Ayvaz[1], İ. Tosun Satır[2], Ç. Dönmez Güngüneş[3]

[1]*Institute of Graduate Education, Hitit University, 19030, TÜRKIYE*
[2]*Faculty of Science and Letters/ Department of Chemistry, Hitit University, 19030, TÜRKIYE*
[3]*Faculty of Health Sciences/ Department of Nutrition and Dietetics, Hitit University, 19200, TÜRKIYE*
E-mail: cigdemdz@gmail.com

The treatment of textile wastewater with iron-doped nano-bioadsorbent has some significant advantages due to its magnetic properties, environmentally friendly way of production, low cost and high yield of removal. In this study, two different biomasses (Gleditsia triacanthos and Cynara Scolymus) were used to synthesize iron doped nano-bioadsorbant for the removal of textile dyes (Methylene Blue and Safranine O) from wastewater. The synthesized materials were characterized using SEM, FTIR, Mössbauer Spectroscopy, and Zeta Potential Analysis. According to the results, the bio-nanocomposite material can be used for 20 cycles and can remove textile dyes with a yield of %99.5 and %97 respectively in 24 h. The prepared nano-bioadsorbant have a high potential in environmental applications as it can be removed from the wastewater using an external magnetic field due to its highly magnetic property which is confirmed with Mössbauer Spectroscopy.

Acknowledgements

The Scientific and Technological Research Council of Turkey (TUBITAK-2210-C)

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Molecular Spintronics Towards Spin Qubits for Quantum Computer and High Density Memory Devices I-II-III-IV

06.05.2023 SATURDAY

Abstract ID: 279

TUNABLE SPIN TRANSITIONS IN HETEROMETALLIC CYANIDO-BRIDGED MOLECULAR MATERIALS

Tomasz Charytanowicz, Szymon Chorazy, Barbara Sieklucka

Faculty of Chemistry, Jagiellonian University, Gronostajowa 2, 30-387 Kraków, POLAND
E-mail: barbara.sieklucka@uj.edu.pl

One of the most exciting classes of multifunctional solids is a spin crossover (SCO) molecular materials class, being at the forefront of molecular science research due to its potential applications in data storage and the construction of molecular switches and sensors. Spin crossover materials exhibit at least two different spin states with characteristic magnetic, optical and mechanical properties. They can be switched between these states by external stimuli such as temperature, light, pressure, electric field or guest molecules. In this regard, our research was connected to the spin transition compounds built of octacyanidometallate ions of Nb(IV), Mo(IV,V), W(IV,V), and Re(V) metal centers, used as auxiliary building blocks for the construction of spin crossover materials. They exhibit a series of multi-stimuli-switchable spin transitions, including cooperative ones for data storage applications, or gradual ones applicable for the construction of sensors [1-4]. In particular, we reported on the Fe-Nb and Fe-Re coordination polymers (CP) that exhibit multi-state and multi-stimuli-responsive SCO effects. We presented pressure-induced Fe–Nb SCO photomagnet [2], layered Fe–Re framework with hysteretic SCO behavior switchable by temperature, light, and pressure [3], and polar Fe–Re chain material exhibiting thermal spin bistability leading to the switching of magnetic moment, visible light absorption, SHG signal, and electrical conductivity. We also explored the pyridine-based ligands in Fe–Re CP, whose structure and physical properties are governed by the position of a benzyl substituent of the pyridine ligand [4].

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Abstract ID: 390

STRONGLY CORRELATED PHENOMENA IN TWO-DIMENSIONAL COORDINATION POLYMERS

Z. Zhang[1], K. Awaga[2], A. Yamaguchi[3], T. Matsushita[4]

[1]*Kumamoto University, International Research Organization of Advanced Science and Technology, 860-8555, Kumamoto, JAPAN*
[2]*Nagoya University, Dept. of Chemistry, 464-8062, Nagoya, JAPAN*
[3]*University of Hyogo, Dept. of Material Science, 678-1297, Ako-gun, Hyogo, JAPAN*
[4]*Nagoya University, Dept. of Physics, 464-8602, Nagoya, JAPAN*
E-mail: zhongyuezhang@kumamoto-u.ac.jp

In recent years, two-dimensional coordination polymers have attracted vast attention for their outstanding conductivity, which opens the gate of utilizing molecular-based materials as main component in electronic devices. To date, most studies focused on the development of new materials as well as the fabrication of devices, yet the potentially existing strongly correlations in these materials have been overlooked for a long time. Herein, using advanced measurement techniques, we unveiled the strongly correlated spin-spin interactions in a pristine 2D coordination polymer, $Cu_3(HHTP)_2$, which leads to a quantum spin liquid ground state and quantum critical phase transition under the applied magnetic field. Furthermore, by examining the electrochemically doped 2D coordination polymer, CuTHQ with quantitative ESR and magnetic susceptibility measurement, it is revealed that the system of CuTHQ is converted from a Kagome spin lattice to a honeycomb electronic structure, meanwhile, the existence of strongly correlated electrons in highly doped CuTHQ was demonstrated with the emergence of temperature independent paramagnetism. These research results emphasized the future of unearthing exotic physics in properly designed low-dimensional molecular systems.

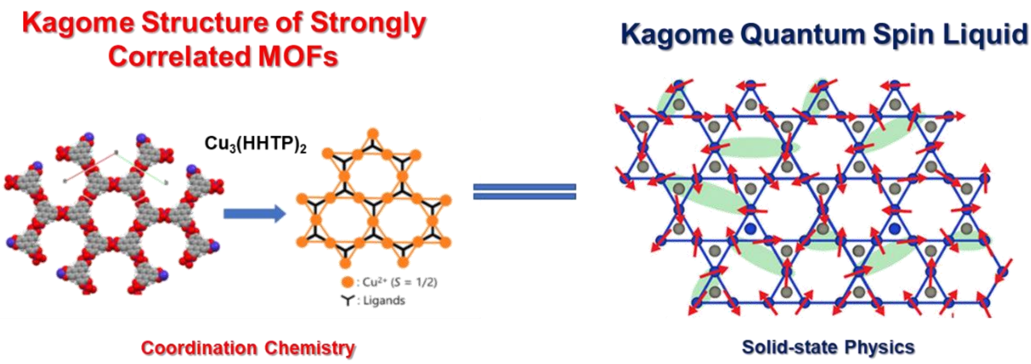

Fig. 1: *Strongly correlated spin-spin interactions in $Cu_3(HHTP)_2$ results a quantum spin liquid ground state.*

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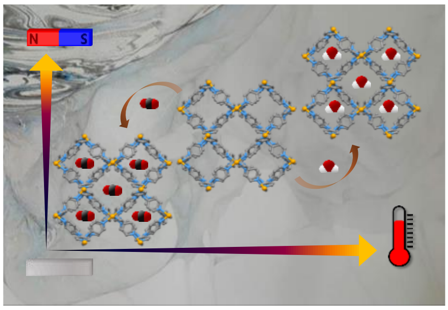
Abstract ID: 420

CONSTRUCTION OF COORDINATION NETWORKS FOR SPIN CROSSOVER

Kil Sik Min

Kyungpook National University, Dept. of Chemistry Education, 41566, Daegu, REPUBLIC OF KOREA
E-mail: minks@knu.ac.kr

Coordination networks have attracted much attention in chemistry and material science because of their potential applications for molecular magnetism and gas storage. To do that, it is quite essential to design new building units for constructing network structures in coordination polymers. In this research, we have introduced novel groups to secondary amine of bis(4-pyridyl)amine for midification of functionality. The new ligands are bis(4-pyridyl)benzylamine (bpba), bis(4-pyridyl)pyridylamine(bppa), and *N*,*N*,*N´*,*N´*-tetrakis(pyridine-4-yl)methanediamine (tpmd). From the self-assembly of iron(II) ion and the above ligands, we have synthesized various coordination networks and also characterized fully, *i.e.*, EA, IR, UV/Vis, and X-ray crystallography; [Fe(bpba)$_2$(NCS)$_2$]•2CH$_3$OH•H$_2$O (**1**), [Fe(bpba)$_2$(NCSe)$_2$] (**2**), [Fe(bppa)$_2$(NCS)$_2$]•CH$_3$OH•0.5H$_2$O (**3**), [Fe(tpmd)$_2$(NCS)$_2$]•5.5H$_2$O (**4**), [Fe(tpmd)$_2$(NCSe)$_2$]•7H$_2$O (**5**), and [Fe(tpmd)(NCBH$_3$)$_2$]•4H$_2$O (**6**). Coordination networks **1**-**4** are displayed in two-dimensional structures and show paramagnetic behaviors without any spin crossover. **5** exhibits two-step spin crossover due to the coordination of NCSe$^-$ ligands. At 300 K **5** is fully high-spin state. However, at 100 K **5** becomes *ca.* 50% high spin and 50% low spin of iron(II) ions. This was indentified from the single crystal X-ray structures at both 300 and 100 K. **6** displays spin crossover behaviors in hydrated and dehydrated networks. The iron(II) ions in **6** showed switchable electronic states between high spin and low spin at *ca.* 236 and 225 K for **6**•4H$_2$O and **6**, respectively. Very interestingly, **6** with CO$_2$ showed a large SCO temperature shift to 196 K. The CO$_2$ adsorbed single crystal X-ray structures are well identified at different temperatures. In addition, we have constructed other coordination networks for comparison, i.e., [Cd(tpmd)$_2$(NCS)$_2$], [Cd(tpmd)$_2$(NCSe)$_2$], and [Cd(tpmd)$_2$(NCBH$_3$)$_2$], and so forth. These will be included for discussion. In this presentation, we will describe the detailed preparation, structure, magnetism, and sorption properties.



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Abstract ID: 471

ENGINEERING SPIN EXCITATIONS IN 2D MAGNETIC MATERIALS

J.J. Baldoví, A.M. Ruiz, D.L. Esteras, A. Rybakov, G. Rivero, D. López-Alcalá, S. Dey

Instituto de Ciencia Molecular, Universitat de València, 46980, Paterna, SPAIN
E-mail: j.jaime.baldovi@uv.es

The recent isolation of two-dimensional (2D) magnets offers tantalizing opportunities for spintronics and magnonics at the limit of miniaturization.[1] Among the key advantages of atomically-thin materials are their flexibility, which provides an exciting avenue to control their properties by strain engineering, and the more efficient tuning of their properties with respect to their bulk counterparts. In this presentation we will provide an overview of our recent results on this fascinating topic. First, we will focus on the magnetic properties, magnon dispersion and spin dynamics of the air-stable 2D magnetic semiconductor CrSBr (TC = 146 K)[2] and will investigate their evolution under mechanical strain and Coulomb screening using first-principles.[3] Our results provide a deep microscopic analysis of the competing interactions that stabilize the long-range ferromagnetic order and the orientation of the spin in the monolayer.[4]

Then, we will apply our approach to some of the derivatives of the family of transition-metal phosphorus trichalcogenides and we will show the possibility of tuning spin wave transport by atomic-layer substitution, building a so-called Janus single-layer.[5] Finally, we will introduce novel hybrid molecular/2D heterostructures using sublimable organic molecules to show, as a proof-of-concept, the potential of a chemical approach for magnon spintronics applications

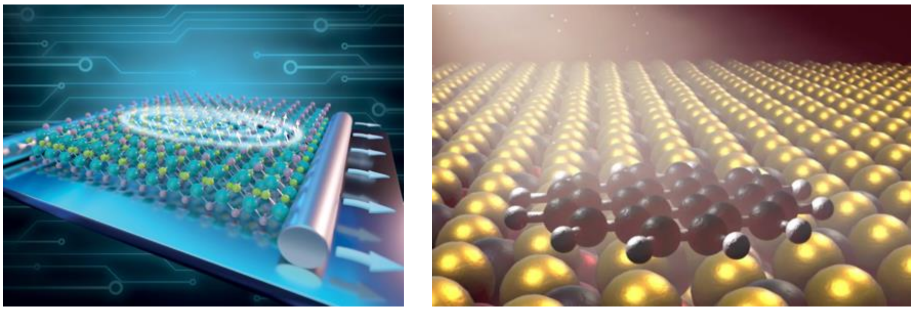

Fig. 1: *Artistic representation of (left) strain-engineering of spin waves in single-layer CrSBr and (right) a coronene molecule on the surface of a 2D magnetic material.*

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Abstract ID: 478

SYNTHESIS OF MOLECULAR NANOGRAPHENES AND GRAPHENE NANORIBBONS WITH MAGNETIC PROPERTIES

A. Narita[1,2]

[1] *Okinawa Institute of Science and Technology Graduate University, Organic and Carbon Nanomaterials Unit, 904-0495, Okinawa, JAPAN*
[2] *Max Planck Institute for Polymer Research, 55128, Mainz, GERMANY*
E-mail: akimitsu.narita@oist.jp

Graphene nanostructures are attracting attentions for their intriguing optical, electronic, and magnetic properties that are dependent on their precise chemical structures. Whereas defined structures are difficult to obtain by typical top-down fabrication methods, such as lithographic patterning of graphene, bottom-up chemical synthesis can achieve atomically precise molecular nanographenes and graphene nanoribbons (GNRs). In addition to the methods of synthetic organic chemistry, such graphene nanostructures can also be synthesized on metal surfaces, using tailor-made molecular precursors, and directly visualized by scanning probe microscopy (SPM) [1]. This on-surface synthesis method enabled the exploration of various zigzag-edged graphene nanostructures, which are typically highly unstable but demonstrate intriguing size- and structure-dependent electronic and magnetic properties. For example, we have synthesized rhombus-shaped molecular nanographenes with four zigzag edges, which showed a closed-shell character with four benzene rings in each zigzag side. In contrast, its larger homolog with five benzene rings in each zigzag side demonstrated open-shell properties with singlet ground state and a large magnetic exchange coupling of ~100 meV (1160 K) [2]. Moreover, by modulating the zigzag-edged structures, we could further increase the magnetic exchange coupling in molecular nanographenes up to 190 meV [3]. On the other hand, careful design of the molecular precursor enables incorporation of zigzag edges in GNRs, which can induce localized electronic spins (Fig. 1), and show ferromagnetic or antiferromagnetic coupling depending on their relative alignment [4].

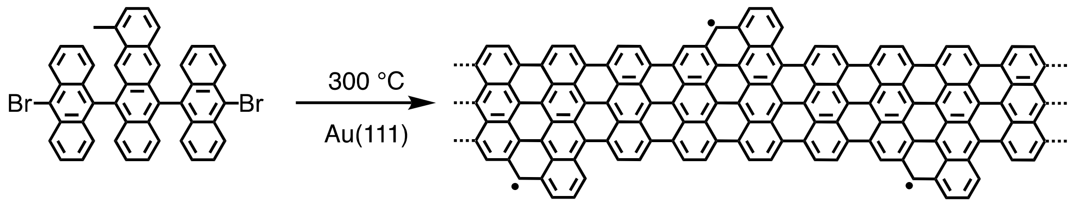

Fig. 1: *On-surface synthesis of GNRs with zigzag edges hosting localized electronic states.*

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Abstract ID: 370

CREATION OF Co(II) SINGLE-ION MAGNETS BY DOPING INTO Zn(II) DIAMAGNETIC METAL-ORGANIC FRAMEWORKS

Masanori Wakizaka[1], Masahiro Yamashita[2]

[1]*Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, 6-3 Aramaki-Aza-Aoba, Aoba-Ku, Sendai 980-8578, JAPAN*
[2]*Department of Chemistry, Graduate School of Science, Tohoku University, 6-3 Aramaki-Aza-Aoba, Aoba-Ku, Sendai 980-8578, JAPAN*
E-mail: masanori.wakizaka.a7@tohoku.ac.jp

The combination of single-ion magnets (SIMs) and metal-organic frameworks (MOFs) is expected to produce new quantum materials. The principal issue to be solved in this regard is the development of new strategies for the synthesis of SIM-MOFs. This work demonstrates a new simple strategy for the synthesis of SIM-MOFs where a diamagnetic MOF is used as the framework into which the SIM sites are doped.[1] 1 mol%, 0.5 mol%, and 0.2 mol% of the Co(II) ions are doped into the Zn(II) sites of $[CH_6N_3][Zn^{II}(HCOO)_3]$, a hybrid organic-inorganic perovskite (HOIP). The doped Co(II) sites in the MOFs show isolated single-ion magnetism with a positive D term of zero-field splitting. Remarkably, the Co(II) sites exhibit slow magnetic relaxations under a static magnetic fields, indicating field-induced SIMs. A study of the temperature dependency of the relaxation time suggests that a combination of phonon bottleneck and Raman processes occur within the material because of suppressing spin-lattice relaxation by the rigid framework. The relaxation time was elongated at lower levels of doping, a phenomenon that is completely different from bulk Co(II) magnets. Thus, this work represents a proof of concept for the creation of single-ion doped magnets in MOFs/HOIPs. This simple synthetic strategy will be widely applied for the creation of quantum magnetic materials.

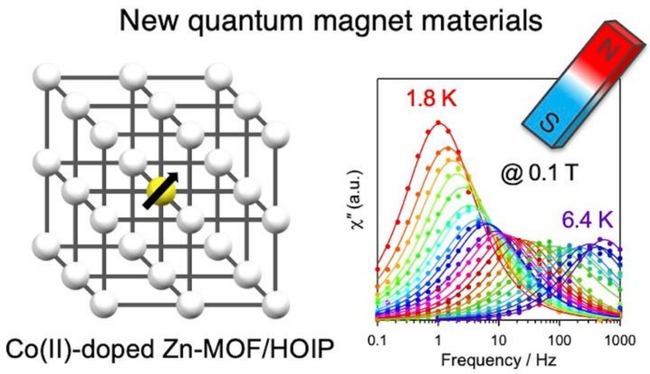

Fig. 1: A *schematic image of Co(II) ion doped MOF/HOIP together with the imaginary part of the alternating current susceptibility (χ'') of the 1 mol% doping sample.*

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MULTIFUNCTIONAL MOLECULAR CRYSTALS BY SUPRAMOLECULAR APPROACH

T. Nakamura

Research Institute for Electronic Science, Hokkaido University, N20W10, Kita-Ku, Sapporo 001-0020, JAPAN
E-mail: tnaka@es.hokudai.ac.jp

Molecular machines have been extensively studied, and a variety of artificial molecular machines have already been reported, including molecular motors, propellers, switches and shuttles. We are developing supramolecular systems that show molecular motion in crystals. In a crystal, molecules are fixed in position forming directional and high-density array. The cooperative motion of individual molecules through intermolecular interactions enables various functions in crystals, such as polarity conversion and mass transport, to be realized as a consequence of the periodicity of the crystals [1, 2]. In this study, we attempted to realize multifunctional materials by introducing supramolecular cations based on crown ethers into magnetic $[Ni(dmit)_2]^-$ ($dmit^{2-}$ = 2-thioxo-1,3-dithiole-4,5-dithiolate) crystals. Type-I multiferroic was also realized by combining a ferromagnetic two-dimensional honeycomb layer of $[Mn^{II}Cr^{III}(oxalate)_3]^-$ with a ferroelectric supramolecular rotator.

The $[Ni(dmit)_2]^-$ crystal with a supramolecular structure of dibenzo[24]crown-8 with pyridazinium as a counter cation exhibit negative thermal expansion (NTE), which is accompanied by a deviation in the temperature dependence of the magnetic behavior [3]. Supramolecular approach is also an efficient strategy for building multifunctional trigger systems. In the crystal of (4-aminopyridinium)(benzo[18]crown-6)$[Ni(dmit)_2]^-$, the dynamic degrees of freedom affect the magnetic and dielectric properties and induce NTE [4]. The disordered benzo[18]crown-6 formed polar domains within the crystal, resulting in relaxor ferroelectricity. With increasing temperature, the translational motion of the benzo[18]crown-6 caused uniaxial NTE, and disrupts the magnetic exchange interaction between $[Ni(dmit)_2]^-$ crystals.

A type I multiferroic was developed by combining a two-dimensional ferromagnet $[Mn^{II}Cr^{III}(oxalate)_3]^-$ with a ferroelectric molecular rotator structure. $[Mn^{II}Cr^{III}(oxalate)_3]^-$ exhibits a ferromagnetic transition around 5 K and incorporates various cations between two-dimensional honeycomb sheets [5]. A supramolecular structure, (*o*-fluoroanilinium)(benzo[18]crown-6), was introduced between the layers. (*o*-fluoroanilinium$^+$)(benzo[18]crown-6)$[Mn^{II}Cr^{III}(oxalate)_3]^-$ crystallized in the *Cc* space group. The crystal exhibits a ferroelectric transition with large hysteresis around 450 K. Ferroelectricity was evidenced by the sign reversal of pyroelectric current by an external electric field. The honeycomb layers of $[Mn^{II}Cr^{III}(oxalate)_3]^-$ exhibited ferromagnetic ordering below 5 K. The crystal is the first example of type-I multiferroic based on $[Mn^{II}Cr^{III}(oxalate)_3]^-$ layer structure.

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Abstract ID: 448

CONTROL OF MAGNETIC AND ELECTRIC POLARIZATION VIA ELECTRON TRANSFER IN MOLECULAR CRYSTALS

O. Sato, S.-Q. Wu, S.-Q. Su, S. Kanegawa

Kyushu University, Institute for Materials Chemistry and Engineering, 8190395, Fukuoka, JAPAN
E-mail: sato@cm.kyushu-u.ac.jp

The design and synthesis of new molecular compounds whose physical properties can be controlled by external stimuli have recently attracted much attention. Various switchable compounds have been developed [1]-[6]. An important challenge in the field is the control of the electric polarization of molecular compounds. The change in polarization mostly occurs by ion displacement. When electrons are adopted as the source of the polarization change instead of typical ion displacement and molecular reorientation, faster switching rate, and better durability, and even more interestingly, the photo- and magnetic-field-effect is expected. However, such a fundamental idea, which represents the concept of electronic pyroelectricity (polarization switching via electron transfer), has not been evaluated in non-ferroelectric molecular crystals. We report the electronic pyroelectricity in a valence-tautomeric cobalt complex [2], a dinuclear [CrCo] complex [3], a dinuclear [FeCo] complex [4], and a spin crossover iron complex [5]. Polarization changes in the [CrCo] complex stem from intramolecular electron transfer between Co and the ligand [3]; $Co^{III\text{-}LS}$–$dhbq^{3-}$–Cr^{III} □ $Co^{II\text{-}HS}$–$dhbq^{2-}$–Cr^{III} (LS = low spin, HS = high spin). Furthermore, photoinduced polarization switching was found to have a time constant of 280 fs by ultrafast pump–probe spectroscopy [6].

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Abstract ID: 269

STRATEGIES OF USING CYANIDO METAL COMPLEXES FOR CONSTRAINING THE LANTHANIDE(III) GEOMETRY TOWARDS SINGLE-MOLECULE MAGNETS

S. Chorazy[1], J.J. Zakrzewski[1], M. Zychowicz[1], M. Liberka[1], P. Bonarek[1], J. Wang[2,3], Y. Xin[3], K. Nakabayashi[3], B. Sieklucka[1], S. Ohkoshi[3]

[1]Jagiellonian University, Faculty of Chemistry, Gronostajowa 2, 30-387 Krakow, POLAND
[2]University of Tsukuba, Faculty of Pure and Applied Sciences, Department of Materials Science, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8573, JAPAN
[3]The University of Tokyo, School of Science, Department of Chemistry, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, JAPAN

E-mail: simon.chorazy@uj.edu.pl

In the last several years, we are witnessing impressive progress in the design and synthesis of novel molecules based on trivalent lanthanide ions that serve as high-performance Single-Molecule Magnets (SMMs). The related lanthanide-based molecular nanomagnets reveal the large magnetic anisotropy leading to the effect of slow relaxation of magnetization providing the magnetic hysteresis loop of a molecular origin [1]. Therefore, they are great candidates for the next revolution in the construction of high-density data storage devices; moreover, they were also presented as promising candidates for multifunctional molecular materials with added electrical and optical functionalities [2]. In these regards, there is a continuous need for efficient strategies of the rational design of lanthanide(III)-bases SMMs. We present here two synthetic pathways on how to achieve the tunable magnetic anisotropy of Dy(III) centers by using cyanido transition metal complexes as the supporting ligands applied together with the anisotropy-inducing O-donor organic ligands (Fig. 1, left) or as the direct source of lanthanide magnetic anisotropy (Fig. 1, right). Further functionalization of obtained Dy(III)-based SMMs towards optical properties and the responsivity to external stimuli is also discussed [3,4].

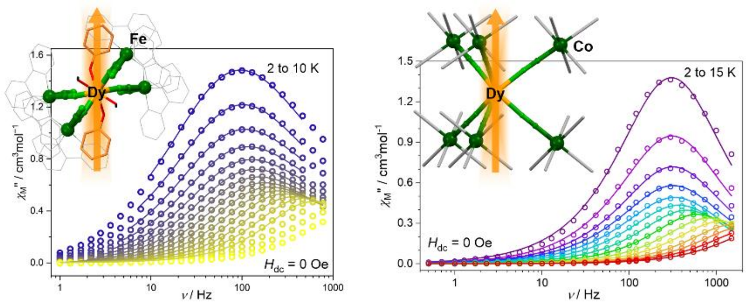

Fig. 1: *Molecular fragments and the representative ac magnetic characteristics of Dy(III)-based Single-Molecule Magnets constructed using the supporting cyanido metal complexes.*

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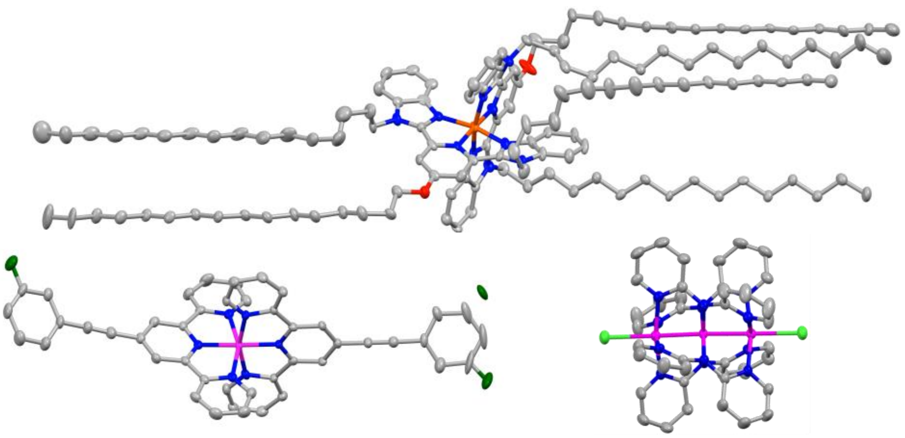
Abstract ID: 449

MAGNETIC PROPERTIES FOR COBALT(II) AND IRON(II) SCO COMPOUNDS

Shinya Hayami

Kumamoto University, Dept. of Chemistry, 8608555, Kumamoto, JAPAN
E-mail: hayami@kumamoto-u.ac.jp

Ferroelectric spin crossover (SCO) behavior is demonstrated to occur in the cobalt(II) complex, $[Co(FPh\text{-}terpy)_2](BPh_4)_2$ (**1**; FPh-terpy = 4'-((3-fluorophenyl)ethynyl)-2,2':6',2''-terpyridine) and is dependent on the degree of rotation of the ligand's polar fluorophenyl ring. The SCO behavior is accompanied by the rotation of the fluorobenzene ring, leading to destabilization of the low-spin (LS) cobalt(II) state; with the magnitude of rotation able to be controlled by an electric field. This first example of spin-state conversion being dependent on the rotation of a ligand-appended fluorobenzene ring in a SCO cobalt(II) compound provides new insight for the design of a new category of molecule-based ferroelectric materials.Ferroelectricity induced by spin transition associated with a crystal – liquid crystal phase transition is also demonstrated in achiral molecules. Iron(II) metallomesogens incorporating alkyl chains of type $[Fe(3C16\text{-}bzimpy)_2](BF_4)_2$ (**2**; bzimpy = 2,6-bis(benzimidazol-2'-yl)pyridine) that exhibit spin crossover (SCO) phenomena have been synthesized. Compound **2** were each demonstrated to show SCO behavior along with the occurrence of a phase transition between the crystalline (Cr) state and corresponding chiral smectic C (SmC*) state. The distortion of the coordination sphere in the high spin state triggers the generation of the SmC* state. The liquid crystalline compounds do not display ferroelectric behavior in their Cr state but do exhibit ferroelectric hysteresis loops in their SmC* state. These findings will undoubtedly open up strategies for the design of new FLCs based on metal-centered spin transitions. Furthermore, $[Co_3(dpa)_4Cl_2]$ (**3**; dpa = di(2-pyridyl)amine) that exhibit spin crossover (SCO) phenomena have been synthesized. Compound **3** were also demonstrated to show SCO behavior.



Abstract ID: 459

HYBRID POLYOXOMETALATE REDOX MATERIALS

G.N. Newton

GSK Carbon Neutral Laboratories for Sustainable Chemistry, University of Nottingham, Nottingham, NG7 2TU, U.K.
E-mail: graham.newton@nottingham.ac.uk

Polyoxometalates (POMs) have received considerable attention in recent years as potential components in future energy storage devices thanks to their structural stability and rapid, reversible redox properties. Due to their discrete nature, their use as components in devices relies on their stable combination with conductive solid or liquid-phase supports.[1] In our recent research we have been developing a range of POM-based redox materials and exploring their potential applications.

We recently showed that encapsulation of POMs within the cavities of single-walled carbon nanotubes leads to host-guest materials with exceptional redox stability (Figure 1).[2-4] Here a range of new POM@carbon redox-active nanomaterials will be presented, and their physical properties discussed. The use of these systems as model systems to study fundamental physical phenomena will be demonstrated.

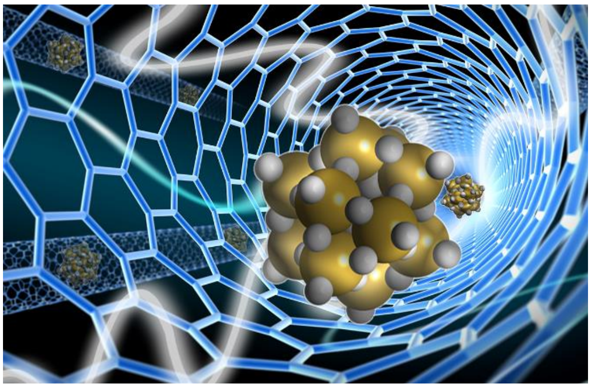


Fig. 1: *Redox-active polyoxometalates encapsulated within the cavities of single-walled carbon nanotubes.*

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Nanocomposites: Properties and Applications

06.05.2023 SATURDAY

Abstract ID: 125

TAILORING PROPERTIES IN RARE EARTH MISCHMETAL (MMNd)-Fe-B PERMANENT MAGNETS

Zubair Ahmad

Ibn-e-Sina Institute of Technology, H-11/4, 46000, Islamabad, PAKISTAN
E-mail: dza.isit@yahoo.com

Rare Earth Nd-Fe-B type permanent magnets are used in automobile industry, medical sectors, aerospace technology, efficient motors or generators, electro-mechanical, magneto-mechanical devices and advanced electrical energy vehicles. Industrial production of Rare Earth based magnets depend critically on the rare earth Nd/Pr/Dy/Tb/Y/Ce/La metal, metal purity and process technology which significantly influenced the manufacturing cost of these magnets. One strategy is to develop $Nd_2Fe_{14}B$ compounds without use of expensive Dy/Tb metals and to avoid complex processes. Second attractive way is to fabricate mischmetal compounds using economical and high abundance rare earth metals Ce/La/Ho. Third viable way is to enhance magnetic properties of Rare Earth free magnets such as MnBi/ ZrCo/Alnicos/FeCrCoMo. The mischmetal (MMNd)-Fe-B; (MM=NdPrCeLa) is an un-separated Rare Earth metal compounds which contains around 52 at.% Ce, 28 at.% La, 14.7 at.% Nd, 5.1 at.% Pr and others 0.2 at.%. Mischmetal compounds have less magnetic performance relative to $Nd_2Fe_{14}B$ compounds but it exhibits higher magnetic properties over magnetically hard Ba/Sr ferrites, Alnico-8, Alnico-9, PtCo and Fe-Cr-Co-Mo type permanent magnets. Moreover, the mass production of these compounds can reduced the production cost as well as environmental pollutions and thus has less utilization impact of rare earth element sources.

Present research work describes the development and properties of mischmetal $(MM_{30}Nd_{70})_{30.4}Fe_{68.2}Al_{0.4}Cu_{0.2}B_{0.8}$ permanent magnets. XRD studies showed tetragonal $RE_2Fe_{14}B$ phase and less RE-rich and $CeFe_2$ phases. Microscopic examinations elucidated that magnet microstructure composed of main magnetically $MM_2Fe_{14}B$ hard phase, RE-rich intergranular phase and magnetically soft $CeFe_2$ phase. Henkel plot demonstrated the existence of exchange coupling between magnetic phase grains. Thermal studies showed Curie temperature of 310°C for the Mischmetal $(MM_{30}Nd_{70})_{30.4}Fe_{68.2}Al_{0.4}Cu_{0.2}B_{0.8}$ magnet. Magnetic evaluations provoked coercivity H_{cj} of 619-1295kA/m, remanenec B_r of 1.0-1.15T and maximum energy product density of 185-241 kJ/m^3 for the $(MM_{30}Nd_{70})_{30.4}Fe_{68.2}Al_{0.4}Cu_{0.2}B_{0.8}$ type magnetic alloys.

Abstract ID: 297

STRUCTURAL AND MAGNETIC INVESTIGATION OF NOVEL SOFT/SOFT (1-x)$MgFe_2O_4$/(x)$Mn_{1.95}Sn_{0.05}O_3$ NANOCOMPOSITES

Salam Noureddine[1], Nour El Ghouch[2], R. Awad[3]

[1]*Physics Department, Faculty of Science, Lebanese University, Beirut, LEBANON*
[2]*Chemistry Department, Faculty of Science, Beirut Arab University, Beirut, LEBANON*
[3]*Physics Department, Faculty of Science, Beirut Arab University, Beirut, LEBANON*
E-mail: n.ghosh@bau.edu.lb

In the current study, the structural and magnetic properties of nanocomposite (1-x)$MgFe_2O_4$/(x)$Mn_{1.95}Sn_{0.05}O_3$ were investigated. The samples were synthesized using co-precipitation and high speed balling techniques. X-ray powder diffraction (XRD) measurements confirmed the high purity and crystallinity of the synthesized samples. Furthermore, the transmission electron microscope (TEM) and the high-resolution transmission electron microscope (HRTEM) were used to examine the morphology and the structure of the prepared samples. The elemental composition and the oxidation states of the elements (Mg^{2+}, Mn^{3+}, Mn^{4+}, Sn^{2+}, Sn^{4+}, Fe^{3+} and O^{2-}) forming the nanocomposites were determined by using the X-ray photoelectron spectroscopy (XPS). Additionally, Fourier transform infrared spectroscopy (FTIR) confirms the purity and the vibrational modes of each phase as well as the formation of pure $MgFe_2O_4$, $Mn_{1.95}Sn_{0.05}O_3$ and nanosized $MgFe_2O_4$/$Mn_{1.95}Sn_{0.05}O_3$ composites. The vibrating sample magnetometer of the prepared nanocomposites exhibited a weak ferromagnetic behavior. The saturation magnetization and the coercivity values are found to be in the ranges 1.05-14.59 emu/g and 1.306-66.846 G, respectively. Besides, a single peak was observed in the switching field distribution curves which indicates the exchange couple interaction between $MgFe_2O_4$ and $Mn_{1.95}Sn_{0.05}O_3$ nanoparticles.

Abstract ID: 324

RECENT ADVANCES IN NANOCOMPOSITES: PROPERTIES AND APPLICATIONS

R. Awad[1,2], A.M. Abdallah[1], M. Anas[1,2], A.I. Abou-Aly[2]

[1]*Physics Department, Faculty of Science, Beirut Arab University, Beirut, LEBANON*
[2]*Department of Physics, Faculty of Science, Alexandria University, Alexandria, 21511, EGYPT*
E-mail: ramadan.awad@bau.edu.lb

The synthesis of nanocomposites, by combining nano/materials with various characteristics, initiate brand-new materials with improved physical properties and extraordinary functionalities. This combination forms composites of nanomaterials/superconductors, ferrite/oxide nanocomposites, soft/hard magnetic nanocomposites, and nanomaterials/polymers composites.

The incorporation of nanomaterials into superconductors aims to introduce strong flux pinning centers in the superconductors. This yielded enhancement in the critical current density, superconducting transition temperature, improved thermal stability, increased mechanical strength, and improved magnetic properties. The composites of nanomaterials/superconductors can serve as advanced materials with an extended range of applications, that are suitable for energy, electronics, and medical imaging fields.

The interaction of nano ferrites with nano oxides as nanocomposites may generate interfaces that result in versatile properties. The ferrite/oxide nanocomposites attained enhanced performance, rendering them functional materials, that are useful in the field of energy (magnetic storage media), environment (photocatalysts and adsorbents), and electronics (sensors).

The soft/hard magnetic nanocomposites generated new material for exchange-spring magnets. When soft/hard magnetic phases are exchange-coupled, they yield the combination of high saturation magnetization from the soft magnetic phase and high coercivity from the hard magnetic phase, producing materials with outstanding magnetic properties. These materials are suitable for radar-absorbing technology, permanent magnets, and electromagnetic compatibility.

The reinforcement of polymers by nanomaterials demonstrated boosted properties, especially for radiation shielding applications. Polymer composites proved to be excellent candidates for shielding problems, due to their reduced heaviness and increased flexibility. By combing the hydrogen-rich polymers and metallic additives (nanomaterials), dual-purpose shields are fabricated for both neutron and gamma – X-ray shielding.

Overall, the fabrication of nanocomposites has provided new insights into the advancement in the industrial sector, to the wide applicability of the nanocomposites, owing to their enhanced properties.

New Phenomena and Applications in Molecular Magnets-III

06.05.2023 SATURDAY

Abstract ID: 362

MOLECULAR NANOSPINTRONICS: THEORY SHAKES HANDS WITH EXPERIMENT

G. Lefkidis[1,2], J. Liu[3], B.C. Mummaneni[4], R. Shi[1], W. Hübner[1]

[1]RPTU Kaiserslautern-Landau, Dept. of Physics, 67663 Kaiserslautern, GERMANY
[2]Northwestern Polytechnical University School of Mechanics, Civil Engineering and Architecture, 710072 Xi'an, CHINA
[3]Institute of Theoretical Chemistry, Ulm University, 89081 Ulm, GERMANY
[4]Fraunhofer Institute for Industrial Engineering, 70569 Stuttgart, GERMANY
E-mail: lefkidis@rptu.de

As the thirst for computer power is ever-growing and computer technology slowly reaches the classical limits of conventional semiconductor electronics, new alternatives are needed. Innovation is thinkable with respect to the materials (e.g., employing nanostructures), and with respect to the logic (using quantum logic). Both paths can be met with magnetic molecules as building blocks, paving the way toward full-fledged magnetic nanologic. Our results can help us to elucidate the microscopic mechanisms behind ultrafast spin dynamics and pave the way towards designing of future nanospintronic devices.

First, we investigate the time-dependent photoinduced dynamics in a Fe_3 molecule (Fig. 1a) [1], revealing spin-flipping channels. Second, we analyze substrate effects, by exemplarily investigating the adsorption of iron porphyrin on Cu (100) (Fig. 1b) using second-harmonic generation. Third, we look into the magnetic properties of two magnetic polymers of Cu(II) complexes, the magnetic behavior of which can be controlled through different stackings [2]. Fourth, we study the ultrafast dynamics of $[Dy_2Ni_2(L)_4(NO_3)_2(DMF)_2]$ (Fig. 1c), and by comparing theory with experiment we unveil the (partial) metal-to-oxygen charge transfer and estimate the thermal system-to-bath coupling constant [3]. Finally as concrete examples of possible realization of quantum logic we present a charge-spin gear box on the synthesized magnetic nanostructure $Co_3Ni(EtOH)$ [4], and the implementations of the Controlled-NOT, Hadamard, SWAP, and Pauli gates states in $[Dy_2Ni_2(L)_4(NO_3)_2(DMF)_2]$ [5].

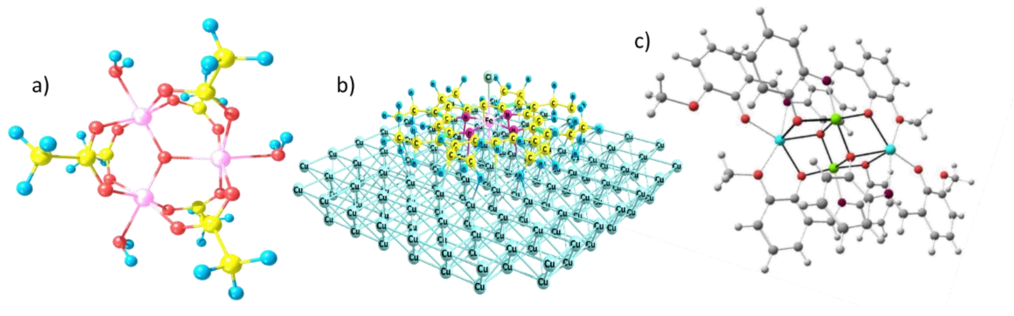

Fig. 1: *Some of the systems investigated: a) $Fe^{III}_2Fe^{II}O(CH_3CO_2)_6(H_2O)_3$. b) Iron porphyrin on Cu(100). c) $[Dy_2Ni_2(L)_4(NO_3)_2(DMF)_2]$.*

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Abstract ID: 424

NEUTRON SCATTERING EXPERIMENTS WITH HIGH MAGNETIC FIELDS IN ORGANIC MAGNETS

J. Campo[1], Y. Hosokoshi[2]

[1]*Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC - Universidad de Zaragoza, 50009, Zaragoza, SPAIN*
[2]*Osaka Metropolitan University, 599-8231, Sakai, JAPAN*
E-mail: javier.campo@csic.es

Purely organic magnets with π-electron spins have essentially negligibly small spin-orbit couplings and are attractive materials because they are archetypical Heisenberg spin systems in which the quantum fluctuations play an important role. The spin size and the connectivity of the network is the key factor of the novel magnetic states arising from quantum fluctuations. Among the representative stable organic radical skeleton, nitroxide radical (-N-O·) has the advantage of making antiferromagnetic spin networks. The positive and negative partial charges on the N and O atoms, respectively, easily gives the intermolecular contact between the NO groups on which the singly occupied molecular orbital (SOMO), that is the molecular orbital with the unpaired electrons, is distributed. The intermolecular overlap between SOMO's always yields the antiferromagnetic interactions [1,2]. The stacking of planar π-conjugated molecules gives one-dimensional (1D) network. When two or more NO groups are substituted on a molecule, double spin chain with different spin size is formed [2,3]. After the extensive study on the 1D Heisenberg antiferromagnet, there is growing attention to the effect of the quantum fluctuations in two- or three-dimensional (2D or 3D) Heisenberg antiferromagnets, but the experimental realization is still rare.

Considering the nitroxide radical as magnetic entity we were able to growth and macroscopically study several compounds with different dimensionalities with different magnetic behaviours (frustrated spin ladder, 3D honeycomb with AF LRO [4] or 3D Kagomé layers, etc…). In this presentation several examples will be shown in order to highlight the crucial role of the neutron scattering experiments to understand the basic physics of these interesting materials.

Many times, in organic magnets the first step to understand the magnetic behavior is the study of the overlapping between the magnetic molecular orbitals which is directly related with the experimental spin density determination, and this is often done by using polarized neutrons with applied magnetic fields [5], what will be also presented.

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Abstract ID: 562

QUANTUM SPIN STATES IN FRUSTRATED MAGNETS MADE OF ORGANIC RADIALS

Y. Hosokoshi

Osaka Metropolitan University, Dept. of Physics, 599-8531, Sakai, Osaka, JAPAN
E-mail: yhoso@omu.ac.jp

Quantum spin system is attractive because quantum fluctuation induces various exotic quantum phenomena. Organic radical system is a good candidate to study quantum phenomena on various spin lattices. The ideally isotropic nature of π-electron spin enables us to observe quantum effect even on the ferromagnetic system [1] or three-dimensional magnetic system [2] for the first time. We have developed a wide variety of spin lattices and our recent approach using a ferromagnetic dimer of $S = 1/2$ or an $S = 1$ species will be presented. The spin frustrated lattice with ferromagnetic interaction is current interests because of its novel quantum spin states. The observed quantum spin states and relation with frustration will be discussed.

The intramolecular interaction between two radial species is controllable based on the concept of spin polarization [3]. We have developed a family of biradical of nitronyl nitroxide with changing the molecular dihedral angles and revealed the relationship between the intramolecular interactions and π-conjugation. The large dihedral angle is effective to expand intermolecular interaction on multidirectional pathway, and a four-leg spin ladder and two-dimensional system are realized.

The biradical system with expanded π-conjugation is examined. When using a biphenyl group, the intermolecular π-π stacking in crystals results in the intermolecular interaction through π-conjugation. A biradical system with a biphenyl group shows intermolecular interactions not only by a direct contact between radical sites but also through the contact between biphenyl groups. As a results, neighboring two molecules forms a 4-spin cluster model of $S = 1/2$, which sometimes shows frustrated spin structure by the nearest and the next nearest neighbor interactions. In magnetic fields, anomalous spin state is observed.

The biradical system with *t*-butyl nitroxide has been also studied. Due to the large intermolecular interaction, the unit of 1,3-bis(*N*-*t*-butylaminoxyl)benzene behaves as a good $S = 1$ species [4]. The expansion of π-conjugation brings good stability and crystallinity. Two- and three-dimensional lattices of $S = 1$ is realized and the peculiar quantum spin states will be presented.

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Special Memorial Session - Milestone Contributions of Alex Muller

06.05.2023 SATURDAY

Abstract ID: 656

Complexity and Spin-Orbit Coupling Favoring High Tc Superconductivity in Natural and Artificial Heterostructures

Antonio Bianconi

RICMASS

Italy

E-mail: …

TBA

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04.05.2023 THURSDAY

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04.05.2023 THURSDAY

Superconducting Spintronics I-II-III-IV

06.05.2023 SATURDAY

Abstract ID: 180

COMPOSITE MAGNONS IN S/F AND S/AF THIN-FILM HETEROSTRUCTURES

A.M. Bobkov[1], I.V. Bobkova[1,2], S.A. Sorokin[2], Akashdeep Kamra[3], Wolfgang Belzig[4]

[1]*Moscow Institute of Physics and Technology, Dolgoprudny, 141700 RUSSIA*
[2]*National Research University Higher School of Economics, Moscow, 101000 RUSSIA*
[3]*Condensed Matter Physics Center (IFIMAC) and Departamento de Fisica Teorica de la Materia Condensada, Universidad Autonoma de Madrid, E-28049 Madrid, SPAIN*
[4]*Fachbereich Physik, Universitat Konstanz, D-78457 Konstanz, GERMANY*
E-mail: bobkov.am@mipt.ru

The ability to control the dispersion law of spin waves is one of the most important requirements for the engineering of magnonic devices. We show that thin-film hybrid structures consisting of a ferromagnetic (F) or antiferromagnetic (AF) insulator and a superconductor (S) or normal metal (N) have broad prospects in this field. Due to the presence of a surface exchange interaction between the magnetic insulator and the metal, an effective exchange field is induced in the latter, which repeats the profile of the magnetization of the magnet, including the magnon. This leads to the appearance of spin polarization of the quasiparticles in the superconductor and the generation of triplet Cooper pairs in it. Moreover, the spin polarization of quasiparticles is not co-directed with the local exchange field (the effect of dynamic delay), and therefore creates a rotational moment that acts on the magnetization of the magnet. In addition, a magnon with a nonzero wave vector creates around itself a cloud of triplet Cooper pairs of electrons with equal spins, which dress it, increasing its effective mass and screening its spin.

In structures with a ferromagnet and an antiferromagnet, due to the difference in their characteristic frequencies (GHz for ferromagnets and THz for antiferromagnets), the processes described above play a different role and the effect of a superconductor on a magnet looks different. In a typical ferromagnet, spin-triplet pairs exert the main influence. They dress the magnon, increase its mass, and screen the spin. The resulting composite particle was called magnon-Cooparon [1]. For structures with an antiferromagnetic insulator, the renormalization of the magnon spectrum involves both the polarization of quasiparticles and spin-triplet pairs. Unlike a ferromagnet, the spectrum of magnons in an antiferromagnet contains two modes, which for an easy-axis antiferromagnet are degenerate in energy at zero applied magnetic field. Interaction with a superconductor leads to the removal of this degeneracy [2]. One of the interesting practical results of our work is the proposal of a method for direct measurement of the exchange field induced by a magnet in a superconductor (or a normal metal, which is considered as the limiting case of a superconductor at high temperature).

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Abstract ID: 404

MAGNETIC FIELD-INDUCED MIRAGE GAP AND SINGLET-TRIPLET MIXING IN ISING SUPERCONDUCTORS

S. Patil[1], G. Tang[2], R. Klees[3], C. Bruder[4], W. Belzig[1]

[1]*Department of Physics, Universität Konstanz, 78457 Konstanz, GERMANY*
[2]*Graduate School of China Academy of Engineering Physics, 100193 Beijing, CHINA*
[3]*Institute for Theoretical Physics and Astrophysics and Würzburg-Dresden Cluster of Excellence ct.qmat, Julius-Maximilians-Universität Würzburg, 97074 Würzburg, GERMANY*
[4]*Department of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel, SWITZERLAND*
E-mail: wolfgang.belzig@uni-konstanz.de

Superconductivity is commonly destroyed by a magnetic field due to orbital or Zeeman-induced pair breaking. Surprisingly, the spin-valley locking in a two-dimensional superconductor with spin-orbit interaction makes the superconducting state resilient to much stronger magnetic fields. We investigate the spectral properties of such an Ising superconductor in a magnetic field taking into account disorder [1]. The interplay of the in-plane magnetic field and the Ising spin-orbit coupling leads to noncollinear effective fields. We find that the emerging singlet and triplet pairing correlations manifest themselves in the occurrence of "mirage" gaps: at (high) energies of the order of the spin-orbit coupling strength, a gaplike structure in the spectrum emerges that mirrors the main superconducting gap. We show that these mirage gaps are signatures of the equal-spin triplet finite-energy pairing correlations and due to their odd parity are sensitive to intervalley scattering.

Furthermore, we study a Josephson junction formed by two Ising superconductors that are in proximity to ferromagnetic layer [2]. This leads to highly tunable spin-triplet pairing correlations which allow to modulate the charge and spin supercurrents through the in-plane magnetic exchange fields. For a junction with a nonmagnetic barrier, the charge current is switchable by changing the relative alignment of the in-plane exchange fields, and a pi-state can be realized. Furthermore, the phases of both the charge and spin currents are tunable for a junction with a strongly spin-polarized ferromagnetic barrier.

Finally, we investigate the influence of a triplet-pairing interaction on the Mirage gap and the Josephson effect in layered and planar heterostructures.

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MAGNETIC CONTROL OVER THE SUPERCONDUCTING THERMOELECTRIC EFFECT

César González-Ruano[1], Diego Caso[1], Jabir Ali Ouassou[2], Jacob Linder[2], Farkhad G. Aliev[1,3]

[1] *Dpto. Física Materia Condensada, Universidad Autónoma de Madrid, 28049 Madrid, SPAIN*
[2] *Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, NO-7491 Trondheim, NORWAY*
[3] *IFIMAC and INC, Universidad Autonoma de Madrid, Madrid 28049, SPAIN*
E-mail: farkhad.aliev@uam.es

Thermoelectric generators exhibit several attractive properties which have made them an ideal choice for e.g. sensitive lab equipment, automotive industry, medical applications or deep space missions. Currently, there is a significant research interest in determining better material platforms for creating novel thermoelectric devices. Over the past decade, it has been shown both theoretically [1,2] and experimentally [3] that a giant thermoelectric effect can arise when superconductors are coupled to strongly spin-polarized ferromagnets. The thermopower of such devices is orders of magnitude higher than metallic thermoelectric devices at comparable temperatures, and many applications of this effect have already been proposed.

Here, we demonstrate a new key advantage of superconductor-ferromagnet hybrids as a platform for novel thermoelectric devices, which was recently predicted by us [4]. We experimentally show that the thermopower in V/MgO/Fe/MgO/Fe/Co superconductor-spin valve hybrids (which recently revealed equal spin superconducting triplet generation due to spin-orbit coupling and symmetry filtering [5,6]) can be controlled via the relative magnetic alignment of the ferromagnetic electrodes [7]. Importantly, we confirm the theoretical prediction that by rotating one magnetic layer we can not only substantially change the thermoelectric effect but can even reverse its sign [4,7] with an optimum antiparallel alignment of the ferromagnetic electrodes (as confirmed by the experiments and modelling). The description of the experimental results is improved by the introduction into the model of an interfacial domain wall in the spin filter layer interfacing the superconductor. Surprisingly, the application of high in-plane magnetic fields induces a double sign inversion of the thermoelectric effect, which exhibits large values even at applied fields up to twice the superconducting critical field. The demonstrated *in situ* control, which diverges from conventional thermoelectrics, could lead to the development of a novel kind of superconducting thermoelectric generators and sensors.

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Abstract ID: 126

PROXIMITY EFFECT AT SUPERCONDUCTOR/ANTIFERROMAGNET INTERFACES

G.A. Bobkov[1], I.V. Bobkova[1,2], V.M. Gordeeva[1], A.M. Bobkov[1], Akashdeep Kamra[3]

[1]*Moscow Institute of Physics and Technology, Dolgoprudny, 141700 RUSSIA*
[2]*National Research University Higher School of Economics, Moscow, 101000 RUSSIA*
[3]*Condensed Matter Physics Center (IFIMAC) and Departamento de Fisica Teorica de la Materia Condensada, Universidad Autonoma de Madrid, E-28049 Madrid, SPAIN*

E-mail: bobkova.iv@phystech.edu

The proximity effect at superconductor/ferromagnet (S/F) interfaces is well-studied: the exchange field suppresses singlet superconductivity via the partial conversion of the singlet superconducting correlations to the triplet ones. Moreover, in the ferromagnetic metal the proximity induced singlet and triplet correlations acquire nonzero pair momentum, what leads to the spatial oscillations of the condensate wave function, oscillations of the critical temperature of S/F bilayers as a function of the F layer width and 0-π transitions in S/F/S Josephson junctions [1]. Naively, one can expect that fully compensated antiferromagnet with zero average interface magnetization does not produce triplet correlations. We demonstrate that it is not the case. We consider proximity effect at an interface between a fully compensated antiferromagnet and a superconductor (S/AF) and obtain that the proximity to the antiferromagnet also leads to the partial conversion of the singlet correlations to the triplet ones. Their amplitude flips sign from one lattice site to the next, just like the Neel spin order in the AF [2]. Thus, we call them Neel triplet Cooper pairs. Their formation comes at the expense of destroying the spin-singlet correlation which reduces the S critical temperature. It is shown that the behavior of Neel triplets in the presence of disorder strongly differs from the behavior of conventional triplets – they are suppressed by the nonmagnetic disorder, what leads to the enhancement of the superconducting critical temperature with increasing the disorder strength.

It is demonstrated that the Neel triplets give rise to the spin-valve effect in AF/S/AF trilayers. The absolute spin-valve effect can be obtained for some parameter ranges. Also, it is predicted that the Neel triplets can lead to the oscillations of the critical temperature of S/AF bilayers as a function of the AF width.

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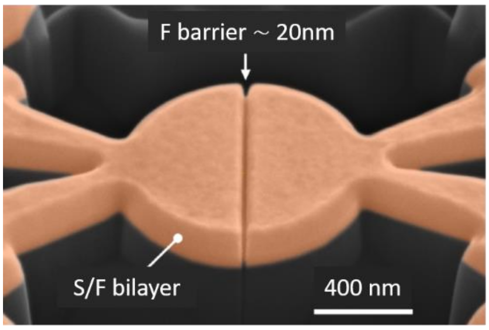
THE UNUSUAL NATURE OF SPIN-TRIPLET SUPERCURRENTS IN GEOMETRICALLY CURVED JOSEPHSON JUNCTIONS

R. Fermin[1], J. Yao[1], M. Silaev[2], J. Aarts[1], K. Lahabi[1]

[1] *Kamerlingh Onnes Laboratory, Leiden University, 2300 RA Leiden, the NETHERLANDS*
[2] *Department of Physics and Nanoscience Center, University of Jyväskylä, FI-40014, FINLAND*
E-mail: lahabi@physics.leidenuniv.nl

Spin-polarized Cooper pairs in superconductor-ferromagnet (S-F) hybrid structures provide the opportunity to combine coherent transport with spintronic phenomena. Over the last two decades, the nature of interactions between spin-triplet correlations and magnetic texture (e.g. domain walls and vortices) has been the subject of intense theoretical discussions, while the relevant experiments remain scarce. To address this, we have developed nanostructured Josephson junctions with carefully designed geometries, where spin-triplet supercurrents are generated and controlled by the spin texture of a single mesoscopic ferromagnet. This enables us to realize Josephson junctions, which can host both 0- and π-channels, [1] and non-volatile superconducting memory elements with a bistable magnetic texture. [2]

Moreover, we find that device geometry can have unprecedented consequences for triplet transport. A prime example of this is the highly-localized "rim currents", which only appear in disk-shaped junctions, structured from a S-F bilayer. We examine the origin of this unusual behavior, and find that the curvature of the bilayer-vacuum boundary plays a crucial role.



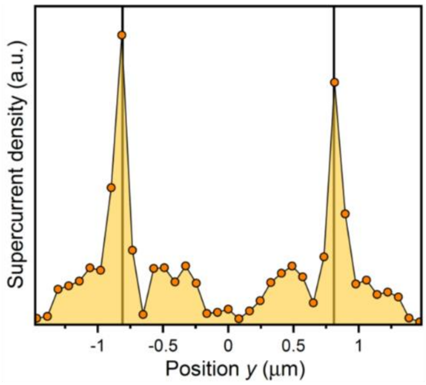


Fig. 1: *Disk-shaped Josephson junction, prepared by nanostructuring a S/F bilayer (left). Distribution of spin-triplet supercurrent across the disk, showing highly-localized channels at the rim (right). [1]*

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EFFECTS OF A HELICAL STATE ON THE DYNAMIC PROPERTIES OF THE TOPOLOGICAL SUPERCONDUCTING SYSTEMS

T. Karabassov[1,2], I.V. Bobkova[2,1], A.A. Golubov[3], A.S. Vasenko[1,4]

[1]HSE University, 101000 Moscow, RUSSIA
[2]Moscow Institute of Physics and Technology, Dolgoprudny, 141700 RUSSIA
[3]University of Twente, 7500 AE Enschede, THE NETHERLANDS
[4]I.E. Tamm Department of Theoretical Physics, P.N. Lebedev Physical Institute, Russian Academy of Sciences, 119991 Moscow, RUSSIA

E-mail: iminovichtair@gmail.com

Recently helical state became an active area of research in the field of superconductivity. Such an interest is driven by the possibility of using the helical state for the superconducting diode effect realization [1]. In the present research we study the effects caused by the helical state, which emerges in the system due to the presence of the magnon. For this purpose, we consider an effective model of the superconducting system with a strong spin-orbit coupling. Such systems can be experimentally designed in the forms of hybrid structures or synthesized as materials with intrinsic properties [2]. Employing the Keldysh formalism for the quasiclassical Green's functions in the diffusive limit we obtain fully self-consistent solution of the problem in the presence of the weak magnon. We demonstrate that in the system under consideration the magnon has a direct impact on the pair potential. This leads to the appearance of the Higgs mode. Furthermore, we reveal the effect of the helical state on the Higgs mode and other properties of the system [3].

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MANIFESTATION OF MIXED PAIRING SYMMETRY IN SUPERCONDUCTING HYBRID STRUCTURES

A.A. Golubov [1], B.J. Geurts[2], T.H. Kokkeler[1,2], Y. Tanaka[4]

[1] *Faculty of Science and Technology, University of Twente, THE NETHERLANDS*
[2] *Faculty of Electrical Engineering, Mathematics and Computer Science, University of Twente, THE NETHERLANDS*
[3] *Donostia International Physics Center (DIPC), 20018 Donostia-San Sebastian, SPAIN*
[4] *Department of Applied Physics, Nagoya University, Nagoya 464-8603, JAPAN*
E-mail: a.golubov@utwente.nl

We derive a boundary condition for the Nambu-Keldysh Green's function in diffusive normal metal - unconventional superconductor junctions applicable for mixed parity pairing [1]. Applying this theory to an of s + p-wave superconductor, we calculate local density of states (LDOS) in the diffusive normal metal (N) and charge conductance of a junction between N and s + p-wave superconductor. When the s-wave component of the pair potential is dominant, LDOS has a gap like structure at zero energy and the dominant pairing in N is even-frequency spin-singlet s-wave. On the other hand, when the p-wave component is dominant, the resulting LDOS has a zero energy peak and the dominant pairing in N is odd-frequency spin-triplet s-wave. The results show the robustness of the anomalous proximity effect specific to spin-triplet superconductor junctions.

Using the developed approach, multi-terminal (SNN) junctions are investigated where the superconducting potential is a mixture between s-wave and p-wave potentials [2]. The ways are proposed to determine whether S has a mixed pair potential and to distinguish between s + chiral and s + helical p-wave superconductors. It is found that a difference in conductance for electrons with opposite spins arises if both an s-wave and a p-wave components are present, even in the absence of a magnetic field. It is shown that a setup containing two SN junctions provides a clear difference in spin conductance between the s + chiral p-wave and s + helical p-wave symmetries.

Further, we propose new approach to distinguish p-wave from s-wave symmetry by measuring conductance a four terminal junction consisting of S and N terminals [3]. The N-terminals are used to manipulate the energy distribution functions of electrons in the junction in order to control the charge transport. It is shown that the differential conductance of junctions containing p-wave and s-wave superconductors is distinctly different, thus providing experimental test to detect potential p-wave superconductivity.

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Abstract ID: 479

SUPERCONDUCTIVITY IN PbTe/SnTe SEMICONDUCTOR HETEROSTRUCTURE: A CANDIDATE FOR SPIN-TRIPLET SUPERCONDUCTOR

P. Sidorczak[1,2], W. Wołkanowicz[3], K. Gas[3], A. Kaleta[3], S. Gierałtowska[3], R. Minikayev[3], S. Kret[3], M. Sawicki[3], T. Wojtowicz[2], D. Wasik[1], M. Gryglas-Borysiewicz[1], K. Dybko[2,3]

[1] *Faculty of Physics, University of Warsaw, 02-093, Warsaw, POLAND*
[2] *International Research Centre MagTop, Institute of Physics, Polish Academy of Sciences, 02668, Warsaw, POLAND*
[3] *Institute of Physics, Polish Academy of Sciences, 02668, Warsaw, POLAND*
E-mail: psidorczak@fuw.edu.pl

The superconductivity of IV-VI semiconductor heterostructures has been a puzzling phenomenon for many years [1,2]. The underlying mechanism seems to be based on the inversion of the band structure induced by compression due to periodic dislocation grids on the interface, which gives rise to topological crystalline insulator surface states. At the same time, the resulting periodically varying strain acting on these states creates topological flat band, which promotes superconducting phase transition [3]. However, the pairing mechanism behind this superconductivity has not yet been fully demonstrated, to the best of our knowledge.

Here we present the results of soft point contact spectroscopy (PCS) of superconducting PbTe/SnTe heterostructures, in which the presence of dislocations was revealed using transmission electron microscopy. The PCS experiments exhibit a distinct zero-bias conductance peak (ZBCP). It can be fitted within a theoretical model involving an Anderson-Brinkman-Morel electron pairing potential [4]. This superconducting mechanism realizes p-wave pairing symmetry and was initially introduced to explain the spin-triplet phase of the superfluid ^{3}He. Recent works have expanded this formalism to explain flatband-induced superconductivity [5].

In the PCS experiments, we used both silver and nickel contacts (normal metal and highly spin-polarized metal). The observed spectra do not depend on the spin polarization, which is a signature of p-wave pairing potential. We will present a discussion that sheds light on the mechanism of the unconventional superconductivity observed in this class of narrow-gap semiconductor heterostructures.

The research was partially supported by the Foundation for Polish Science through the IRA Programme co-financed by EU within SGOP and the National Science Centre (Poland) through OPUS (UMO-2017/27/B/ST3/02470) project.

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SUPERCONDUCTING BASE ELEMENTS FOR ARTIFICIAL NEURAL NETWORK

Anatolie Sidorenko[1,2], Nikolai Klenov[3], Igor Soloviev[3], Sergey Bakurskiy[3], Yurii Savva[2], Arkadii Lomakin[2], Olga Kojus[2], Vladimir Boian[1], Andrei Prepelitsa[1], Maria Lupu[1], Alexander Vakhrushev[2,4]

[1]*Institute of Electronic Engineering and Nanotechnologies of Technical University of Moldova, Academiei str., 3/3, Chisinau, MOLDOVA*
[2]*I.S. Turgenev Orel State University Komsomolskaya str. 95, 302026, Orel, RUSSIA*
[3] *Moscow State University, Skobeltsyn Institute of Nuclear Physics, Moscow, 119991, RUSSIA*
[4]*Nanotechnology and Microsystems Department, Izhevsk State Technical University, 426069, RUSSIA*
E-mail: sidorenko.anatoli@gmail.com

Energy efficiency and the radically reduction of the power consumption level becomes a crucial parameter constraining the advance of supercomputers. The most promising solution is design and development of the non-von Neumann architectures, first of all – the Artificial Neural Networks (ANN) based on superconducting elements. Superconducting ANN needs elaboration of two main elements – nonlinear switch (neuron) [1] and linear connecting element (synapse) [2]. We present results of our design and investigation of superconducting spin-valves and superconducting synapse, based on layered hybrid structures superconductor-ferromagnet.

Results of our theoretical and experimental study of the proximity effect in a stack-like superconductor/ferromagnet (S/F) superlattice with Co- ferromagnetic layers of different thicknesses and coercive fields, and Nb-superconducting layers of constant thickness equal to coherence length of niobium, are presented.

The superlattices Nb/Co demonstrate change of the superconducting order parameter in thin s-films due to switching from the parallel to the antiparallel alignment of neighboring F-layers. We argue that such superlattices can be used as tunable kinetic inductors for ANN synapses design.

The study was supported by the Russian Science Foundation by Grant (RSF) No. 20-62-47009 “Physical and engineering basis of computers non-von Neumann architecture based on superconducting spintronics” (theory development, samples measurements, results evaluation), and by the Moldova State Program Project «Nanostructuri şi nanomateriale funcţionale pentru industrie şi agricultură» no. 20.80009.5007.11 (samples fabrication).

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Abstract ID: 516

OBSERVATION OF ROBUST ZERO-ENERGY STATE AND ENHANCED SUPERCONDUCTING GAP IN A TRILAYER HETEROSTRUCTURE OF $MnTe/Bi_2Te_3/Fe(Te,Se)$

C. Chen[1,3], T. Zhang[1], D. L. Feng[2,1]

[1]*Department of Physics, State Key Laboratory of Surface Physics and Advanced Material Laboratory, Fudan University, Shanghai 200438, CHINA*
[2]*Department of Physics, University of Science and Technology of China, Hefei 230026, CHINA*
[3]*College of Physics and Electronic Information Engineering, Zhejiang Normal University, Jinhua, 321004, CHINA*
E-mail: cchen_physics@fudan.edu.cn

The interface between magnetic material and superconductors has long been predicted to host unconventional superconductivity, such as spin-triplet pairing and topological nontrivial pairing state, particularly when spinorbital coupling (SOC) is incorporated. To identify these unconventional pairing states, fabricating homogenous heterostructures that contain such various properties are preferred but often challenging. Here, we synthesized a trilayer-type van der Waals heterostructure of $MnTe/Bi_2Te_3/Fe(Te,Se)$, which combined s-wave superconductivity, thickness-dependent magnetism, and strong SOC. Via low-temperature scanning tunneling microscopy, we observed robust zero-energy states with notably nontrivial properties and an enhanced superconducting gap size on single unit cell (UC) MnTe surface. In contrast, no zero-energy state was observed on 2-UC MnTe. First-principle calculations further suggest that the 1-UC MnTe has large interfacial Dzyaloshinskii-Moriya interaction and a frustrated AFM state, which could promote noncolinear spin textures. It thus provides a promising platform for exploring topological nontrivial superconductivity [1].

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Abstract ID: 555

NONEQUILIBRIUM AND SPIN PHENOMENA IN HYBRID SUPERCONDUCTOR-FERROMAGNET STRUCTURES

V.V. Ryazanov[1,2,3], T.E. Golikova[1], L.N. Karelina[1], V.V. Bolginov[1], E.R. Khan[4]

[1]Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka, 142432 RUSSIA
[2]*Moscow Institute of Physics and Technology, Dolgoprudny, 141700 RUSSIA*
[3]*National University of Science and Technology MISIS, 4 Leninsky prosp., Moscow 119049, RUSSIA*
[4]Faculty of Physics, National Research University Higher School of Economics, Moscow, 101000 RUSSIA
E-mail: valery.ryazanov@gmail.com

Our recent investigations are related to superconducting spintronics in superconducting ferromagnet/superconductor (SF) structures. Fundamentally new structures and approaches for applications in superconducting electronics and spintronics are proposed. Among them Josephson SFS structures с π-periodic current-phase relation [1], S-N/F-S devices with spin diffusion and spin injection [2], memory elements on the basis of SFS contacts [3]. We have repeated also well-known experiment by J.J.A. Baselmans et al [4] using the spin-polarized injection to Josephson barrier of SNS junction [5] (see Fig.1). We have observed two clearly distinct transitions: both from conventional (0-) to π-state (with inversion of superconducting phase difference) and back π-0 transition. We suppose that the "Baselmans effect" mechanism related to energy electron redistribution is significantly complemented by influence of "induced magnetism" due to spin-diffusion [2].

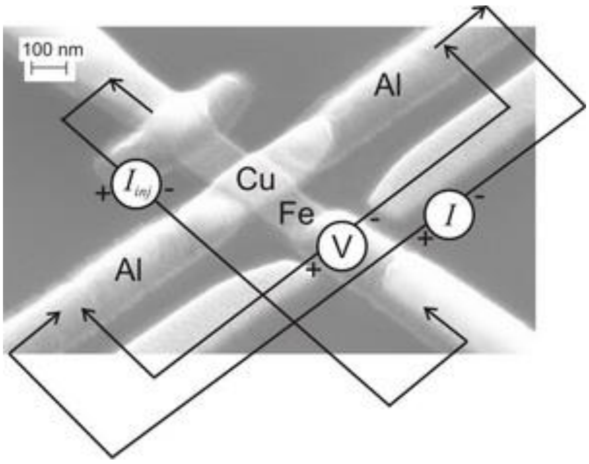

Fig. 1: *S-N/F-S structure with spin-injection.*

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Superconductivity and Magnetism in 3D Nanoarchitectures III-IV-V-VI

06.05.2023 SATURDAY

Abstract ID: 124

FABRICATION OF NANOSTRUCTURES FOR ADVANCED VORTEX PINNING IN HIGH-T_c SUPERCONDUCTORS

B. Aichner[1], M. Karrer[2], K. Wurster[2], C. Schmid[2], P.A. Korner[1], L. Backmeister[1], B. Budinská[1], S. Keppert[3], J.D. Pedarnig[3], O.V. Dobrovolskiy[1], R. Kleiner[2], E. Goldobin[2], D. Koelle[2], W. Lang[1]

[1]*University of Vienna, Faculty of Physics, 1090 Vienna, AUSTRIA*
[2]*Universität Tübingen, Physikalisches Institut, Center for Quantum Science (CQ) and LISA+, 72076, Tübingen, GERMANY*
[3]*Johannes Kepler University Linz, Institute of Applied Physics, 4040, Linz, AUSTRIA*
E-mail: bernd.aichner@univie.ac.at

The controlled fabrication of dense defect structures suitable for pinning Abrikosov vortices is challenging in high-T_c cuprate superconductors since conventional etching techniques are only poorly applicable. Nevertheless, controlling the motion of vortices is essential for applying superconductors in electronic devices. This urges the need for a process that allows for the fabrication of vortex pinning structures precisely and reproducibly in these materials.

A novel way of creating artificial pinning structures in cuprate superconductors, such as $YBa_2Cu_3O_{7-\delta}$, is to locally suppress the material's critical temperature T_c by irradiation with helium ions in a helium ion microscope. With this method, it is possible to create defect clusters that can accommodate one or more magnetic vortices. This leads to vortex-matching effects, i.e., pronounced maxima in the critical current and minima in resistivity at the magnetic field values, for which the vortex lattice is commensurate to the defect lattice. These matching fields depend on the distance between the defect clusters, and due to the high resolution achievable with He ion irradiation, we succeeded in creating regular defect arrays with matching fields up to 6 T. To our knowledge, this is the highest matching field ever reported for regular artificial pinning arrays in cuprate superconductors.

Simulations of the T_c-suppression show that the defect clusters created in the helium ion microscope are column-shaped and penetrate the whole superconducting film for typical film thicknesses of 30 to 50 nm. The one-dimensional shape of the defect columns also shows up in vortex pinning, as verified by angle-resolved measurements [1]. A thorough analysis of current-voltage characteristics suggests that a new vortex phase appears in these arrangements, which we identified as an ordered Bose glass phase [2].

One significant advantage of the helium ion microscope is the free choice of the irradiation pattern. This allowed us to create pinning arrays based on a quasi-kagomé pattern, which enables reproducibly switching between two stable vortex arrangements by changing the temperature [3].

Altogether, these findings establish the helium ion microscope as a promising tool for nanofabrication that allows us to create vortex-pinning structures of unprecedented density.

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Abstract ID: 151

DIRECT OBSERVATION OF A SUPERCONDUCTING VORTEX DIODE

Alon Gutfreund[1], Hisakazu Matsuki[2], Vadim Plastovets[3], Avia Noah[1], Laura Gorzawski[2], Nofar Fridman[1], Guang Yang[2], Alexander Buzdin[3], Oded Millo[1], Jason W.A. Robinson[2], Yonthan Anahory[1]

[1]The Hebrew University of Jerusalem, Racah Institute of Physics, 9190401, Jerusalem, ISRAEL
[2]University of Cambridge, Department of Materials Science & Metallurgy, CB3 0FS, UK
[3]Université de Bordeaux, Département de Physique, 5798, F-33405, Bordeaux, FRANCE
E-mail: yonathan.anahory@mail.huji.ac.il

The interplay between magnetism and superconductivity can lead to unconventional proximity and Josephson effects. A related phenomenon that has recently attracted considerable attention is the superconducting diode effect, in which a non-reciprocal critical current emerges [1,3]. Although superconducting diodes based on superconducting/ferromagnetic (S/F) bilayers were demonstrated more than a decade ago [4], the precise underlying mechanism remains unclear. While not formally linked to this effect, the Fulde-Ferrell-Larkin-Ovchinikov (FFLO) state is a plausible mechanism, due to the 2-fold rotational symmetry breaking caused by the finite center-of-mass-momentum of the Cooper pairs. Here, we directly observe, a tunable superconducting vortex diode in Nb/EuS (S/F) bilayers. Based on our nanoscale SQUID-on-tip (SOT) microscope [5,6] and supported by *in-situ* transport measurements, we propose a theoretical model that captures our key results. Thus, we determine the origin for the vortex diode effect, which builds a foundation for new device concepts.

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Abstract ID: 223

FREQUENCY-LOCKING IN SUPERCONDUCTING NANOTUBES AND NANORIBBONS UNDER MODULATED TRANSPORT CURRENT AND MAGNETIC FIELD

I. Bogush[1,2], V. M. Fomin[1,2]

[1]*Institute for Integrative Nanosciences, Leibniz IFW Dresden, Helmholtzstraße 20, D-01069 Dresden, GERMANY*
[2]*Moldova State University, str. A. Mateevici 60, MD-2009 Chişinau, REPUBLIC OF MOLDOVA*
E-mail: bogush94@gmail.com

We study the alternating voltage generation in Nb superconducting nanoarchitectures under the transport current and magnetic field using numerical solution simulation of the time-dependent Ginzburg-Landau equation (TDGL). We consider two types of nanoarchitectures. The first one is a nanoribbon, which is simple in fabrication. The second one is a thin open nanotube, which provides novel properties of the vortex motion. The vortex dynamics are governed by the component of the magnetic field normal to the surface. Due to the nanotube geometry, the normal magnetic field is not homogeneous. In addition, vortices in two half-cylinders of the nanotube are moving in opposite directions (see [1] and references therein). If the radius of the nanotube is small enough, vortices in both half-cylinders appreciably interact with each other [2]. We study effects associated with modulation of the transport current and/or the magnetic field by a weak sinusoidal signal. We show that if the modulation frequency is close enough to the frequency of the vortex nucleation in the case of no modulation, then the frequency-locking effect emerges, i.e., the vortex nucleation frequency becomes equal to the external modulation frequency. We investigate the width of the frequency-locking interval as a function of the modulation depth, its sensitivity in response to the change in the direction of the constant complonent of the magnetic field, and discuss opportunities to investigate this effect experimentally. We demonstrate the quantitative difference in the frequency-locking effect between nanoribbons and open nanotubes. This effect can find application in fluxonics for generating vortices with an adjustable nucleation frequency as well as for sensing of weak magnetic fields.

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Abstract ID: 225

DOMINO EFFECT OF THERMOMAGNETIC INSTABILITIES IN SUPERCONDUCTING FILMS WITH MULTIPLY-CONNECTED TOPOLOGICAL STRUCTURES

Lu Jiang[1,2], Cun Xue[3], S. Marinković[2], E. Fourneau[2,4], Tie-Quan Xu[5], Xin-Wei Cai[5], N.D. Nguyen[4], You-He Zhou[1,6], A.V. Silhanek[2]

[1]School of Aeronautics, Northwestern Polytechnical University, Xi'an 710072, PEOPLE'S REPUBLIC OF CHINA
[2]Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, Université de Liège, B-4000 Sart Tilman, BELGIUM
[3]School of Mechanics, Civil Engineering and Architecture, Northwestern Polytechnical University, Xi'an 710072, PEOPLE'S REPUBLIC OF CHINA
[4]Solid-State Physics—Interfaces and Nanostructures, Q-MAT, CESAM, Université de Liège, B-4000 Sart Tilman, BELGIUM
[5]Applied Superconductivity Research Center, State Key Laboratory for Artificial Microstructure and Mesoscopic Physics, School of Physics, Peking University, Beijing, 100871, PEOPLE'S REPUBLIC OF CHINA
[6]Key Laboratory of Mechanics on Disaster and Environment in Western China, Ministry of Education of China, Department of Mechanics and Engineering Sciences, Lanzhou University, Lanzhou 730000, PEOPLE'S REPUBLIC OF CHINA
E-mail: asilhanek@uliege.be

Magnetic flux lines in superconductors are topologically-protected quantum objects which can be deformed when moving at very high velocities. These extreme conditions can be transitorily realized when superconductors undergo a thermomagnetic instability for which the sample topology come also into play [1]. In this work, we experimentally study and visualize magnetic flux avalanches in superconducting films with multiply-connected geometries, including single and double rings [2]. We observe a domino effect in which avalanches triggered at the outer ring, stimulate avalanches at the inner ring thus impairing the expected magnetic shielding resulting from the outer ring. We implement numerical simulations in order to gain more insight into the underlying physical mechanism and demonstrate that such event is not caused by the heat conduction, but mainly attributed to the local current distribution variation near the preceding flux avalanche in the outer ring, which in turn has a ripple effect on the local magnetic field profile in the gap. Furthermore, we find that the domino effect of thermomagnetic instabilities can be switched on/off by the environmental temperature and the gap width between the concentric rings. These findings provide new insights on the thermomagnetic instability in superconducting devices with complex topological structures, such as the superconductor–insulator–superconductor multilayer structures of superconducting radio-frequency cavities.

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Abstract ID: 302

EXPERIMENTS AND SIMULATIONS ON SPIN DYNAMICS IN MAGNETOCHIRAL NANOTUBES AND FERROMAGNETIC 3D NANONETWORKS

M.C. Giordano[1], H. Guo[1], M. Hamdi[1], A. Mucchietto[1], A.J.M. Deenen[1], D. Grundler[1,2]

[1]*Ecole Polytechnique Federale de Lausanne (EPFL), Institute of Materials, 1015 Lausanne, SWITZERLAND*
[2]*EPFL, Institute of Electrical and Micro Engineering, 1015 Lausanne, SWITZERLAND*
E-mail: dirk.grundler@epfl.ch

Three-dimensional (3D) nanoarchitectures prepared from materials with magnetic or superconducting order are expected to give rise to novel phenomena and functionalities. Particularly interesting are the properties due to curved surfaces which are engineered on the nanoscale [1]. To obtain nanotubular ferromagnets with radii on the order of 100 nm, we optimized atomic layer deposition (ALD) of ferromagnetic Ni (Fig. 1a) [2] and $Ni_{80}Fe_{20}$ (Permalloy, Py) [3]. The technique allowed us to create individual nanotubes prepared as ferromagnetic shells around micro-meter-long single-crystalline semiconductor (GaAs) nanowires (Fig. 1a). We explored their spintronic properties [4] and collective spin excitations at GHz frequencies. Recently, we identified signatures of magnetochiral spin-wave (magnon) properties, originally predicted for infinitely long Py nanowires [5]. Current work addresses interconnected Ni nanotubes for 3D nanomagnonics (Fig. 1b). Here, we use a polymeric 3D nanoscaffold produced by two-photon lithography and prepare 10 to 30 nm thick Ni shells by means of ALD. Magnon spectra (Fig. 1c) are obtained by micro-focus inelastic light scattering (BLS) spectroscopy performed on the top surface. In our talk, we will report our recent experimental data and micromagnetic simulations of 3D ferromagnetic nanoarchitectures.

The work is funded by SNSF via grants 177550 and 197360.

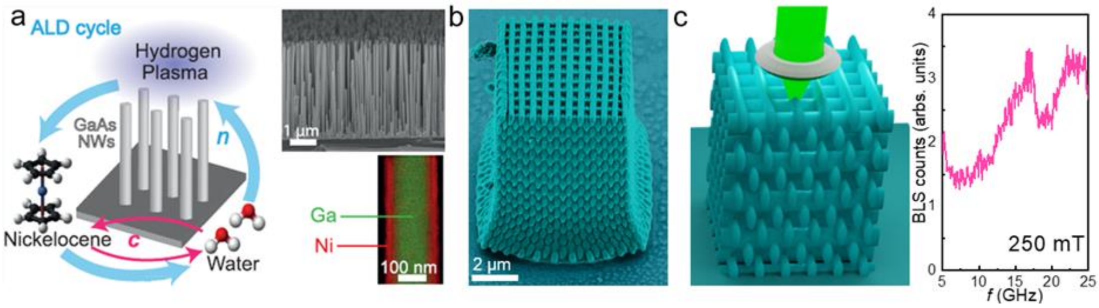

Fig. 1: ***a*** *ALD process for Ni nanotubes on vertically standing GaAs nanowires [1].* ***b*** *Polymeric nanoscaffold overgrown with a Ni shell by ALD.* ***c*** *Sketch of BLS spectroscopy and magnon spectrum.*

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NANOBRIDGE SQUIDS AS MULTILEVEL MEMORY ELEMENTS

D.A.D. Chaves[1, 2], L. Nulens[2], H. Dausy[2], B. Raes[2], D. Yue[2], W.A. Ortiz[1], M. Motta[1], M.J. Van Bael[2], J. Van de Vondel[2]

[1]*Departamento de Física, Universidade Federal de São Carlos, São Carlos 13565-905, SP, BRAZIL*
[2]*Quantum Solid-State Physics, Department of Physics and Astronomy, KU Leuven, Celestijnenlaan 200D, B-3001 Leuven, BELGIUM*

E-mail: jorisvandevondel1981@gmail.com

Multilevel memory systems are technologically appealing, for instance, due to an increase in storage density. In past years, alternative non-semiconducting materials were proposed as non-volatile multilevel memories in photonic and antiferromagnetic systems. With the development of novel computing schemes working at cryogenic temperatures, superconducting memory elements have become essential. In this context, superconducting quantum interference devices (SQUIDs) are promising candidates, as they may trap different discrete amounts of magnetic flux. This implies that information can be stored in the SQUID's different vorticity states. Indeed, flux based qubits and memory elements relying on phase-slip physics have already been proposed [1, 2]. In addition, a yTron current combiner can be used for non-destructive current readout and is capable of differentiating between discrete magnetic flux values trapped in superconducting loops [3].

For a fully superconducting device, we previously demonstrated that the kinetic induction of the junctions may be tuned via nanofabrication (Fig. 1), allowing control over the $I_c(B)$ characteristics of the device [4]. In this work, we demonstrate that a field-assisted writing scheme allows such a device to operate as a multilevel memory by the readout of eight distinct vorticity states at zero magnetic field. We present an alternative mechanism based on single phase slips which allows to switch the vorticity state while preserving superconductivity. This mechanism provides a possibly deterministic channel for flux control in SQUID-based memories, under the condition that the field-dependent energy of different vorticity states are nearby.

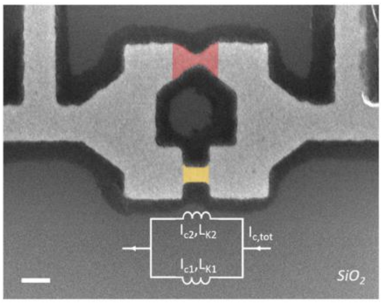

Fig. 1: *Scanning-electron-microscopy (SEM) image of a prototypical SQUID device. Area indicated in red corresponds to the Dayem bridge, while the yellow area indicates the nanobridge. Width W and length L of the latter are indicated. White scale bar represents 200 nm. White circuit diagram presents an equivalent electronic circuit of the SQUID.*

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Abstract ID: 76

CURVILINEAR MAGNETISM: FUNDAMENTALS AND PERSPECTIVES

Denis D. Sheka

Taras Shevchenko National University of Kyiv, 01601 Kyiv, UKRAINE
E-mail: sheka@knu.ua

Recent advances in nanotechnologies have enabled fabrication of the novel class of 3D curved magnetic nanoarchitectures, where the fundamental properties are determined by the geometry [1]. Active exploration of this new material class turns light on the fundamentals of magnetism of nanoobjects with curved geometry and applications of 3D-shaped curved magnetic nanoarchitectures, leading to remarkable developments in shapable magnetoelectronics, magnetic sensorics, spintronics, 3D magnonics, and microrobotics. Today, fundamental and applied research of curved nanoarchitectures and related curvature-induced effects in these objects are united in curvilinear magnetism, which is a rapidly developing research area of modern magnetism aimed to explore geometry-induced effects in curved magnetic wires and films [2].

By exploring geometry-governed magnetic interactions, curvilinear magnetism offers a number of intriguing effects in curved magnetic wires and curved magnetic films. Emergent interactions, induced by the curvilinear geometry manifest themselves in topological magnetization patterning and magnetochiral effects in conventional magnetic materials. These curvature-induced interactions can be not only local (when they stem from the exchange energy) [3] but also non-local (when they are due to magnetostatics) [4]. As a consequence, family of novel curvature-driven effects emerges, resulting in theoretically predicted unlimited domain wall velocities, chirality symmetry breaking etc [5]. Current and future challenges of the curvilinear magnetism will be discussed [6].

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Abstract ID: 222

ARTIFICIAL CHIRAL NANOSTRUCTURES FOR TOPOLOGICAL CONTROL OF MAGNETISM: 3D NANOFABRICATION AND X-RAY IMAGING

Naëmi Leo, Amalio Fernández-Pacheco

INMA, CSIC – University of Zaragoza, 50009, Zaragoza, SPAIN
E-mail: naemi.leo@unizar.es

Three-dimensional nanostructures are opening exciting pathways towards controlling nanomagnetic and spintronic effects with shape, curvature and connectivity not achievable in planar devices [1]. These properties allow to create novel functionalities, such as supporting emergent topological spin structures by the geometrically defined shape anisotropy [2,3], complex magnetotransport signatures in spintronic circuits [4], and unconventional spin dynamics [5]. Understanding and utilizing these effects in three-dimensional device nanomagnetic architectures for future applications with improved device density and low-power operation thus requires the development of novel fabrication [6] as well as observations methods [4,7], combined with nanomagnetic simulations.

Here, I will focus on focused-electron-beam-induced deposition (FEBID) [6] for controlled writing of three-dimensional structures with superb control of size and shape. I will discuss the preparation of even complex geometrical designs, such as shown in Fig. 1, using the python-based software f3ast [8], which – similar to a slicing program for a normal 3D printer – takes a 3D stl model file and returns deposition instructions based on layer-by-layer nanoscale FEBID growth.

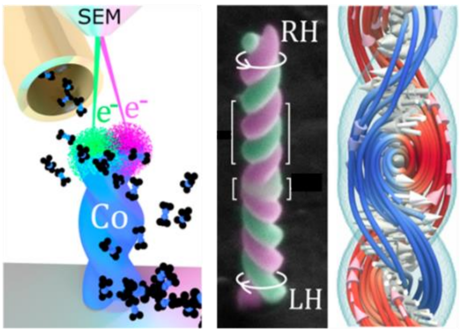

Fig. 1 *Left: Growth of chiral magnetic nanostructures with FEBID. Right: Double helix with chirality interface that supports complex topological spin structures [2].*

This method to grow complex nanoscale architectures for example allows to control the magnetic chirality by 3D geometrical effects [2,3]. Chirality is a key ingredient in the formation of complex spin structures and, using double-helix structures grown by FEBID, we can define nanoscale chirality interfaces where two magnetic domains of opposite structural chirality are forced to meet at a nanometric volume. I will discuss the emergent spin textures and field-driven behavior based on micromagnetic simulations results and synchrotron x-ray experiments.

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Abstract ID: 334

TENSION-FREE DIRAC STRINGS AND STEERED MAGNETIC CHARGES IN 3D ARTIFICIAL SPIN ICE

Sabri Koraltan[1,2]

[1] *Physics of Functional Materials, University of Vienna, Vienna, AUSTRIA*
[2] *Vienna Doctoral School in Physics, University of Vienna, Vienna, AUSTRIA*
E-mail: sabri.koraltan@univie.ac.at

Dipolar Spin Ices (DSI) are geometrically frustrated magnetic materials, where the moments are arranged on the sites of a pyrochlore lattice [1]. The ground-state obeys the ice-rule, where two magnetic moments point to the center of the tetrahedral unit cell and two point out. If the rule is broken, i.e. one moment is switched, a net magnetic charge is observed at the center of the tetrahedron, referred to as magnetic monopoles. The trace of the switched magnetic moments is referred to as a Dirac string, which has magnetic monopoles at its ends. However, these materials require cryogenic conditions for the stability of monopoles. To study the magnetic monopoles on more suitable platform, artificial spin ices (ASI) consisting of elongated magnetic islands were considered [2]. Their 2D nature lifts the degeneracy of the ground state, as not all ice-rule obeying vertices have equal energies. Due to this differentiation between energetic states of the vertices, the Dirac strings bind the monopoles and store energy, limiting the mobility within the lattice.

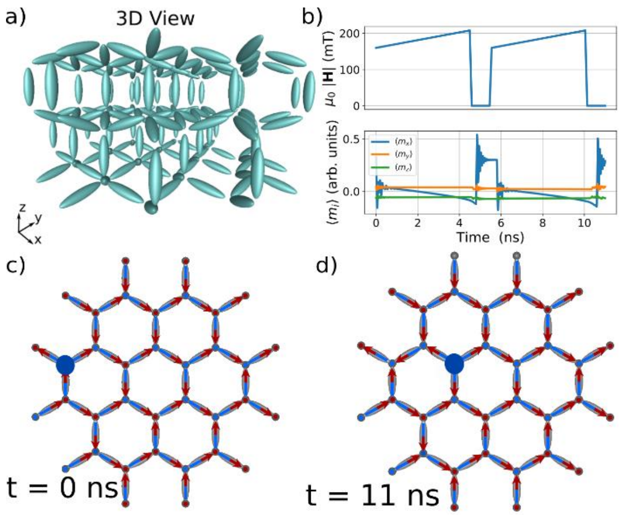

Fig. 1: *3D illustration of the 3DASI lattice in a), in which the magnetic charges can be propagated vertex by vertex upon application of a magnetic field pulse as demonstrated in b), where the magnetic charges moves from its location from c) to its new location in d).*

Here, we combine the advantages of DSI and 2D ASI, and present a 3D ASI lattice [3], where 3D ellipsoids with nearly perfect ising behavior are arranged on an Ice Ih crystal. This symmetry recovers the lifted degeneracy of the ground state and enables tension-free Dirac strings.

Based on the definitions of "truly" unbound magnetic monopoles, we show that the mobility threshold for magnetic charges is by 2 eV lower than their unbinding energy, while the propagation barrier is constant. The energy of the system does not increase with the length of the Dirac string, showing its tension-free nature. Furthermore, we apply external global fields and steer one magnetic monopole in the desired direction without creating additional magnetic charges, see Fig. 2. Finite temperature micromagnetic analysis reveals that the magnetic monopoles within the 3D ASI lattice are stable and unbound at room temperature.

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Abstract ID: 149

MICROSCALE METASURFACES FOR ON-CHIP MAGNETIC FLUX CONCENTRATION

E. Fourneau[1], J.A. Arregi[2], A. Barrera[3], N.D. Nguyen[4], S. Bending[5], A. Sanchez[6], V. Uhlíř[2,7], A. Palau[3], A.V. Silhanek[1]

[1]*Université de Liège, EPNM, QMAT, CESAM, Liège, BELGIUM*
[2]*CEITEC BUT, Brno University of Technology, Brno, CZECHIA*
[3]*Institut de Ciència de Materials de Barcelona, ICMAB-CSIC, Bellaterra, SPAIN*
[4]*Université de Liège, SPIN, Q-MAT, CESAM, Liège, BELGIUM*
[5]*University of Bath, Centre for Nanoscience and Nanotechnology, Bath, UNITED KINGDOM*
[6]*Universitat Autonoma de Barcelona, Department of Physics, Bellaterra, SPAIN*
[7]*Brno University of Technology, Institute of Physical Engineering, Brno, CZECHIA*
E-mail: emile.fourneau@uliege.be

Magnetic metamaterials inspired by optics transformation and combining ferromagnetic and superconducting layers have demonstrated promising perspectives to improve the efficiency of macroscopic magnetic flux concentrators [1]. Following this proof-of-concept, we investigate the effects of downscaling these devices, resulting in thin film metasurfaces suitable for on-chip integration. We scrutinize the influence of the non-linear magnetic response of the ferromagnetic components, their magnetic irreversibility, the formation of magnetic domains, as well as the effects of geometry and size of the devices. We demonstrate that well-designed magnetic metasurfaces with microscale lateral dimensions can have a large concentration gain but also the unique property of isotropic amplification, i.e., constant field concentration without a preferential direction of the external magnetic field. Our results prove that the implementation of metasurfaces at the microscale opens up new technological possibilities for enhancing the performance of magnetic field detectors and remotely charging small electric devices, thus paving the way towards new approaches in information and communication technologies.

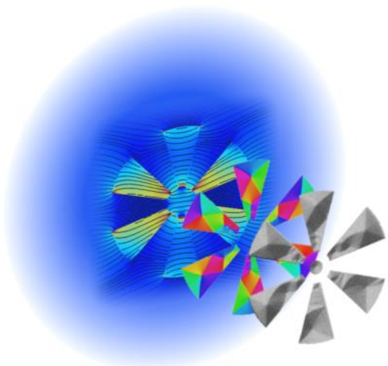

Fig. 1: *Magnetic response of a 6-petal magnetic metasurface obtained using finite-element simulation, micromagnetic simulation and magneto-optical Kerr effect microscopy.*

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Abstract ID: 363

PROBING AND TWISTING FERROMAGNETIC CrSBr MONOLAYERS

S. Mañas-Valero, C. Boix-Constant, E. Coronado

University of Valencia - ICMol, 46980 Paterna, Valencia, SPAIN
E-mail: samuel.manas@uv.es

Two-dimensional (2D) magnetic materials offer unprecedented opportunities for fundamental and applied research in spintronics and magnonics. Beyond the pioneering studies on 2D CrI_3 and $Cr_2Ge_2Te_6$, the field has expanded to 2D antiferromagnets exhibiting different spin anisotropies and textures. Of particular interest is the layered metamagnet CrSBr, a relatively air-stable semiconductor formed by antiferromagnetically-coupled ferromagnetic layers (Tc~150 K) that can be exfoliated down to the single-layer. It presents a complex magnetic behavior with a dynamic magnetic crossover, exhibiting a low-temperature hidden-order below T*~40 K.

Here, the magneto-transport properties of CrSBr vertical heterostructures in the 2D limit are inspected. The results demonstrate the marked low-dimensional character of the ferromagnetic monolayer, with short-range correlations above T_c and an Ising-type in-plane anisotropy, being the spins spontaneously aligned along the easy axis b below T_c. By applying moderate magnetic fields along a and c axes, a spin-reorientation occurs, leading to a magnetoresistance enhancement below T*. In multilayers, a spin-valve behavior is observed, with negative magnetoresistance strongly enhanced along the three directions below T*. These results show that CrSBr monolayer/bilayer provides an ideal platform for studying and controlling field-induced phenomena in two-dimensions, offering new insights regarding 2D magnets and their integration into vertical spintronic devices [1].

In addition, based on the previous results, we fabricate an artificial magnet by twisting 90 degrees two CrSBr ferromagnetic monolayers with an easy-axis in-plane anisotropy, thus forming an "orthogonally-twisted bilayer". The magneto-transport properties reveal multistep spin switching with a magnetic hysteresis opening, which is absent in the pristine case. By tuning the magnetic field, we modulate the remanent state and coercivity and select between hysteretic and non-hysteretic magneto-resistance scenarios. This complexity is fundamentally different from that achieved in Moiré superlattices. Our results highlight the control over the magnetic properties in vdW heterostructures, leading to a variety of field-induced phenomena and opening a fruitful playground for creating artificial magnetic symmetries and manipulating non-collinear magnetic textures [2].

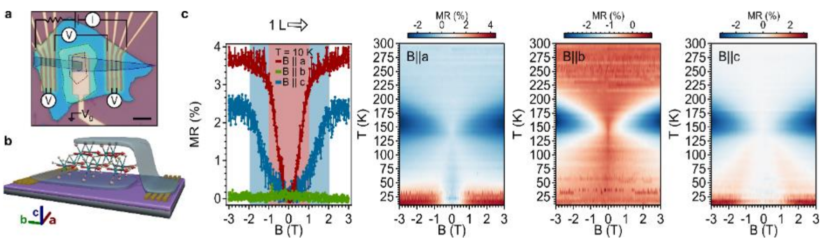

Fig. 1: *Vertical van der Waals heterostructure based on CrSBr monolayer. a) Device image. Scale: 5 µm. b) Artistic view of device shown in a. c) Magneto-transport properties of the van der Waals heterostructure.*

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VOLTAGE-CONTROLLED MAGNETIC TUNNEL JUNCTIONS FOR EMBEDDED MEMORY AND MACHINE LEARNING

Pedram Khalili

Department of Electrical and Computer Engineering, Northwestern University, Evanston, IL 60208, USA
E-mail: pedram@northwestern.edu

Magnetic random-access memory (MRAM) based on perpendicular magnetic tunnel junctions (MTJs) is gaining traction for embedded memory applications, due to its nonvolatility, low energy consumption, relatively high density, and small mask overhead. One of the requirements of embedded MRAM for Cache applications is to switch the magnetization direction with high speed (~ 3-10 ns for L2/L3 Cache) and with high endurance. The existing writing mechanism based on current-induced spin-transfer torque (STT) requires significant current density through the MTJ, thus limiting its energy efficiency, endurance, and ability to scale the access transistor size. Voltage-controlled magnetic anisotropy (VCMA) has emerged as an alternative mechanism which, owing to its electric-field-controlled principle, may solve this problem and enable higher bit density and ultra-low power switching in advanced CMOS nodes.

Previous works on VCMA-induced switching in perpendicular MTJs achieved write voltages > 2 V in bits with diameter down to 50 nm. In this talk, we report our recent progress in developing advanced VCMA-MRAM bits with write voltages below 1 V. We also demonstrate scaling of this switching mechanism down to 30 nm MTJ diameter, in voltage-controlled MTJs which simultaneously provide VCMA > 130 fJ/Vm, TMR > 170%, and thermal anneal stability at 400˚C for compatibility with embedded CMOS in advanced nodes [1].

We then discuss the application of MTJ devices for electrically controlled stochasticity, true random number generation, and stochastic computing architectures. As a proof of concept, we demonstrate the implementation of an artificial neural network (ANN) using MRAM-based stochastic computing (SC) units [2]. Experimentally measured stochastic bitstreams from a series of 50 nm MTJs are used to implement this SC-ANN. The MTJ-based SC-ANN achieves 95% accuracy for handwritten digit recognition on the MNIST database. MRAM-based SC-ANNs provide a promising solution for ultra-low-power and compact machine learning, especially in edge, mobile, and IoT devices.

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Thin Films and Interface Superconductivity

06.05.2023 SATURDAY

Abstract ID: 248

CORRELATED DISORDER AS A WAY TOWARDS ROBUST SUPERCONDUCTIVITY

A.V. Krasavin[1,2], V.D. Neverov[1,2], A.E. Lukyanov[1,2], A. Vagov[1,3], M.D. Croitoru[1,4]

[1] *HSE University, 101000, Moscow, RUSSIAN FEDERATION*
[2] *National Research Nuclear University MEPhI, Moscow, RUSSIAN FEDERATION*
[3] *University of Bayreuth, 95447, Bayreuth, GERMANY*
[4] *Universidade Federal de Pernambuco, 50670-901, Recife-PE, BRAZIL*
E-mail: avkrasavin@gmail.com

In our work, we theoretically justify an approach that makes it possible to significantly improve superconducting characteristics through the use of materials with spatially correlated disorder. This result enriches the understanding of the effects associated with disorder in superconductors and also introduces another control parameter for designing superconducting materials with desired properties.

The calculations were performed in the framework of the Bogolyubov – de Gennes mean field theory [1] using the correlated disorder model, in which the spatial correlations of the disorder potential in the reciprocal space obey the power law

$$S_V(q) \sim q^{-\alpha},$$

in the limit of small q, where the exponent α determines the *degree of correlation*.

The calculated phase diagram (Fig. 1) highlights the general trend that correlations inhibit the destructive influence of disorder on superconductivity.

The results show that spatial correlations in the disorder potential are a very important factor that significantly changes the superconducting properties and therefore cannot be ignored for disordered materials. In addition, manipulation of disorder correlations, when possible, can be used as another design parameter to modify superconductivity characteristics and develop materials with desired functional properties.

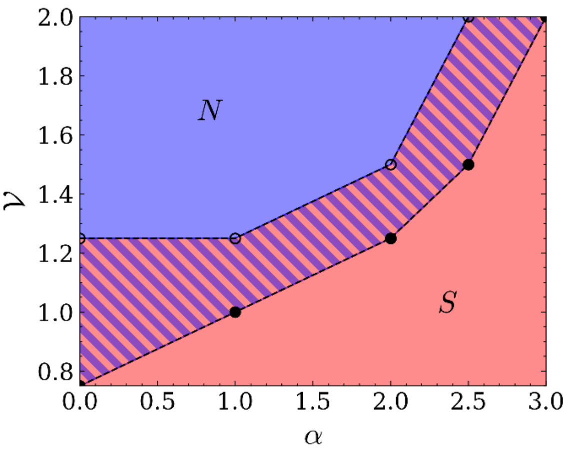

Fig. 1: *Phase diagram for disordered superconductors in coordinates (Degree of correlation × Disorder strength). Red S and blue N regions denote regions of non-zero and zero superfluid stiffness, respectively. Two boundaries between the S and N domains are found using the fluctuations-corrected superfluid stiffness (solid symbols) and without this correction (open symbols).*

The work was supported by the HSE University Basic Research Program and the MEPhI Program Priority 2030.

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Abstract ID: 253

SUPERCONDUCTOR-INSULATOR TRANSITION UNDER IN-PLANE MAGNETIC FIELD

M. Šindler, C. Kadlec, F. Kadlec

Institute of Physics, Academy of Sciences, Cukrovarnická 112, 16253 Prague 6, CZECH REPUBLIC
E-mail: sindler@fzu.cz

The complex conductivity of an ultrathin superconducting NbN film was investigated by terahertz time-domain spectroscopy under an in-plane magnetic field [1]. The external in-plane magnetic field up to 7 tesla diminishes the superconducting properties of the ultrathin NbN film. The dissipation below the optical gap increases while the imaginary part changes only slightly. We believe that we observe the onset of a superconductor-insulator transition in which nanoscale inhomogeneity is induced by the field. Our observed data support the effective medium model [2] with the normal state inclusions in the superconducting matrix following a linear dependence of both the pair-breaking scattering rate Γ and the superconducting volume fraction on the applied magnetic field, see Fig 1. The conductivity of superconducting state is well described by the model for Dynes superconductors [3] with the optical gap independent on the applied field.

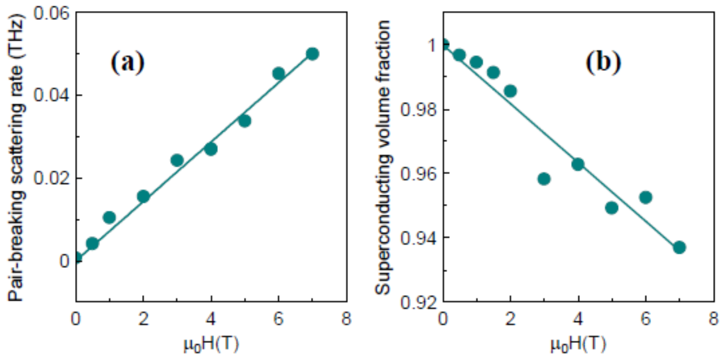

Fig. 1: *(a) Pair-breaking scattering rate and (b) superconducting volume fraction dependence on in-plane magnetic field. Points were retrieved from the fit, line represents their linear fit.*

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Abstract ID: 539

MASS OF SMALL POLARON IN $La_{2-x}Sr_xCuO_4$ FILMS: EFFECT OF FILM'S THICKNESS

B.Ya. Yavidov, D.G‘, Khajibaev, S.M. Otajonov

Nukus state pedagogical institute named after Ajiniyaz, 230105 Nukus, UZBEKISTAN
E-mail: bakhrom.yavidov@gmail.com

It is well known that polarons are important ingredients of superconductivity (SC) of cuprates and pnictides [1]. There are also overwhelming experimental evidences on polaronic nature of charge carriers in cuprates. That is why the study of the properties of polarons is important, in particular, in $La_{2-x}Sr_xCuO_4$ (LSCO) cuprate's films whose SC differs from that of bulk samples [2].

Here, we report the preliminary results of our study on LSCO film's thickness dependence of small polaron's mass. There is a hope that such a study could be useful in interpretation of SC and normal properties of LSCO films, in particular, the effects of thickness and strain on SC of optimally doped LSCO thin films [3].

We consider LSCO films within the framework of extended Holstein-extended Hubbard model (EHEHM) that enable us to take into account the strains of LSCO film's lattice. The model has recently been used to satisfactorily interpret the experimental results on LSCO films [4,5]. We firstly directly relate the strains to the thickness of the film, and then relate, through the strains, the mass of small polaron to the film's thickness. The numerical calculation of the mass of small polaron, m_{ab}, within the ab-plane of LCSO films show that m_{ab} decreases and increases as the film thickness decreases in the systems LSCO/LSAO and LSCO/STO, respectively. The value of m_{ab} for the very thick samples is $\approx 7m_e$. The latter is close to recent experimental data of Ref. [6] where $m_{ab} \approx (4.9\pm0.8)m_e$ is obtained.

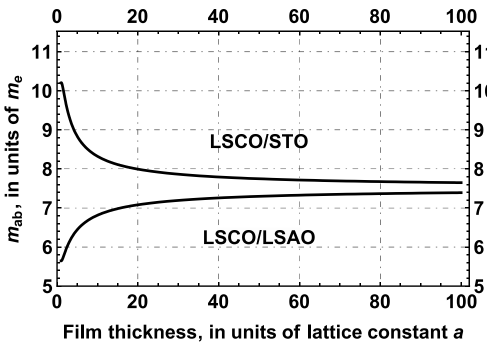

Fig. 1: *The value of m_{ab} as a function of LSCO film thickness, grown on LSAO and STO substrates.*

Our findings might be useful in explanation of thickness and strain related phenomena in LSCO and other cuprates.

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Topological and Low-Dimensional Superconductivity I-II

06.05.2023 SATURDAY

Abstract ID: 129

HIGH-TEMPERATURE POLARONIC LATTICE DISTORTIONS AND CHARGE ORDERING IN 1T-TaS_2

E.S. Bozin[1], M. Abeykoon[2], S. Conradson[3], G. Baldinozzi[4], P. Sutar[3], D. Mihailovic[3]

[1]*Condensed Matter Physics and Materials Science Division, Brookhaven National Laboratory, Upton, NY 11973, USA*
[2]*Photon Sciences Division, Brookhaven National Laboratory, Upton, NY 11973, USA*
[3]*Dept. of Complex Matter, Jozef Stefan Institute, Jamova 39, SI-1000 Ljubljana, SLOVENIA*
[4]*Centralesupélec, CNRS, SPMS, Université Paris-Saclay, bât Eiffel, Gif-sur-Yvette, Île-de-France, 91190, FRANCE*
E-mail: emil.bozin@gmail.com

Interesting emergent behavior in quantum materials arises when the interaction of electrons with the lattice leads to partial localization and ordering of charge at low temperatures. The triangular lattice of some transition metal dichalcogenides additionally presents an interesting case, where spin order is frustrated, leading to an additional complex interplay of interactions involving spin, charge, and lattice degrees of freedom. Here we present a study of local symmetry breaking of the lattice structure in the layered dichalcogenide material 1T-TaS_2 using x-ray pair-distribution function measurements. Remarkably, we observe symmetry-breaking polaronic distortions of the lattice structure around individual localized electrons at temperatures well above any of the known long-range ordered charge density wave phases in 1T-TaS_2. These characteristic polaronic signatures, associated with electronic instabilities of individual monolayers, remain on cooling through the spin and charge ordered states, eventually revealing a new transition near 50 K to a state displaying partially restored symmetry and significant inter-layer dimerization. The order parameter associated with the observed local atomic displacements and symmetry-allowed polaron spin structure in the ground state suggests that charge ordering is driven by the crystallization of polarons, rather than conventional Fermi surface nesting. Symmetry analysis shows that the distorted structure is consistent with a breakup of the quantum spin liquid phase at low temperature, concurrent with the disappearance of domains in the charge order [1].

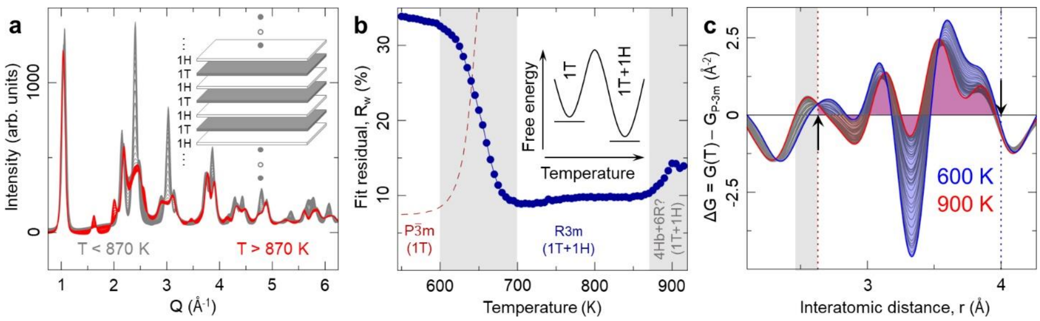

Fig. 1: *Polymorphic transformations on warming in the M-phase of 1T-TaS_2.* ***a*** *Stack of diffraction patterns showing polymorphic transformations on warming, T > 600 K. Red stack, T > 870 K, reveals additional transformation.* ***b*** *Transformation temperatures charted by fit residuals of $P\bar{3}m$ and R3m models, as indicated. Inset: sketch of the free energy of TaS_2, depicting metastable state (1T) and more stable configurations (1T+1H) achieved at elevated temperature.* ***c*** *Stack of narrow r-range difference PDFs, ΔG, obtained by subtracting a reference undistorted PDF from experimental data. The distortion signal, used to estimate the distorted fraction, persists to the highest measured temperature.*

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Abstract ID: 408

PROTECTION OF ISING SPIN-ORBIT COUPLING IN BULK MISFIT SUPERCONDUCTORS

P. Samuely[1,2], O. Šofranko[2], M. Gmitra[1], J. Haniš[2], M. Kuzmiak[1], J. Kačmarčík[1], P. Szabó[1], Tristan Cren[3], L. Cario[4], D. Wickramaratne[5], I.I. Mazin[6], T. Samuely[2]

[1] *Centre of Low Temperature Physics, Institute of Experimental Physics SAS, Košice, SLOVAKIA*
[1] *Centre of Low Temperature Physics, Pavol Jozef Safarik University, Košice, SLOVAKIA*
[3]*Institut des NanoSciences de Paris, Sorbonne Université, FRANCE*
[4]*Institut des Matériaux Jean Rouxel, Université de Nantes, FRANCE*
[5]*Center for Comp. Materials Science, U.S. Naval Research Laboratory, Washington DC, USA*
[6]*Department of Physics and Astronomy, George Mason University, Fairfax VA, USA*
E-mail: samuely@saske.sk

Low-dimensional materials can exhibit remarkable properties different from their bulk counterparts. $NbSe_2$ monolayer is an Ising superconductor with the in-plane upper critical field violating the Pauli limit, while no such behavior occurs in bulk $NbSe_2$ [1]. However, in contrast to bulk, low-dimensional materials are often unstable and impractical for applications. Utilizing various experimental techniques, we found that $(LaSe)_{1.14}(NbSe_2)$ and $(LaSe)_{1.14}(NbSe_2)_2$ bulk layered misfit superconductors exhibit a two-dimensional band structure equivalent to a highly doped $NbSe_2$ monolayer [2]. Moreover, their in-plane upper critical fields exceed the Pauli limit by a factor of up to 10 [3]. From first-principles calculations backed by experimental results we obtained the values of the reduced interlayer coupling and strong spin-orbit splitting. This quantitative analysis enabled us to explain the microscopic origin of the Ising spin-orbit coupling in bulk superconductors.

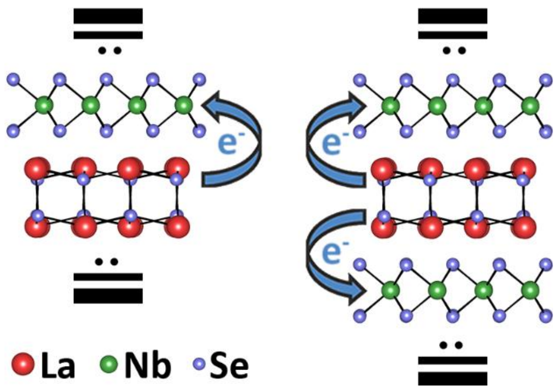

Fig. 1: *Left: $(LaSe)_{1.14}(NbSe_2)$ Right: $(LaSe)_{1.14}(NbSe_2)_2$.*

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Abstract ID: 409

BEREZINSKII–KOSTERLITZ–THOULESS TRANSITION IN THE TYPE-I WEYL SEMIMETAL $PtBi_2$

Bernd Büchner

Leibniz Institut für Festkörper- und Werkstoffforschung, GERMANY
E-mail: b.buechner@ifw-dresden.de

We present studies of anomalous superconductivity in the in trigonal $PtBi_2$ representing a two-dimensional van der Waals material with type-I Weyl semimetal band structure. Transport measurements show an unusually robust low dimensional superconductivity in thin exfoliated flakes up to 126 nm in thickness (with T_c ~ 275–400 mK), which constitutes the first report and study of unambiguous superconductivity in a type-I Weyl semimetal. Remarkably, a Berezinskii-Kosterlitz-Thouless transition with T_{BKT} ~ 310 mK is revealed in up to 60 nm thick flakes, which is nearly an order of magnitude thicker than the rare examples of two-dimensional superconductors exhibiting such a transition. Whereas bulk probes do not show superconductivity, tunneling spectroscopy yields evidence for superconductivity even at higher temperatures pointing to the possibility of surface superconductivity. Based on our findings we argue that $PtBi_2$ is an ideal platform to study low dimensional and unconventional superconductivity in topological semimetals.

Abstract ID: 3

EVIDENCE FOR UNCONVENTIONAL SUPERCONDUCTIVITY AND NONTRIVIAL TOPOLOGY IN PdTe

Ramakanta Chapai[1], P. V. Sreenivasa Reddy[2], Lingyi Xing[1], David E. Graf[3], Amar B. Karki[1], Tay-Rong Chang[2], Rongying Jin[1,4]

E-mail: rjin@mailbox.sc.edu

PdTe is a superconductor with T_c ~4.25 K. Below T_c, the electronic specific heat initially decreases in T^3 behavior (1.5 K < T < T_c) then exponentially decays. Using the two-band model, the superconducting specific heat can be well described with two energy gaps Δ_1 = 0.372 meV and Δ_2 = 1.93 meV. The calculated bulk band structure consists of two electron bands (α and β) and two hole bands (γ and η) at the Fermi level. Experimental detection of the de-Haas van Alphen (dHvA) oscillations allows to identify four frequencies (F_α = 65 T, F_β = 658 T, F_γ = 1154 T, and F_η = 1867 T for H // a), consistent with theoretical predictions. Nontrivial α and β bands are further identified via both calculations and the angle dependence of the dHvA oscillations. Our investigations strongly suggest that PdTe is a candidate for unconventional superconductivity.

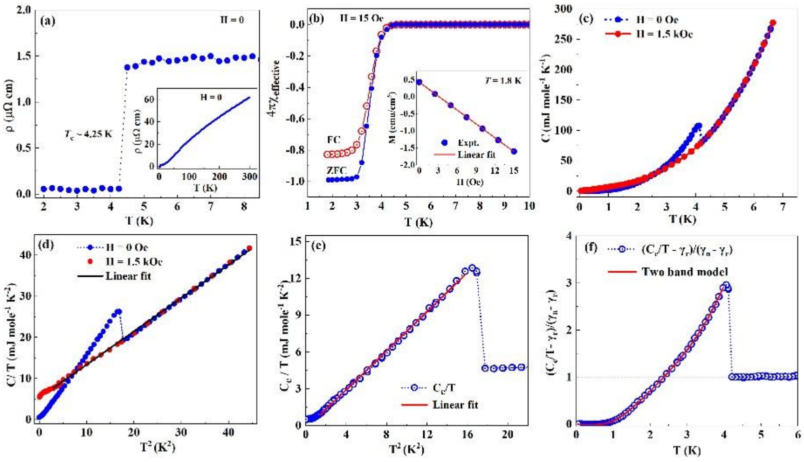

Fig. 1: *Superconductivity in PdTe. (a) Zero-field electrical resistivity of PdTe showing zero resistance below 4.25 K. Inset: Temperature dependence of the electrical resistivity between 2 and 300 K. (b) Magnetic susceptibility of PdTe in both ZFC and FC modes. Inset: magnetization as a function of H at 1.8 K, where the solid line is a fit of M using $M = A(H-H_0)$ for determining the residual field H_0. (c) Specific heat (C) of PdTe under H = 0 and 1.5 kOe. (d) C/T versus T^2. The black solid line is the fit of the data under field to the relation $C/T = \gamma + \beta T^2$. (e) Electronic specific heat plotted as C_e/T versus T^2. The solid line represents the line fit of data. (f) $(C_e/T-\gamma_r)/(\gamma_n-\gamma_r)$ versus T. The solid line is the fit of data to the two-band model.*

Abstract ID: 232

THE IMPORTANCE OF ELECTRONIC EXCITATIONS IN THE GENERATION OF HIDDEN PHASES IN MAGNETITE

Benoit Truc

EPFL, Laboratory for Ultrafast Microscopy and Electron Scattering, 1015, Lausanne, SWITZERLAND
E-mail: benoit.truc@epfl.ch

Magnetite is probably the most studied transition metal oxide system as it undergoes a peculiar metal-insulator transition around 125K accompanied by structural reduction symmetry concomitant with a magnetic reorientation, the so-called Verwey transition (VT). Recently, a new type of bond-dimerized state involving charge and orbital ordering has been discovered, the trimeron. The quasiparticle formed by the linear arrangement of three Irons atoms is considered as the building block of the low-temperature (LT) phase and responsible for the structural and electrical conductivity changes. The phase transition can be understood as an order-disorder process in which the coherence length of the trimeron network decreases abruptly at VT upon heating. At LT, by illuminating the system using 800nm (1.55eV) ultrashort light pulses, the trimeron order is melted, leading to the recovery of the high-temperature cubic phase. Previous ultrafast experiments have not considered other electronic excitations that can be triggered by tuning the photon energy pulse. Such fine details are essential for external manipulations of the intertwined degrees of freedom. Here, using time-resolved electron diffraction that provides sub-pm/ps spatio-temporal resolution, we report the generation of hidden structural phases by triggering specific electronic excitations. In particular, by comparing 800nm (1.55eV) and 400nm (3.10eV) ultrashort illumination, we show two opposite behaviors in the structural response. Upon 800-nm photoexcitation, d-d electronic excitations are triggered and destroy the trimeron network. The structure relaxes towards a cubic phase involving multistep processes, highlighting the strong phonon-phonon interactions. Using 400nm (3.10eV) photon energy is enough to activate charge transfers, and an enhancement of the monoclinic distortion is observed. In our proposed scenario, the 400nm photoexcitation acts as photodoping and fills the vacancies left in the imperfect Wigner crystal formed by the trimeron arrangement which leads to the reinforcement of the monoclinic state. Our findings demonstrate the ability to establish novel hidden phases in quantum materials via specific electronic excitations in a strongly correlated environment relevant to ultrafast technologies.

Abstract ID: 238

THE FEATURES OF EXCITATION SPECTRUM IN INTERACTING MAJORANA WIRES OF BDI CLASS

M.S. Shustin[1], S.V. Aksenov[2], I.S. Burmistrov[1,3]

[1]*L. D. Landau Institute for Theoretical Physics, 142432 Chernogolovka, RUSSIA*
[2]*Kirensky Institute of Physics, Federal Research Center KSC SB RAS, 660036 Krasnoyarsk, RUSSIA*
[3]*Laboratory for Condensed Matter Physics, HSE University, 101000 Moscow, RUSSIA*
E-mail: mshustin@yandex.ru

In the last years, quasi-1D hybrid structures Al-EuS-InAs, consisting of an InAs semiconducting nanowire, covered by thin Al and EuS layers are actively studied (see, for example [1–3]). At low temperatures, the Al layer goes into a superconducting (SC) state and becomes a donor of Cooper pairs in InAs. The EuS layer has a ferromagnetic order and induces magnetic correlations in the InAs due to the proximity effect. As a result, the electronic subsystem of such a structure has the properties of a spin-polarized superconducting nanowire (SW) with Rashba spin-orbit interaction. An experimental study of this system led to the discovery of a stable zero-bias peak, which indirectly indicates the Majorana modes. However, the obtained experimental data are interpreted ambiguously and are the subject of discussions [4]. One of the problems hampering the MM detection is possibility of strong electron correlations in the InAs-core SW [5].

In the study we show that the generalized Kitaev chain [6] with next-nearest-neighbors hoppings, anomalous pairings and an intersite fermion repulsion with an amplitude V can serve as a low-energy model of the spin-polarized strongly correlated SW. Such a model belongs to the BDI symmetry class and allows the realization of eight topological phases. It is shown that, in the mean-field approximation, the topological transitions are accompanied by the filling of Fermi modes corresponding to nodal quasi-momenta of the SC order parameter ("nodal modes"). This made it possible to determine the structure of the many-body ground state in the different topological phases. It is found that beyond the mean-field description the main corrections to the self-energy contain not only the contributions $\sim V^2$ due to the filling of the gapped bulk modes, but also the corrections $\sim V/L$ associated with the filling of the "nodal modes". The latter corrections lead to a renormalization of the system excitation spectrum and a sharp change in the effective mass during the topological transitions. In addition, the study of the quasiparticles structure in the topological phases and the features of their damping in the interacting SW was carried out by both self-energy analysis and density matrix renormalization group calculations. Thus, it is expected that the electron interactions in the SW of a finite length L would result in the modifications of the quasiparticle spectrum pointing out to the topological transitions that can be measured in practice via, e.g., ARPES or cyclotron resonance measurements.

The study is supported by Russian Science Foundation, project No. 22-42-04416.

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Topological and Unconventional Superconductivity

06.05.2023 SATURDAY

Abstract ID: 93

TOPOLOGY ENABLED UNCONVENTIONAL SUPERCONDUCTIVITY IN A TIME-REVERSAL SYMMETRY BREAKING BULK SUPERCONDUCTOR

J.R. Badger[1], Y. Quan[2,3,4,5], M. Staab[2], S. Sumita[6], A. Rossi[2,7], K. Devlin[1], K. Neubauer[2], D.S. Shulman[8], J.C. Fettinger[1], P. Klavins[2], S.M. Kauzlarich[1], D. Aoki[9], I. Vishik[2], W.E. Pickett[2], V. Taufour[2]

[1]*Department of Chemistry, University of California, Davis, California 95616, USA*
[2]*Department of Physics and Astronomy, University of California, Davis, California 95616, USA*
[3]*Present address: Department of Physics, University of Florida, Gainesville, Florida 32611, USA*
[4]*Department of Materials Science and Engineering, University of Florida, Gainesville, Florida 32611, USA*
[5]*Present address: Quantum Theory Project, University of Florida, Gainesville, Florida 32611, USA*
[6]*Condensed Matter Theory Laboratory, RIKEN CPR, Wako, Saitama 351-0198, JAPAN*
[7]*Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
[8]*Department of Physics, University of California, Berkeley, California, 94720, USA*
[9]*IMR, Tohoku University, Oarai, Ibaraki 311 - 1313, JAPAN*
E-mail: valentin.taufour@hotmail.com

Unconventional superconductors have Cooper pairs with lower symmetries than in conventional superconductors. In most unconventional superconductors, the additional symmetry breaking occurs in relation to typical ingredients such as strongly correlated Fermi liquid phases, magnetic fluctuations, or strong spin-orbit coupling in noncentrosymmetric structures. In this presentation, I will show that the time-reversal symmetry breaking in the superconductor $LaNiGa_2$ is enabled by its previously unknown topological electronic band structure, with Dirac lines and a Dirac loop at the Fermi level [1,2]. Two symmetry related Dirac points even remain degenerate under spin-orbit coupling. These unique topological features enable an unconventional superconducting gap in which time-reversal symmetry can be broken in the absence of other typical ingredients. Our findings provide a route to identify a new type of unconventional superconductors based on nonsymmorphic symmetries and will enable future discoveries of topological crystalline superconductors. I will discuss how a symmetry guided discovery of topological superconductors can be realized.

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Abstract ID: 136

UNCONVENTIONAL SUPERCONDUCTIVITY IN TOPOLOGICAL KRAMERS NODAL-LINE SEMIMETALS

T. Shang[1], J. Zhao[2], L.-H. Hu[3], J. Ma[4], D. J. Gawryluk[5], X. Zhu[1], H. Zhang[1], Z. Zhen[1], B. Yu[1], Y. Xu[1], Q. Zhan[1], E. Pomjakushina[5], M. Shi[5], T. Shiroka[5,6]

[1]*School of Physics, East China Normal University, Shanghai 200241, CHINA*
[2]*Center for New Energetic Materials, Southwest University, Mianyang 621010, CHINA*
[3]*Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA*
[4]*Department of Physics, City University of Hong Kong, Kowloon, HONG KONG*
[5]*Paul Scherrer Institut, CH-5232 Villigen PSI, SWITZERLAND*
[6]*Laboratorium für Festkörperphysik, ETH Zürich, CH-8093 Zürich, SWITZERLAND*
E-mail: tshiroka@phys.ethz.ch

Crystalline symmetry is a defining factor of the electronic band topology in solids, where many-body interactions often induce a spontaneous breaking of symmetry. Superconductors lacking an inversion center are among the best systems to study such effects or even to achieve topological superconductivity. Here, we demonstrate that *T*RuSi materials (with *T* a transition metal) belong to this class. Their bulk normal states behave as three-dimensional Kramers nodal-line semimetals, characterized by large antisymmetric spin-orbit couplings and by hourglass-like dispersions. Our muon-spin spectroscopy measurements show that certain *T*RuSi compounds spontaneously break the time-reversal symmetry at the superconducting transition, while unexpectedly showing a fully gapped superconductivity. Their unconventional behavior is consistent with a unitary ($s + ip$) pairing, reflecting a mixture of spin singlets and spin triplets. By combining an *intrinsic* time-reversal symmetry breaking superconductivity with *nontrivial* electronic bands, *T*RuSi compounds provide an ideal platform for investigating the rich interplay between unconventional superconductivity and the exotic properties of Kramers nodal-line/hourglass fermions.

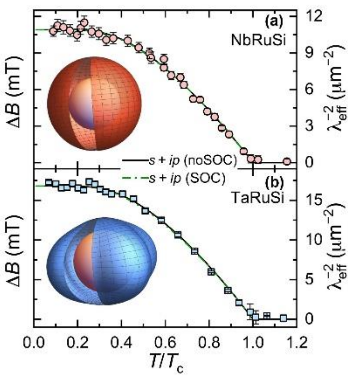

Fig. 1: *Superfluid density vs. reduced temperature T/T_c for NbRuSi (a) and TaRuSi (b). Fits use the gap functions shown in the insets with a nonsymmetric (s + ip) pairing in the weak and strong SOC limit.*

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Abstract ID: 312

FRAUNHOFER PATTERN IN THE PRESENCE OF MAJORANA AND ANDREEV BOUND STATES

F. Dominguez[1], E.G. Novik[2], P. Recher[1,3]

[1]Institut für Mathematische Physik, Technical University Braunschweig, 38106, Braunschweig, GERMANY
[2]Technische Universität Dresden, Institute of Theoretical Physics, 01062, Dresden, GERMANY
[3]Laboratory of Emerging Nanometrology, 38106, Braunschweig, GERMANY
E-mail: p.recher@tu-braunschweig.de

Topological states are recent concepts in condensed matter physics that have important implications for example in metrology, due to their robust transport properties or in topological quantum computation through the braiding of Majorana bound states. Here, we propose a novel topological Josephson junction with the normal region being a quantum spin Hall insulator. Using the BHZ model and numerical tight-binding simulations, we show that the Fraunhofer pattern in the presence of Majorana edge modes in the superconductors behaves dramatically different with respect to size and period as compared to the situation without Majorana edge modes [1]. The two regimes are connected to each other by the application of a Zeeman field. By investigating the different scattering processes in the junction by means of an analytical scattering model, we can show that the presence of Majorana edge modes can induce strong crossed Andreev reflection via the two edges (leading to non-local triplet pairing) that is otherwise strongly suppressed by virtue of the spin-momentum locking of the helical edge states. We further argue that the effect originates from a truly non-local feature of separated Majoranas that can be measured in equilibrium and at finite temperature. We further compare the predicted signatures of separated Majorana edge modes against conventional Andreev bound states and show that parameter regimes exist where the two cases can be distinguished. Together with predictions for the two-terminal conductance [2], the present setup offers unique and experimentally accessible signatures of topological superconductivity.

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Topological Superconductivity, Majorana Modes and Topological Quantum Computation

06.05.2023 SATURDAY

Abstract ID: 184

ARTIFICIAL ATOMIC STRUCTURES ON SUPERCONDUCTORS FOR ENGINEERING QUANTUM STATES: THEORETICAL INSIGHTS

Thore Posske[1,2]

[1]*I. Institute for Theoretical Physics, Universität Hamburg, D-22607 Hamburg, GERMANY*
[2]*Centre for Ultrafast Imaging, Luruper Chaussee 149, D-22761 Hamburg, GERMANY*
E-mail: tposske@physnet.uni-hamburg.de

Magnetic and nonmagnetic adatoms on the surface of a superconductor can induce a variety of localized quantum states, among which are Yu-Shiba-Rusinov states, (precursor) Majorana modes, and the recently discovered Mashiba-Shibata states [1], which can be seen as elemental form of proximity induced superconductivity. I will give theoretical insight on these localized states in artificial adatom structures and discuss ideas how to combine them to increase the level of control about their key properties.

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Abstract ID: 203

BRAIDING OF MAJORANA ZERO MODES IN TOPOLOGICAL SUPERCONDUCTORS

Stephan Rachel

School of Physics, University of Melbourne, Parkville, AUSTRALIA
E-mail: stephan.rachel@unimelb.edu.au

There has been tremendous experimental progress in recent years in establishing magnet-superconductor hybrid (MSH) systems as a promising platform for Majorana physics.

In the first part of this talk, I will discuss MSH structures with Re or Nb as a superconducting substrate, and Fe or Mn as magnetic adatoms. In particular, I will illustrate the theoretical challenges to simulate and understand the topological superconductivity and their concomitant Majorana modes in such materials

In the second part of this talk, I will explain our first steps to investigate the braiding of Majorana zero modes. In particular, I will focus on braiding errors which can be introduced from sources such as quasiparticle poisoning and Majorana hybridization, and how these error rates behave in a full quasiparticle background.

Abstract ID: 311

MAJORANA VORTEX MODES IN MAGNET-SUPERCONDUCTOR HYBRIDS WITH A TRIANGULAR LATTICE: LOCAL DENSITY OF STATES STUDY

A.O. Zlotnikov

Kirensky Institute of Physics, FRC KSC SB RAS, 660036, Krasnoyarsk, RUSSIA
E-mail: zlotn@iph.krasn.ru

It is known that a helical long-range magnetic order in quasi-1D and quasi-2D superconducting (SC) structures with spin-singlet pairings can lead by itself to topological superconductivity (TSC) (for example, [1]). Such magnet-superconductor hybrids (MSH) were realized experimentally [2, 3]. It is widely accepted that in 2D TSC the spatially separated Majorana modes are localized on vortex cores (these modes are abbreviated as MVM), instead of the edges [4]. Since MVM are not well described in MSH, in the present study a vortex cluster (such cluster can be created in an experiment [5]) is considered in the structure having layers with a triangular lattice [6]. The proposed MSH support 120° spin order and chiral $d_{x^2-y^2}+id_{xy}$ SC state, both induced by the symmetry of the triangular lattice.

We show that, even though nearby excitation energies of subgap states are very close to each other, the energy gap for MVM separating them from other vortex bound states is an order of magnitude higher. It is found that in the presence of helical spin order its value can be estimated from the excitation energy of vortex bound states in the pure chiral d-wave state. By studying local density of states near the vortex cores, the possibility to experimentally detect the described MVM by STM is demonstrated (see Fig. 1).

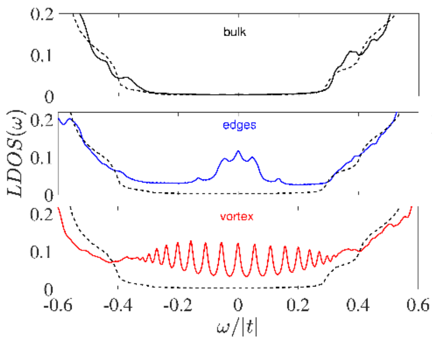

Fig. 1: *Local density of states (LDOS) in the vicinity of the vortex core, near the edges, and far from inhomogeneities in the model. The broadening parameter is $\delta = \Delta/20$, where Δ is the bulk gap.*

The reported study was funded by the Theoretical Physics and Mathematics Advancement Foundation "BASIS".

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Advances In Magnetism and Related Materials I-II

07.05.2023 SUNDAY

Abstract ID: 188

MAGNETO-OPTICAL TRANSPORT PROPERTIES OF A SEMIMETAL WITH A MEXICAN-HAT-LIKE VALENCE BANDS IN TWO AND THREE DIMENSIONS

Z. Rukelj[1], A. Akrap[2]

[1] *Department of Physics, Faculty of Science, University of Zagreb, Bijenička 32, HR-10000 Zagreb, CROATIA*
[2] *Department of Physics, University of Fribourg, 1700 Fribourg, SWITZERLAND*
E-mail: zrukelj@phy.hr

Here we study the single-particle, electronic transport and optical properties of a gapped system described by a simple two-band Hamiltonian with inverted valence bands. We analyze its properties in the three-dimensional (3D) and the two-dimensional (2D) case. The insulating phase changes into a metallic phase when the band gap is set to zero. The metallic phase in the 3D case is characterized by a nodal surface. This nodal surface is equivalent to a nodal ring in two dimensions.

Within a simple theoretical framework, we calculate the density of state, the total and effective charge carrier concentration, the Hall concentration and the Hall coefficient, for both 2D and 3D cases. The main result is that the three concentrations always differ from one another in the present model. These concentrations can then be used to resolve the nature of the electronic ground state.

Similarly, the optical conductivity is calculated and discussed for the insulating phase. We show that there are no optical excitations in the metallic phase. Finally, we compare the calculated optical conductivity with the rule-of-thumb derivation using the joint density of states.

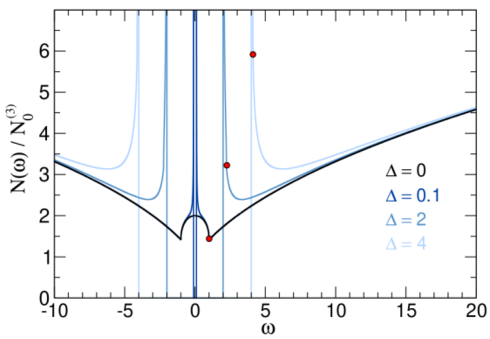

Fig. 1: *The density of states of the 3D system with a Mexican-hat-like valence bands as it depends on energy ω and the band gap parameter Δ.*

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Abstract ID: 231

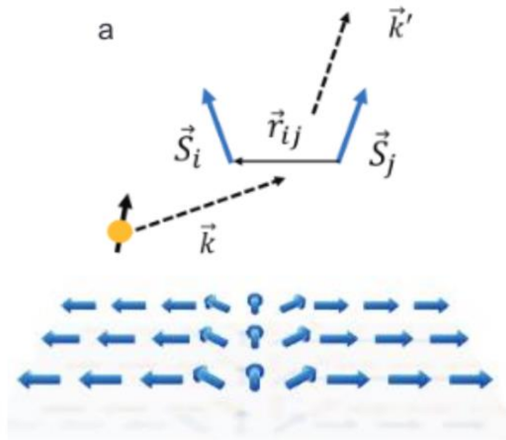
SKEW SCATTERING BY MAGNETIC MONOPOLES AND ANOMALOUS HALL EFFECT IN SPIN-ORBIT COUPLED SYSTEMS

Hiroaki Ishizuka

Dept. of Physics, Tokyo Institute of Technology, 152-8551 Meguro, Tokyo, JAPAN
E-mail: ishizuka@phys.titech.ac.jp

Magnetic textures, such as skyrmion and helix, bring about unconventional transport phenomena when they couple to itinerant electrons. Anomalous Hall effect (AHE) in a skyrmion crystal is one such phenomenon that has been intensively studied over the last couple of decades. The standard interpretation of this Hall effect is that it is due to the effective magnetic field originating from the spin Berry phase [1,2]. The relation between the spin Berry phase and spin chirality connects the skyrmion to this effect. Namely, it is an intrinsic AHE. In addition, recent theoretical studies point out that the thermal fluctuation of spins also induces an AHE related to the spin chirality, which is described by the multiple magnetic scattering [3-5]. These studies reveal the nontrivial role of magnetic structure and fluctuation on electron transport. While intensive studies have been done on chirality-related AHE, most study so far focuses on electron systems without spin-orbit interaction (SOI). On the other hand, a recent study on the effect of SOI on the AHE by spin Berry phase claims the existence of significant correction arising from the SOI. However, much less is understood about the effect of spin-orbit interaction.

In this work, we explore the effect of SOI on another kind of AHE, namely, that by multiple magnetic scattering. Focusing on the two-dimensional electron systems with SOI, such as electrons with Rashba and Dresselhaus interactions, we show that the SOI induces a novel contribution to the AHE [6]. Most importantly, these contributions arise from a lower order in the momentum, implying that they give a larger contribution to the AHE compared to those related to magnetic skyrmion. We also show that the form of the scattering term is strongly restricted by symmetry; in Rashba model, the novel scattering term is limited to magnetic monopoles, whereas AHE in Dresselhaus model is related to a different helical term. We show that the monopole term we found gives a finite AHE in domain walls whose spins rotate in the two-dimensional plane. The results demonstrate the potential of electrons with strong SOI for detecting various magnetic states.



Schematic of the skew scattering by two-spin scattering (above) and a domain wall (below).

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Abstract ID: 481

GRAPHENE SPACER IN TOPOLOGICAL INSULATOR Bi_2Te_3 /GRAPHENE/NiFe HETEROSTRUCTURES FOR EFFICIENT SPIN-ORBIT TORQUES

V. Zatko[1], R. Galceran[1], T. Guillet[1], M. Aoki[2], F. Bonell[3], G. Sauthier[1], M.J. Esplandiu[1], A.I. Figueroa[1], J.F. Sierra[1], S.O. Valenzuela[1]

[1]*Catalan Institute of Nanoscience and Nanotechnology (ICN2), Campus UAB, Barcelona 08193, Bellaterra, SPAIN*
[2]*Department of Electronic Science and Engineering, Kyoto University, Kyoto 615-8510, Kyoto, JAPAN*
[3]*Univ. Grenoble Alpes, CNRS, CEA Spintec, Grenoble 38000, Grenoble, FRANCE*
E-mail: victor.zatko@icn2.cat

Steady progress in two-dimensional materials (2DMs) offers new perspectives for downscaling and improving MRAM performance [1]. Their 2D nature and weak van-der-Waals interaction between layers enable to create atomically thin stacks with sharp interfaces, circumventing roughness and inter-diffusion between the films, which significantly degrade the spin properties of conventional materials [2]. Furthermore, known 2DMs cover a broad range of relevant properties for spintronics. Among them, graphene shows a very low SOC resulting in long spin diffusion length [3], being of great interest to avoid spin depolarization. The van der Waals materials family also includes topological insulators (TIs) that is an alternative of high SOC materials for charge-to-spin conversion (CSI) with unprecedented magnitudes that would be highly relevant for writing operation in MRAM technologies. Indeed, TIs exhibit conducting topological surface states (TSSs) where the spin of the carriers are locked to their momentum. These results in a highly-efficient generation of spin currents with a polarization that depends on the direction of the charge current.

However, materials disruptions at the interface, from band bending to alloying or air exposure, complicate this picture and the expected SOTs are not obtained.

This study aims in using the TI Bi_2Te_3 (BST) as a spin source in order to study its SOT properties. We first describe a step-by-step atmosphere-controlled graphene transfer on top of the TI BST. The coverage of the TI with graphene is checked by Raman spectroscopy and SEM. A complete XPS study is then showed comparing uncovered TI with graphene-protected TI after air exposure. Our data show that graphene preserves the BST chemical bondings that are known to be highly affected by air exposure. ARPES measurements are further confirming the preservation of the TSSs of the TI after graphene passivation that is required in order to maximize its SOT efficiency [4]. The stack is then covered with a NiFe layer forming a BST/graphene/NiFe heterostructure. XPS is carried out on this sample showing that the graphene avoids intermixing between the TI and the FM that is known to be detrimental for SOT. We finally share our measurements of electrical transport including second harmonics measurements of BST/Gr/NiFe stacks that show strong spin-orbit torques estimated to be one order magnitude higher than Co/Pt reference stacks.

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Abstract ID: 320

PHONON CONFINEMENT AND SPIN-PHONON INTERACTION IN STRAINED THIN EuO FILMS

R. Pradip[1], P. Piekarz[2], D.G Merkel[3], J. Kalt[1], O. Waller[1], A.I. Chumakov[4], R. Rüffer[4], A.M. Oleś[5,6], K. Parlinski[2], T. Baumbach[1,7], S. Stankov[1,7]

[1]*Laboratory for Applications of Synchrotron Radiation, Karlsruhe Institute of Technology, 76131, Karlsruhe, GERMANY*
[2]*Institute of Nuclear Physics, Polish Academy of Sciences, 31342, Kraków, POLAND*
[3]*Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Hungarian Academy of Sciences, 1525, Budapest, HUNGARY*
[4]*ESRF-The European Synchrotron, 38000 Grenoble, FRANCE*
[5]*Marian Smoluchowski Institute of Physics, Jagiellonian University, 30348, Kraków, POLAND*
[6]*Max Planck Institute for Solid State Research, 70569, Stuttgart, GERMANY*
[7]*Institute for Photon Science and Synchrotron Radiation, Karlsruhe Institute of Technology, 76344, Eggenstein-Leopoldshafen, GERMANY*
E-mail: svetoslav.stankov@kit.edu

Magnetic oxides with strong electron correlations are often characterized with a remarkable coupling of the lattice, spin and charge with magnons, giving rise to a rich variety of phenomena and functionalities, which can be tailored in next-generation nanoscale devices [1]. Europium monoxide (EuO) is one of the rare ferromagnetic semiconductors known for its giant magneto-optic Kerr [2] and Faraday [3] effects, metal-insulator transition [4], anomalous Hall effect [5], and a model system for a Heisenberg ferromagnet. The large splitting of its conduction band in a ferromagnetic state ensures a full polarization of the charge carriers, which promoted this oxide to a testbed for fundamental research in the field of spintronics [6].

Employing inelastic X-ray scattering, nuclear inelastic scattering and first-principles theory, the lattice dynamics was determined unveiling another phenomenon in this extraordinary material, namely a giant and anisotropic spin-phonon interaction [7]. This imposed an intriguing question about the control of this phenomenon in thin films, relevant for the discussed spin-filter applications as well as for a fundamental research. Our results demonstrate a pronounced confinement in the lattice dynamics of thin EuO films along with a reduction of the spin-phonon coupling strength in tensile-strained epitaxial films [8].

S. S. acknowledges the financial support by the Helmholtz Association (VH-NG-625) and BMBF (05K16VK4). A. M. O. acknowledges support by Narodowe Centrum Nauki (NCN) under Project No. 2016/23/B/ST3/00839 and the Alexander von Humboldt Fellowship (Humboldt-Forschungspreis). P. P. acknowledges support by Narodowe Centrum Nauki (NCN, National Science Centre) under Project No. 2017/25/B/ST3/02586.

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Abstract ID: 421

ELECTRONIC STRUCTURE AND MAGNETIC PROPERTIES OF $FeRhSn_{1-x}Ge_x$ ALLOYS: Ab INITIO STUDY

O. Pavlukhina[1], V. Buchelnikov[1], V. Sokolovskiy[1,2], M. Zagrebin[1]

[1]*Chelyabinsk State University, 454001, Chelyabinsk, RUSSIA*
[2]*National University of Science and Technology 'MISiS', 119049, Moscow, RUSSIA*
E-mail: pavluhinaoo@mail.ru

Nowadays Heusler alloys attract more and more attention owing to the possibility of their application in superconductors, magnetic recording, and spintronic devices [1-3]. Among these, the half-Heisler compounds are of considerable interest for spintronics applications [2-3]. In this work the structural and magnetic properties of $FeRhSn_{1-x}Ge_x$ (x = 0, 0.25, 0.5, 0.75, 1) alloys are investigated by using the density functional theory calculations. The calculations have been carried out by using the 12-atom cell. The half-Heusler alloys crystallize in non-centrosymmetric cubic structure (space group *F-43m*). They can crystallize in three possible configurations, namely, a, β and γ phases. Our results suggest that $FeRhSn_{1-x}Ge_x$ compounds are most stable in γ phase. The equilibrium lattice parameters is found to be a = 5.79, 5.86, 5.94, 5.99 and 6.06 for $FeRhSn_{1-x}Ge_x$ (x = 0, 0.25, 0.5, 0.75, 1), respectively. Additionally, we calculate the total and partial densities of states for the $FeRhSn_{1-x}Ge_x$ alloys. We also estimate the spin polarization of alloys as follows: $P = (N\uparrow(E_F) - N\downarrow(E_F))/(N\uparrow(E_F) + N\downarrow(E_F))$, where $N\uparrow(E_F)$ and $N\downarrow(E_F)$ are the electron density states at the Fermi level (E_F) for the spin up and spin down states. We find that for $FeRhSn_{1-x}Ge_x$ (x = 0, 0.25, 0.5, 0.75, 1) the spin polarization is equal to 100% (Fig. 1). It is seen also that an addition of fourth element to the triple half Heusler alloy shifts the Fermi level in the spin down state. This gives us to increase the polarization of triple half-Heusler alloys by addition of fourth element.

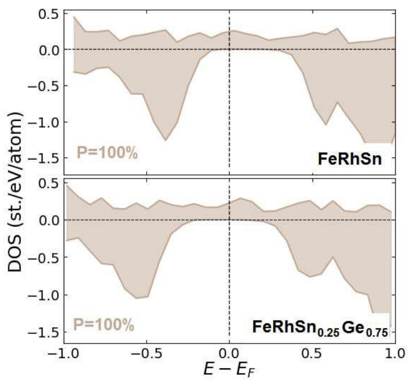

Fig. 1: *The total density of electronic states for the FeRhSn and $FeRhSn_{0.25}Ge_{0.75}$ alloys. Zero energy indicates the position of the Fermi level.*

This work was supported by RSF-Russian Science Foundation No. 22-12-20032.

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Abstract ID: 626

ROOM-TEMPERATURE ANOMALOUS INVERSE SPIN HALL EFFECT IN AN EASY-PLANE ANTIFERROMAGNETIC INSULATOR FOR NÉEL-VECTOR MANIPULATION AND DETECTION

Haijiao Harsan Ma

Xidian University, 710071, Shaanxi, CHINA
E-mail: harsanmhj@gmail.com

Metallic antiferromagnets are demonstrated to show an unconventional spin Hall effect (SHE) and the inverse spin Hall effect (ISHE), which are very promising for Néel-vector detection. However, the ISHE is absent in insulating antiferromagnets, as it does not conduct charge current. Here, we demonstrated the anomalous ISHE at the interface of the easy-plane insulator antiferromagnetic nickel oxide and the heavy metal platinum. We find that, at the interface of NiO/Pt, the ISHE generates an anomalous hysteretic transverse voltage in both Hall and planar Hall measurements, depending on spin-current propagation and the polarization direction. The observation of a nonzero transverse voltage in Pt indicates the appearance of a spin current with longitudinal polarization reflected from NiO, implying Néel-vector reorientation from the transverse to longitudinal direction. Our simulation indicates that the Néel vector can be reoriented by a spin current injected from the heavy metal and an applied magnetic field. The observed anomalous ISHE permits the manipulation and detection of the Néel order in insulating antiferromagnets.

Chiral Magnetism: Solitons and Skyrmions II-III

07.05.2023 SUNDAY

Abstract ID: 135

SPIN PARITY EFFECT IN MONOAXIAL CHIRAL FERROMAGNETIC CHAIN

Sohei Kodama[1], Akihiro Tanaka[2], Yusuke Kato[1]

[1]*The University of Tokyo, Department of Basic Science, 153-8902, Meguro, Tokyo, JAPAN*
[2]*International Center for Materials Nanoarchitectonics, National Institute for Materials Science,1-1 Namiki, Tsukuba, Ibaraki 305-0044, JAPAN*

E-mail: yusuke@phys.c.u-tokyo.ac.jp

We present a fully quantum mechanical account of a novel spin parity effect– physics which depend sharply on whether the spin quantum number S is half-odd integral or integral, which we find to be present in models of monoaxial chiral ferromagnetic spin chains. We begin by calculating the magnetization curve for finite-sized systems, where a magnetic field is applied perpendicular to the helical axis. For the half-odd integer S case, this curve features discontinuous jumps which are identified as a series of level crossings (see the left panels of the figure), each accompanied by a shift of the crystal momentum by an amount of π. In contrast to this, the corresponding curve for integer valued S is continuous and exhibit crossover processes (see the right panels of the figure). The crystal momentum for the latter case is zero throughout. The aspects just mentioned are observed numerically when the strength of the Dzyaloshinskii-Moriya interaction (DMI) *D* is comparable to or larger than that of the ferromagnetic exchange interaction *J*.

To unravel this phenomenon at the fully quantum mechanical as is appropriate to spin chains with a small S, we examine in detail the limiting case of a model consisting of only the DMI and the Zeeman energy (which we dub the "DH model"), which proves to be amenable to a rigorous analysis. While interesting in its own right, we show that the DH model can be used as a leverage to understand the situation at finite J as well. An interesting finding is made at S>1/2, where "quantum solitons" can come in various integer heights f, ranging from 1 to 2S. To accommodate this variety of solitons to its fullest extent into our theory, we modify the DH model in such a way that the set of integers N_f (f = 1,2,⋯ ,2S), the number of solitons of height f, are simultaneously conserved quantities. We then find that the lowest energy eigenstate within the Hilbert space labeled by (N_1,N_2,⋯ ,N_{2S}) has the crystal momentum k = πf N_f. We coin to this the name height parity effect. An inspection of finite sized calculations reveals that the essence of the magnetization process of the DH model (as well as the full model with a finite J) can be understood in terms of a height parity effect only involving solitons of maximal height f = 2S.

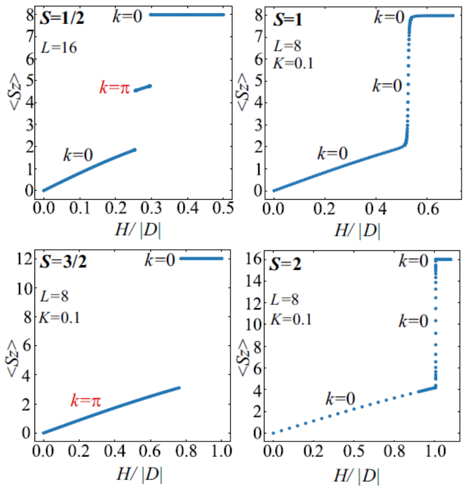

Fig. 1: *Magnetization curves of finite-sized chiral monoaxial ferromagnetic spin chain with J=D[1].*

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Abstract ID: 500

THEORETICAL APPROACH TO CHIRALITY-INDUCED SPIN SELECTIVITY

Jun-ichiro Kishine

The Open Univ. Japan, Chiba, JAPAN
E-mail: kishine@ouj.ac.jp

A remarkable feature of the Chirality-Induced Spin Selectivity (CISS) phenomenon is that it occurs at room temperature and in a non-magnetic state, as long as the molecule or crystal is chiral, as shown in previous experimental studies. Although the commonality and universality of the mechanism are not yet understood, the phenomenon has a broad multiscale nature, ranging from molecules to bulk crystals. The multiscale nature is not only true for the sample size but also for the coherence length of the polarization.

So far, spin-orbit coupling (SOC) has been regarded as the main factor linking the symmetry of a material to its spin polarization. However, the CISS is observed even in materials consisting only of light elements with weak SOC. Thus, the CISS phenomenon has four salient features: room temperature, non-magnetic, multiscale, and insensitivity to SOC strength. Theoretical views include “filter effects,” “polarization accumulation due to virtual magnetic fields (gauge fields in the broad sense),” “macroscopic magnetization response to current,” and “spin pumping,” but these are inconclusive. In this talk, I will attempt to summarize the current state of the research. We will also introduce our view that the coupling of electron and nuclear motion is the main cause of the CISS [1].

We will also touch upon the closely related issue of chiral phonons [2-4]. Then, I would like to return to the question "What is chirality?" (Without this clarification, we cannot even talk about CISS). To clarify this point, it is necessary to identify the chiral order parameter as the basis of the irreducible representation of the point group describing the symmetry of matter. To answer this question, we introduce the view [5] that a multipole basis called an electro-toroidal monopole plays a role as such an order parameter.

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Abstract ID: 604

SOLITON LOCKING PHENOMENON AND MAGNETIC RELAXATION IN MONO-AXIAL CHIRAL MAGNETS

M. Mito[1,2], M. Ohkuma[1], Y. Kousaka[2,3], J. Ohe[4], J. Akimitsu[2,5], K. Inoue[2,6,7]

[1]*Kyushu Institute of Technology, Grad. Sch. of Eng., 804-8550, Kitakyushu, JAPAN*
[2]*Hiroshima University, Chirality Research Center, 739-8526, Higashihiroshima, JAPAN*
[3]*Osaka Metropolitan University, Dep. of Phys. and Electro., 599-8531, Osaka, JAPAN*
[4]*Toho University, Dep. of Phys., 274-8510, Funabashi, JAPAN*
[5]*Okayama University, Res. Inst. for Interdisciplinary Sci., 700-8530, Okayama, JAPAN*
[6]*Hiroshima University, Grad. Sch. of Adv. Sci. and Eng., 739-8526, Higashihiroshima, JAPAN*
[7]*Hiroshima University, Inst. for Adv. Mater. Res., 739-8526, Higashihiroshima, JAPAN*
E-mail: mitoh@mns.kyutech.ac.jp

Monoaxial chiral magnets exhibit a chiral helimagnetic (HM) structure owing to the competition between the exchange interaction and antisymmetric Dzyaloshinskii–Moriya (D–M) interaction. In the presence of a magnetic field (*H*) perpendicular to the helical axis, the HM structure transforms to a chiral soliton lattice (CSL) state. When *H* is larger than the critical magnetic field, the forced ferromagnetic (FFM) state, where all magnetic moments aligned in the direction of *H*, is stabilized. The solions neither appear nor disappear in the crystal. The nucleation and annihilation of solitons were affected by the surface and shape of the crystals [1], and the physical properties exhibited discrete changes accompanying changes in the soliton number [1-4]. Avalanche soliton penetration is activated by acoustic wave [5]. In order to expand the soliton physics toward the electronic application, we must understand the motion of solitons in more detail.

Recently, we experimentally confirmed that solitons have velocity via the observation of magnetic relaxation in two prototype materials, $CrNb_3S_6$ and $MnNb_3S_6$ [6]. This phenomenon is theoretically understood via the micro-magnetic simulations. These results suggest that the velocity of soliton is related with the magnitude of D-M interaction.

However, by modifying the sequence of changing *H*, the number of solitons was not maintained even under the change in *H*. This soliton locking phenomenon was observed in both $CrNb_3S_6$ [1,7] and $MnNb_3S_6$ [8]. Thus, we can manipulate two states, nonequilibrium with the velocity of solitons and equilibrium without the velocity of solitons in one material.

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Abstract ID: 139

DARK DISCRETE BREATHER MODES IN A MONOAXIAL CHIRAL HELIMAGNET WITH EASY-PLANE ANISOTROPY

I.G. Bostrem[1], E.G. Ekomasov[2], J. Kishine[3], A.S. Ovchinnikov[1], Vl.E. Sinitsyn[1]

[1]Institute of Natural Science and Mathematics, Ural Federal University, Ekaterinburg, 620002, RUSSIA
[2]Bashkir State University, Institute of Physics and Technology, Ufa 450076, RUSSIA
[3]Division of Natural and Environmental Sciences, The Open University of Japan, Chiba, 261-8586, JAPAN
E-mail: alexander.ovchinnikov@urfu.ru

Nonlinearity and discreteness are two pivotal factors for an emergence of discrete breather excitations in various media. We argue that these requirements are met in the forced ferromagnetic phase of the monoaxial chiral helimagnet $CrNb_3S_6$ due to the specific domain structure of the compound [1]. The stationary, time-periodic breather modes appear as the discrete breather lattice solutions whose period mismatches with a system size. Thanks to easy-plane single-ion anisotropy intrinsic to $CrNb_3S_6$, these modes are of the dark type with frequencies lying within the linear spin-wave band, close to its bottom edge. They represent cnoidal states of magnetization, similar to the well-known soliton lattice ground state, with differing but limited number of embedded 2π kinks (Fig. 1).

The linear stability of these dark breather modes is verified by means of Floquet analysis. Their energy, which is controlled by two parameters, namely, the breather lattice period and amplitude, falls off linearly with a growth of the kink number. These results may pave a path to design spintronic resonators on the base of chiral helimagnets.

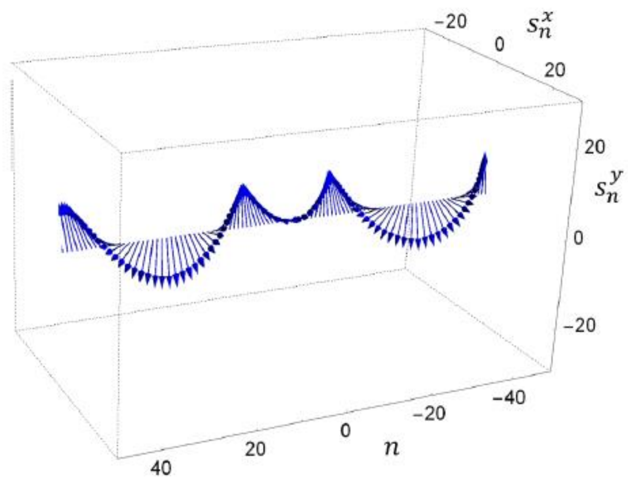

Fig. 1: *The dark discrete breather mode near the bottom edge of the spin-wave band.*

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Abstract ID: 143

EFFECT OF MAGNITUDE AND SIGN OF THE DZYALOSHINSKII-MORIYA INTERACTION ON MAGNETIC STRUCTURE IN HELIMAGNETS $Fe_{1-x}Co_xSi$ and $Fe_{1-x}Co_xGe$

Sergey V. Grigoriev, Oleg I. Utesov

PNPI - NRC KI (Petersburg Nuclear Physics Institute of NRC Kurchatov Institute), RUSSIA
E-mail: grigor@lns.pnpi.spb.ru

Solid solutions of helimagnetic compounds $Fe_{1-x}Co_xGe$ and $Fe_{1-x}Co_xSi$ demonstrate the switching of the sign of magnetic chirality depending on the concentration x. Chirality switching is accompanied by the transformation of the helical structure into a ferromagnetic one at $x_c = 0.60$ for $Fe_{1-x}Co_xGe$ and at $x_c = 0.65$ for $Fe_{1-x}Co_xSi$. The magnetic structure of compounds for iron-rich compounds ($x < x_c$) is described by the Back-Jensen model in which the hierarchy of interactions is strictly holds - exchange (ferromagnetic) J, the second small Dzyaloshinskiy-Moriya (DM) interaction D and a very small cubic anisotropy and anisotropic exchange. In this case, the wave vector $k_s = D/J$ weakly depends on temperature, thus demonstrating that J and D practically do not depend on temperature.

At $x = x_c$, the DM interaction tends to zero due to the different signs for such compounds with Fe and Co. It turned out that cubic anisotropy prevails over the DM interaction and stimulates formation of a ferromagnetic structure. Moreover, the transformation (helimagnet - ferromagnet) for the compound c $x = x_c$ occurs depending on the temperature: the high-temperature phase below the ordering temperature T_c is helimagnetic with the wave vector k_s decreasing with decreasing temperature proportionally to T and abruptly vanishing at a certain temperature T_f.

At concentrations with $x > x_c$, the DM interaction of a different sign (compared to $x < x_c$) restores the helicoidal structure. However, firstly, the cubic anisotropy turns out to be of the same order as the magnitude of the DM interaction, and, secondly, the helix wave vector now strongly increases with decreasing temperature, as if the cubic anisotropy contributed to the appearance of a helicoidal structure, enhancing the DM interaction. Taking into account the fact that CoGe and CoSi compounds are nonmagnetic insulators, we have constructed a percolation model of a ferromagnet based on iron atoms, whose state perturbs the DM interaction, which is determined mainly by cobalt atoms, which are nonmagnetic.

Abstract ID: 418

CHIRAL MAGNETS STUDIED BY SMALL-ANGLE NEUTRON SCATTERING AND MUON SPIN ROTATION

K. Ohishi[1], Y. Kousaka[2], M. Pardo-Sainz[2,3], J. Campo[3], V. Laliena[4], M. Ohkuma[5], M. Mito[5], Y. Cai[6,7], K. M. Kojima[6,7]

[1]Neutron Science and Technology Center, Comprehensive Research Organization for Science and Society (CROSS), 319-1106, Tokai, JAPAN
[2]Graduate School of Engineering, Osaka Metropolitan University, 599-8531, Sakai, JAPAN
[3]Spanish National Research Council (CSIC), 50009, Zaragoza, SPAIN
[4]University of Zaragoza, 50009, Zaragoza, SPAIN
[5]Kyushu Institute of Technology, Zip, City, JAPAN
[6]TRIUMF, V6T 2A3, Vancouver, CANADA
[7]University of British Columbia, V6T 1Z4, Vancouver, CANADA
E-mail: k_ohishi@cross.or.jp

A violation of space-inversion symmetry entails a Dzyaloshinskii-Moriya interaction originating from the spin-orbit interaction, which stabilizes a chiral helimagnetic spin alignment. The chiral helimagnetic structures, forming only one-handed screw magnetic structures, have attracted attention because of the emergence of unique topological magnetic textures such as magnetic skyrmion lattices (SkL) [1] and chiral magnetic soliton lattices [2].

Recently, we suggested theoretically, that at low T the conical (CH) and forced-ferromagnetic (FFM) phases in cubic helimagnets, are not connected but are separated by another SkL, which could be metastable, and a new phase of unknown nature (*B-phase*) just below the critical field H_c at low T [3]. The theoretical prediction of the new SkL phase at low T is in good agreement with the experiments reported in ref [4,5]. On the other hand, by using careful ac susceptibility measurements at low temperature, we determined the magnetic phase diagrams of oriented crystals of MnSi [6]. It is consistent with the theoretical prediction for the new unknown low temperature phase.

To clarify the nature of this new phase at low T near critical field, we performed small-angle neutron scattering (SANS) measurements at TAIKAN in J-PARC [7] and muon spin rotation (μSR) measurements at M15 in TRIUMF. From SANS measurements, at both 0.3 T (CH phase) and 0.5 T (*B-phase*), the SANS patterns show two peaks along the horizontal axis for $H \perp$ in coming neutron beam wave vector $\boldsymbol{k}_i$. These are the magnetic Bragg peaks of the conical state. On the other hand, no diffraction peaks were observed for H // $\boldsymbol{k}_i$, in which, for example, a six-fold-symmetric diffraction pattern due to a formation of SkL is observed in *A*-phase (SkL). These results suggest the CH phase exists in *B-phase* and *B-phase* is different from *A*-phase near T_c. According to the μSR results, we found the internal magnetic field distribution in *B-phase* is apparently different from that in CH and FFM phases, consistent with the SANS results.

In the presentation, we will talk about the results of both SANS and μSR in detail and the pressure effect on other chiral magnets.

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Cryogenics Materials, Engineering and Applications I-II

07.05.2023 SUNDAY

Abstract ID: 350

HYDROGEN CRYO-ELECTROMAGNETICS TURNING POINT FOR APPLIED SUPERCONDUCTIVITY

B.A. Glowacki[1,2]

[1]*Department of Materials Science and Metallurgy, University of Cambridge, Cambridge CB3 0FS, ENGLAND*
[2]*Institute of Power Engineering, 01-330 Warsaw, POLAND*
E-mail: bag10@cam.ac.uk

Dramatic raising prises of liquid helium over the years (as it was predicted in earlier work [1]) are slowing down research often pushing many research labs away from R&D on superconductivity. Rapidly developing world-wide technologies of hydrogen generation, storage and use for future sustainable "ZERO CO_2" market, present an important and timely opportunities for Applied Superconductivity and Hydrogen Cryo-electromagnetics R&D where superconductor materials engineering and cryogenic technologies for direct and indirect cooling of superconducting devices, should path the way to provide the required sustain future energy and cryogenic-superconductor infrastructure under heading of liquid hydrogen – electromagnetics [2,3]. Article will analyse such a symbiotic approach where superconductivity applications can be interlocked with hydrogen economy it would be the solution to most of our energy storage, transmission, and transport problems as well revitalise research labs R&D on superconductivity.

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Abstract ID: 395

HTS DEVICES AND CRYOGENICS FOR ELECTRIC AIRCRAFT AND SHIPS

Sastry Pamidi

FAMU-FSU College of Engineering and Center for Advanced Power Systems
Tallahassee, Florida, UNITED STATES OF AMERICA
E-mail: pamidi@caps.fsu.edu

High Temperature Superconducting (HTS) power systems are being developed for a variety of applications including the electrical power grid, industrial applications, data centers, high energy physics, electric ships, and electric aircraft. There are some common requirements and design features for HTS devices for all the applications. However, the design requirements for electric transportation applications such as electric aircraft and electric ships need high gravimetric and volumetric power densities. The power density demands require that the HTS generators and motors in electric transportation applications operate at temperature between 20 and 50 K to compensate for the reduction in critical current density and AC losses under the substantial magnetic fields present in the rotating machines. HTS power distribution cables support high enough current densities when operated at higher temperatures of 40 - 60 K. The primary challenge with power cables that carry multiple kA are the cable terminations, current leads, and cryogenic interfaces. Innovative designs are needed to address the challenges of dielectric and cryogenic thermal design. We at the Center for Advanced Power Systems (CAPS) are collaborating with other academic institutions and several small businesses to address the challenges of AC losses in HTS rotating machines and making the interfaces (terminations) for HTS cable systems compact. We have ongoing work on cryogenic dielectrics and cooling systems for HTS applications for electric transportation applications. The Presentation will focus on the ongoing research and recent collaborative accomplishments in these areas. Collaborative efforts include superconducting technologies and cryogenics for zero emission electric aircraft.

Acknowledgement: Our research is funded by the Office of Naval Research, Department of Energy, and the National Aeronautics and Space Administration.

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Abstract ID: 493

A METHOD OF HIGH COOLING CAPACITY AT 4 K OF A GIFFORD-MCMAHON CRYOCOOLER WITH LOW ELECTRICAL INPUT

S. Masuyama[1], K. Kamiya[2], T. Numazawa[2]

[1]National Institute of Technology, Oshima College, Dept. of Electronic-Mechanical Eng., 742-2193, Suo-oshima, Yamaguchi, JAPAN
[2]National Institute for Materials Science, Liquid Hydrogen Materials Research Center, 305-0003, Tsukuba, Ibaraki, JAPAN
E-mail: masuyama@oshima-k.ac.jp

Gifford-McMahon (G-M) cryocoolers have been widely used for advanced applications. While the G-M cryocoolers can easily obtain temperatures of 4 K level, they require much electrical input to maintain 4 K. Electrical input of a conventional 1 W class 4 K G-M cryocooler is about 7 kW. A compressor, which connects to a G-M cold head (expansion space and regenerator) via two flexible hoses, consumes most of the electric power. The aim of this study is to reduce the electrical input, and prevent a decrease in cooling capacity at 4 K for G-M cryocooler. We prepared a 2 kW class compressor (SA115, ULVAC Cryogenics), and three types of two stage G-M cold heads (Sumitomo Heavy Industries, Ltd). Each cold head is called "S (0.44)", "M (1.0)", and "L (1.2)" from a difference in the cylinder volume (the parentheses show the second cylinder volume ratio based on M size). Three kinds of materials, Pb (lead), $HoCu_2$, and Gd_2O_2S spheres, were filled in three layers in the second stage regenerator by authors. Figure 1 shows the experimental results of the displacer reciprocating speed dependence on the cooling capacity at 4.2 K. A general reciprocating speed of 4 K G-M cryocoolers is 60 or 72 rpm. From Fig. 1, a decreasing the reciprocating speed is an effective method to obtain a high cooling capacity by using a low electrical input compressor. The L size cold head produced the highest cooling capacity in three cold heads. Its maximum value was 0.95 W at 36 rpm with an electrical input of 1.9 kW. The relative Carnot efficiency achieved 3.5%.

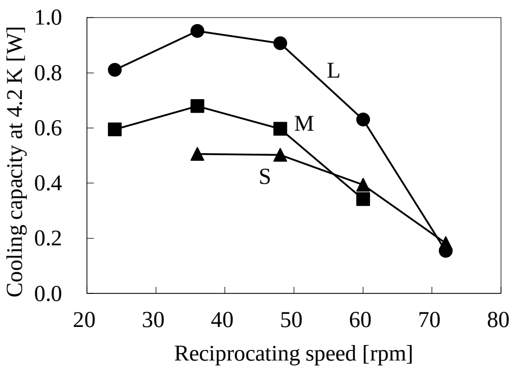

Fig. 1: *Cooling capacity results of three types of cold heads by 2 kW compressor.*

Acknowledgments

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Abstract ID: 96

DEVELOPMENT OF SUPERCONDUCTING LEVEL SENSORS FOR LIQUID HYDROGEN WITH MgB_2 WIRES

K. Kajikawa

Sanyo-Onoda City University, Dept. of Electrical Engineering, 756-0884, Yamaguchi, JAPAN
E-mail: kajikawa@rs.socu.ac.jp

We have developed two types of superconducting (SC) level sensors for liquid hydrogen with magnesium diboride (MgB_2) wires so far [1,2]. One has a conventional structure, in which the SC wire is vertically placed inside a cryostat and the terminal voltage determined by a part of wire length surrounded by the evaporated gas is observed for an optimum operating current as shown in Fig. 1(a) [1]. The other is composed of the SC wire A and a non-SC wire B, which are located in parallel and electrically connected in series with each other as shown in Fig. 1(b) [2]. When an optimum current is applied to these wires, both parts of the wires in the gas could produce voltage signals similar to each other. On the other hand, a part of the non-SC wire B in the liquid also has a voltage drop unlike the case of the SC wire A. Therefore, a difference voltage between both terminal voltages in the wires gives us to obtain the voltage signal dominated by the length of the non-SC wire B in the liquid. The experimental results with liquid hydrogen for both types of level sensors fabricated using MgB_2 wires [1,2] are presented as well as the theoretical consideration on their output errors [3].

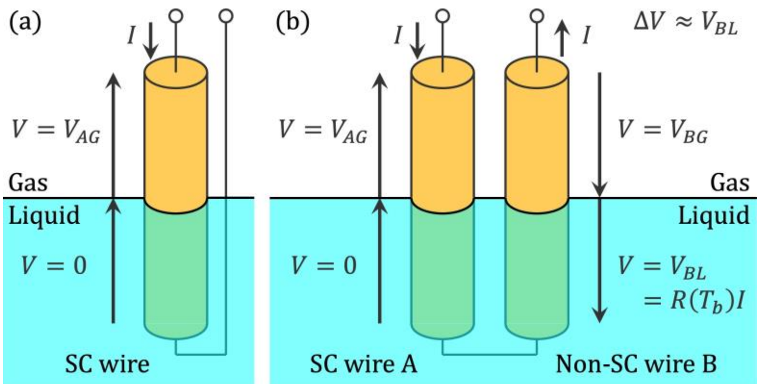

Fig. 1: *Basic structures of (a) conventional and (b) parallel types of SC level sensors.*

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Abstract ID: 240

CURRENT SENSORS AT CRYOGENIC TEMPERATURES

M. Meindl[1], Bastian Westermann[1], Florian Bayer[2], Florian Hilpert[2], Julius Zettelmeier[1], Martin Maerz[1]

[1]*Friedrich-Alexander-Universität Erlangen-Nürnberg, Institute of Power Electronics, 90429, Nuermberg, GERMANY*
[2]*Fraunhofer Institute for Integrated Systems and Device Technology IISB, Power Electronics Division, 91058, Erlangen, GERMANY*
E-mail: markusmeindl@icloud.com

This work aims to investigate current sensors in a cryogenic environment. The sensors are selected based on different measurement principles. First, the behaviours of the sensor at room temperature is investigated. In the next steps, the sensors are immersed in a Dewar container filled with liquid nitrogen (Fig.1, left) in a cryogenic temperature environment, and the measurements are performed again. Findings about function, deviation due to the temperature change and possible failures are documented. In Fig.1 (right), the recommended sensor at room temperature (T_R = 23°C) and cryogenic temperature (T_C = -196°C) is plotted in a diagram. This diagram shows no deviation, and the sensor works well at cryogenic temperatures. With the help of literature research [1-32], theoretical approaches to explaining the causes are developed and discussed. Finally, the results of the sensors are compared with each other in TABLE. Based on the percentage deviations, the flux-gate sensor DRV425 from Texas Instruments is recommended for the future use of these technologies in the cryogenic environment. In addition to the findings on the technologies, this study also lists problems that still need to be investigated.

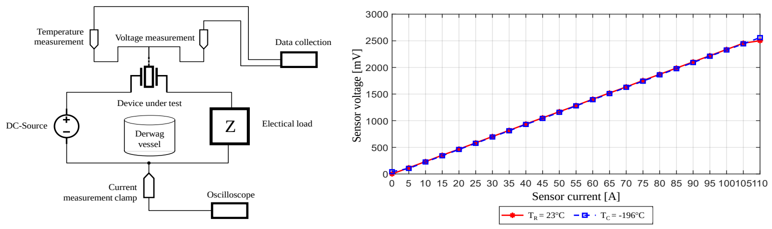

Fig.1: *Experimental set-up (left), measurement DRV 425 at room and cryogenic temperature (right).*

TABLE-I. *Summary and comparison of measurement results.*

Technology	Precision resistance	Magneto resistive resistance	Hall effect core-les	Hall effect cored	Flux-Gate	Rogowski-coil
Sensor	Isabellenhütte BAX-M-L020-01	Sensitec CSF 1000	Allegro ACS37612	LEM HC6F600-S	Texas Instruments DRV425	Theoretical consideration
Measured current	DC-/AC currents	DC-/AC currents	DC-/AC currents	DC-/AC currents	DC-/AC currents	AC-currents
Function at cryogenic temperature	Yes - with deviation	Yes - with deviation	No	Yes - with deviation	Yes - with deviation	Yes - with deviation
Average deviation of cryogenic to the room temp. measurement	-10,08 %	-1,27%	T_C = -196°C → 89,94% T_C = -70°C → -0,18%	17,60 %	-1,30 %	Approx. 2,0 %
Reason for deviation	Temperature-dependent resistance change	- Temperature-dependent resistance change - Manufacturing tolerances of magneto resistive resistance	Electron mobility increases with decreasing temperature		Change in permeability of the core under low temperatures	Changing the geometry parameters and parameters of the substitute elements

Abstract ID: 617

A SINGLE STAGE PULSE TUBE CRYOCOOLER PROTOTYPE

Yunus Koç[1,2], Elvan Coskun[2], Yusuf Oznal[2], Kıvılcım Sonmez[2], Fatıma Almokdat[1], Sukru Celik[5], Serap Safran[1,2], Yasuharu Kamioka[2,3], Shinji Masuyama[2,4], Ali Gencer[1,2]

1 Ankara University, Faculty of Sciences, Physics Department, 06100-Tandogan-Ankara, TÜRKİYE
2 Ankara University, Center of Excellence for Superconductivity Research, 50th Year Campus, 06830-Golbasi-Ankara, TÜRKİYE
3 ColdTech Associates, 6-5, Takanodai, Kodaira,187-0024 Tokyo, JAPAN
4 Electronic-Mechanical Engineering Department, National Institute Technology, Oshima College, JAPAN
5 Sinop University, Department of Energy Systems Engineering, Faculty of Engineering and Architecture, Sinop, TÜRKİYE

E-mail: Ali.Gencer@science.ankara.edu.tr

Pulse tube cryocoolers (PTCs) are based on the theory of oscillatory compression and expansion of an ideal gas within a closed volume to achieve the desired cooling. A case study with design and construction was carried out within the scope of a training school with graduate students and post doctoral researchers to develop a prototype pulse tube cryocooler with a single stage, that operates with 16 bar He gas pressure. It is a system desined with 4 solenoid valves that provide phase shift between gas pressure and gas displacement. In order to increase the gas contact surface in the regenerator, approximately 2000 stainless steel meshes with a multiplier of 300 mesh were used. The PTC consists of a pulse tube placed in a vacuum jacket and connected to each other by copper tubing, and a regenerator filled with stainless steel meshes. In addition, various needle valves are used to bypass He Exchange gas. In this way, the shifts in the gas transition phase could be adjusted more easily. A Programmable Logic Controls (PLC) is used to make solenoid valves with 1 ms precision. While the solenoid valves have A=180ms B=210ms C=230ms D=170ms open times, the conditions of the other needle valves have been changed and a temperature drop up to 53K has been observed. The produced pulse tube is a single stage and has a regenerator and a pulse tube (Fig 1). Regarding the strength of the surface heat pumping effect; k: thermal conductivity, ω: cyclic frequency, ϱ: density and c_p: specific heat at constant pressure, δ: thermal penetration depth is given by

$$\delta=\sqrt{\frac{2\cdot k}{\omega\cdot\rho\cdot c_p}}$$

This system is stabilized at 68 K under a heat load of ~1.36 W when operated under vacuum (<E-5 hPa). Accordingly, the cooling power of the system was found to be 1.36W, and the cooling power of the system was measured as 1.36 W@68 K, ignoring other possible heat losses.

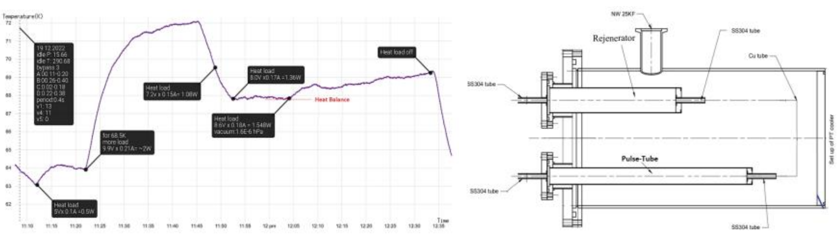

Fig. 1: *Pulse Tube Cryocooler System Diagram and Temperature(K)-Time(min) results and Vacuum Can with Pulse Tube and Regenerator Part.*

In Figure 1, the time-dependent variation of the temperature in the middle of the pulse tube and regenerator at the time of power-on of the Pulse Tube Cooler is given (on the left). In the right image in Figure 1, only the vacuum jacket, pulse tube and regenerator part of the system are shown.

Miscellaneous Topics

07.05.2023 SUNDAY

Abstract ID: 234

ORIENTATION DUALISM OF THE PINNING STUDIED FROM THE CRITICAL CURRENT ANGULAR DEPENDENCES OF YBCO TAPES

V.V. Guryev, S.N. Nikolayev, I.V. Kulikiv, S.V. Shavkin

NRC Kurchatov institute, 123182, Moscow, RUSSIA

E-mail: GuryevVV@mail.ru

In this work, samples of HTS tapes based on $YBa_2Cu_3O_7$ (YBCO) with Y_2O_3 nanoparticles fabricated by the PLD method were studied. The transport method was used to measure the angular dependences of the critical current $I_c(\theta)$ and the upper critical field $H_{c2}(\theta)$. It was found that both angular dependencies do not obey the effective mass anisotropy scaling, also known as Blatter scaling approach [1]. Moreover, in fields up to 0.3 T (77.4 K), a significant inequality of the critical current depending on the direction of the Lorentz force (determined by the transport current) was found for a fixed applied field that declined from the normal direction. This fact is apparently difficult to interpret when analyzing angle dependencies in terms of the maximum entropy approach [2]. On the other hand, the recently proposed approach for the angular dependences analysis based on the anisotropic pinning model (APM) [3] takes into account the orientation dualism of the pinning: anisotropy not only with respect to the direction of the magnetic field, but also with respect to the direction of the Lorentz force. Thus, the model makes it possible to take into account observed features. In addition, the modification of the APM approach enables to describe correctly the asymmetry of the angular dependences of the critical current, which was also observed at some samples. Possible physical reasons for such a modification are discussed.

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Abstract ID: 568

DURABILITY TEST OF PARYLENE C/POLYURETHANE BASED FLEXIBLE CAPACITIVE PRESSURE SENSOR

S. Kurnaz[1], O. Ozturk[2], U. Guduloglu[2], O. Cicek[2], N. Yılmaz[3]

[1]*Kastamonu University, Central Research Laboratory, 37150, Kastamonu, TURKEY*
[2]*Kastamonu University, Dept. of Electrical&Electronics Engineering, 37150, Kastamonu, TURKEY*
[3]*Kastamonu University, Dept. of Mathematics and Science Education, 37150, Kastamonu, TURKEY*
E-mail: sedatkurnaz@kastamonu.edu.tr

Flexible pressure sensors, which combine the unique advantages of conformability, high sensitivity, and cost efficiency, have emerged as a promising solution for applications in wearable healthcare, artificial intelligence systems, and internet of things (IoT) [1]. We present the results of the study of capacitive properties of Parylene C/Polyurethane (1:1) based flexible pressure sensor. We demonstrate the durability test for 100 cycles under 1.39 kPa (Fig. 1a). The results reveal that the sensor provides a stable response under repetitive loading and unloading 100 cycles. Fig. 1b shows the hysteresis depending on the number of cycles. As shown in Fig. 1a, the hysteresis is 2.32%.

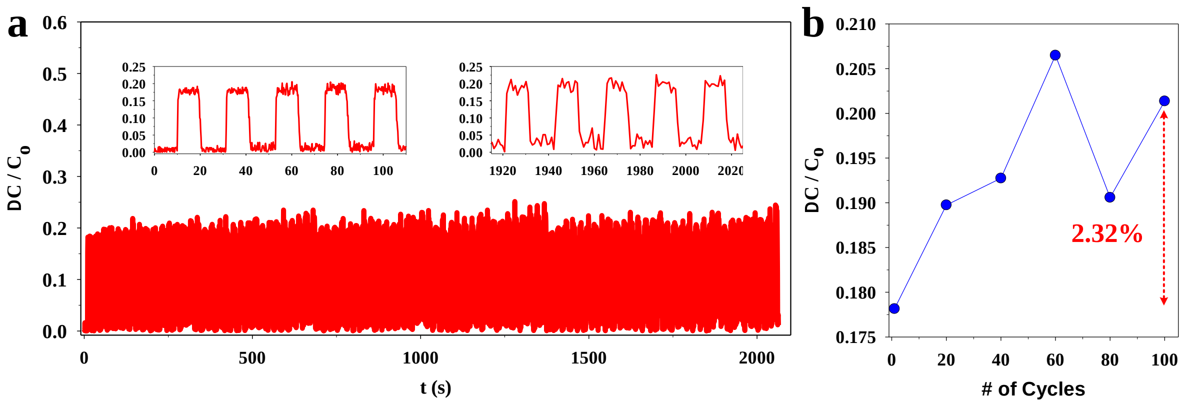

Fig. 1: *Pressure sensing performance of PAC based capacitive pressure sensors. (a) Durability test for 100 cycles under 1.39 kPa. (b) hysteresis depending on number of cycles.*

This work was supported by The Scientific and Technological Research Council of Turkey (TÜBİTAK-120M636).

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Abstract ID: 569

PRESSURE SENSING PROPERTIES OF PARYLENE C/POLYURETHANE BASED PIEZORESISTIVE PRESSURE SENSOR

O. Ozturk[1], S. Kurnaz[2], M.A. Hazar[1], A. Bekar[3], N. Yılmaz[4], O. Cicek[1]

[1]*Kastamonu University, Dept. of Electrical&Electronics Engineering, 37150, Kastamonu, TURKEY*
[2]*Kastamonu University, Central Research Laboratory, 37150, Kastamonu, TURKEY*
[3]*Sinop University, Ayancık Vocational School of Electronic and Automation, 57400, Sinop, TURKEY*
[4]*Kastamonu University, Dept. of Mathematics and Science Education, 37150, Kastamonu, TURKEY*
E-mail: oozturk@kastamonu.edu.tr

With the rapid development of society and science and technology, the demand for intelligent robots is increasing daily, which has increased attention to flexible pressure sensor [1]. Parylene-C is a potential piezoelectric material that its piezoelectric properties were discovered for the first time in 2011 [2]. To investigate changes to the resistance of the sensor according to applied pressure which are swept from 0.07 kPa to 34.72 kPa. The sensitivity is calculated as 0.071 kPa^{-1} for the pressure ranges of 0.07-1.39 kPa as show in Fig. 1a. To quantify the response and relaxation times, the time-resolved response for all cycles are analyzed that the average response time and relaxation time of the sensor are 0.54 s and 0.59 s, respectively (Fig.1b).

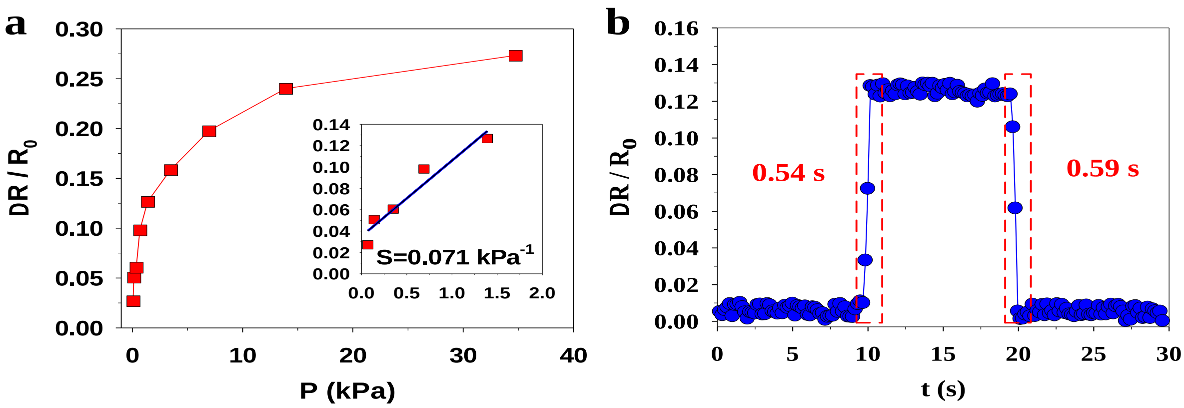

Fig. 1: *Pressure sensing performance of PAC based piezoresistance pressure sensor (a) change in the resistance as a function of applied pressure (inset displays a relative resistance change that the sensitivity is 0.071 kPa^{-1} under the pressure of 0-4 kPa), (b) step responses for one loading and unloading cycle. The graph shows an average response time and relaxation time.*

This work was supported by The Scientific and Technological Research Council of Turkey (TUBITAK-120M636).

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Abstract ID: 588

THE EFFECT OF POST-GROWTH THERMAL TREATMENT OF BULK YBCO SUPERCONDUCTOR ON THE PINNING MECHANISM

B. Çakır[1], Ş. Duman[1], A. Aydıner[2]

[1] *Vocational School of Health Services, Artvin Çoruh University, Artvin 08000, TURKEY*
[2] *Department of Physics, Faculty of Sciences, Karadeniz Technical University, Trabzon 61080, TURKEY*
E-mail: cakirbakiye@hotmail.com

Bulk Y123 sample was produced by the top-seeding method by using a Nd123 seed crystal in Y123 + 30 wt.% Y211 composition. The sample was cut horizontally into two equal part after the oxygenation process. A part of the sample was heated a temperature just below the melting temperature and held at that temperature for 30 minutes. Small slices were cut from each part of the sample. The superconducting transition temperature (T_c) value determined from the resistivity measurements is around 92 K. The critical current density (J_c) was calculated from the magnetization hysteresis loops based on the extended Bean model and the calculated J_c values are 12.08 and 21.13 kA/cm^2 at 77 K in 0 T for the bulk and re-heated bulk sample, respectively. Flux pinning mechanism in the specimens taking from the YBCO superconductor were analyzed and discussed in detail.

Acknowledgments

This study was supported by Office of Scientific Research Projects of Artvin Çoruh University (Project number: 2018.F83.02.04).

Abstract ID: 590

RECENT IMPROVEMENTS IN THE FABRICATION AND MEASUREMENT APPLICATIONS OF YBCO BULK SUPERCONDUCTORS

S.B. Guner[1,5,6], M. Abdioglu[2,5], K. Ozturk[3,5], S. Celik[4,5]

[1] *Department of Physics, Faculty of Arts and Sciences, Recep Tayyip Erdogan University, 53100 Rize, TURKEY*
[2] *Department of Mathematics and Science Education, Faculty of Education, Bayburt University, 69000 Bayburt, TURKEY*
[3] *Department of Physics, Faculty of Arts and Sciences, Karadeniz Technical University, 61080, Trabzon, TURKEY*
[4] *Department of Energy Systems, Faculty of Engineering and Architecture, Sinop University, 57000, Sinop, TURKEY*
[5] *Ankara University, Center of Excellence for Superconductivity Research, 06500, Golbasi, Ankara, TURKEY*
[6] *The Center for Radiation Detector Research and Applications (NRDC), Abant İzzet Baysal Üniversitesi, Bolu, 14280, TURKEY*

E-mail: sbarisguner@gmail.com

The over the last 20 years, significant progress in processing of bulk (RE)BCO superconductors in the form of large single and or controlled multi-seeded samples has been made. A world record of 17.6 T trapped field has been achieved (Cambridge) [1], and a 127 mm diameter (RE)BCO single grain had been fabricated in Japan [2]. One of the most useful (RE)BCO superconductors is YBCO. Superconducting crystal samples, have high levitation force and high trapped magnetic field, are used in many applications such as magnetic bearing, flywheel, motor, generator, high magnetic field permanent magnets and conveying systems [3-6]. In this work, we discuss recent developments in the processing of these materials that enable high performances bulk superconductors to be fabricated by TSMG and buffered-TSMG methods. These include the the development of magnetic levitation and trapped field of samples, the development of practical, batch processing routes for the fabrication of light rare earth superconductors, the processing of complex shaped geometries via controlled multi-seeding with various orientations of scrap bulk samples into high performance, single grains. The complementary research work done across other worldwide research groups will be discussed.

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Quantum Information Technology

07.05.2023 SUNDAY

Abstract ID: 586

FAST MULTI-OSCILLATOR CONTROL WITH A SINGLE QUBIT

Asaf A. Diringer[1], Eliya Blumenthal[1], Avishay Grinberg[1], Liang Jiang[2], Shay Hacohen-Gourgy[1]

[1]*Department of Physics, Technion- Israel Institute of Technology, Haifa 32000, ISRAEL*
[2]*Pritzker School of Molecular Engineering, University of Chicago, Chicago, Illinois 60637, USA*
E-mail: shayhh@gmail.com

Bosonic encoding is an approach for quantum information processing, promising higher resiliency to noise and affording error correction and mitigation at the hardware level. Scaling to multiple modes requires weak interaction for independent control, yet strong interaction for fast control. We show that universal control of multiple modes can be obtained with displacements of the different modes conditioned only on a single qubit ancilla. We develop the conditional not displacement control method which enables fast generation and control of bosonic states in multi-mode systems weakly coupled to a single ancilla qubit. We create entangled and separable cat-states in various modes of the multi-mode cavity at a rate almost two orders of magnitude faster than the standard method [1]. Our scheme allows for fast and efficient multi-mode bosonic encoding and measurement.

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Abstract ID: 589

ELECTRICALLY CONTROLLED CROSSED ANDREEV REFLECTION IN TWO-DIMENSIONAL ANTIFERROMAGNETS

Alireza Qaiumzadeh

Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, NO-7491 Trondheim, NORWAY

E-mail: a.qaiumzadeh@gmail.com

We report generic and tunable crossed Andreev reflection (CAR) in a superconductor sandwiched between two antiferromagnetic layers. We consider recent examples of two-dimensional magnets with hexagonal lattices, where gate voltages control the carrier type and density, and predict a robust signature of perfect CAR in the nonlocal differential conductance with one electron-doped and one hole-doped antiferromagnetic lead. The magnetic field-free and spin-degenerate CAR signal is electrically controlled and visible over a large voltage range, showing promise for solid-state quantum entanglement applications [1].

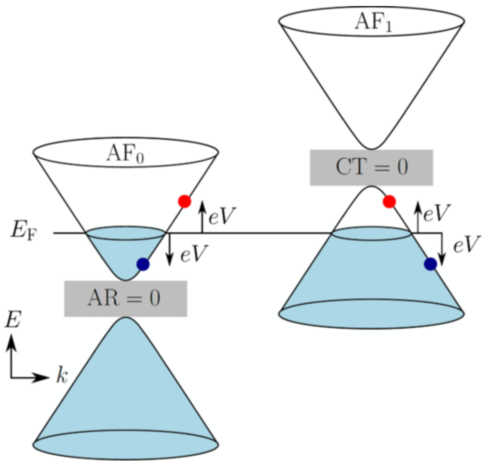

Fig. 1: *The relativistic dispersions of itinerant electrons in 2D antiferromagnetic hexagonal lattices in the leads AF 0 and AF 1 are shown to the left and right, respectively. Electrons (holes) are denoted by red (blue) circles. It is possible to block both AR and CT signals to favor CAR signals by tuning the local Fermi energy close to the gap induced by the antiferromagnetic exchange interaction (gray region).*

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Abstract ID: 610

DARK CURRENT AND DARK COUNT RATE DEPENDENCE ON ANODE GEOMETRY OF InGaAs/InP SINGLE-PHOTON AVALANCHE DIODES

R.O.E. Scowen[1,2], D.J.P. Ellis[1,2], B. Ramsay[2], R.M. Stevenson[1], J.I. Davies[3], D.A. Ritchie[2], A.J. Shields[1]

[1]Toshiba Research Europe Ltd, 208 Cambridge Science Park, Cambridge, UK
[2]Department of Physics, University of Cambridge, Cambridge, UK
[3]IQE plc, Pascal Close, Cardiff, UK
E-mail: roes2@cam.ac.uk

Single-photon detector technology in the short-wave infrared is important for many applications, including quantum communication and imaging. Here, we investigate the influence of physical dimensions of the diffused regions of InGaAs/InP single-photon avalanche diodes (SPADs) on the experimental characteristics used to quantify performance, namely the dark count rate (DCR) of the detector. We show that while the measured dark current increases with the width of the shallow anode shoulder, the DCR decreases. These results indicate that anode geometry is a more appropriate indicator of DCR performance than dark current. For optimum geometries, DCRs of ~1×10-6/ns are observed for SPADs cooled to a TEC-accessible temperature of 243K.

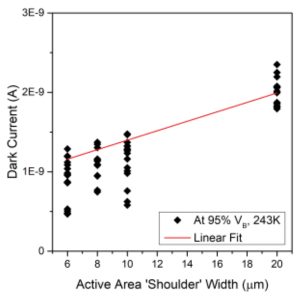

Fig. 1: *Active area 'shoulder' width, defined as the difference between the two diffusion diameters, plotted versus dark current measured at 95% of breakdown voltage at 243K. A linear fit has been calculated (red line).*

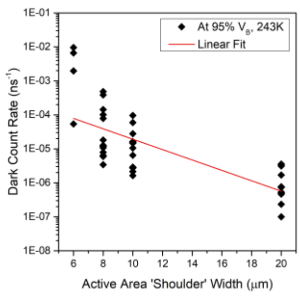

Fig. 2: *Active area 'shoulder' width, defined as the difference between the two diffusion diameters, plotted versus dark count rate measured when the applied bias corresponds to 95% of breakdown voltage at 243K. A linear fit has been calculated (red line).*

Abstract ID: 631

WHAT CAN I DO WITH A NOISY QUANTUM COMPUTER?

Abhinav Kandala

IBM Quantum, 10598, Yorktown Heights, USA
E-mail: akandala@us.ibm.com

Quantum computers can offer dramatic speed-ups over their classical counterparts for certain problems. However, noise remains the biggest impediment to realizing the full potential of quantum computing. While the theory of quantum error correction offers a solution to his challenge, a large scale implementation of fault tolerance is well beyond the reach of current quantum hardware. What can one hope to do then, with existing noisy processors? In this talk I will discuss experiments that produce reliable computations from a noisy 127 qubit quantum processor, at a scale that is well beyond direct classical simulation methods. Our strategy reveals a continuous evolution for quantum computing to benefit from step-by-step improvements in gate fidelities and speed.

Superconductivity and Magnetism in 3D Nanoarchitectures VII-VIII

07.05.2023 SUNDAY

Abstract ID: 157

MAGNETIC FORCE AND SPIN-SENSITIVE ELECTRON MICROSCOPIES OF CoNiB NANOTUBES

M. Staňo[1], V. Uhlíř[1,2]

[1]CEITEC BUT, Brno University of Technology, Purkyňova 123, 612 00 Brno, CZECH REPUBLIC
[2]Institute of Physical Engineering, Brno University of Technology, Technická 2, 61669 Brno, CZECH REPUBLIC
E-mail: michal.stano@ceitec.vutbr.cz

The geometry of magnetic nanotubes gives access to rich physics associated with the interplay of curvature and magnetism, in particular curvature-induced anisotropy and magneto-chirality [1, 2]. Tubes can also host magnetization configurations absent in planar structures, such as azimuthal (vortex-like) domains (Fig. 1a). Typically, magnetic imaging of nanotubes (and often of other 3D / curved nanostructures) is performed at synchrotrons with polarized X-rays [2, 3]. Here we focus on two lab-based techniques: Magnetic Force Microscopy (MFM) and Scanning Electron Microscopy with (spin) Polarization Analysis (SEMPA / spin-SEM) [4]. Using their combination, we show that azimuthal domains can be stabilized (owing to growth-induced anisotropy) even for up to 25-µm-long CoNiB electroless-plated nanotubes with 200-nm-diameter. MFM detects magnetic stray field (derivatives) and is thus insensitive to the flux-closure azimuthal domains. Yet, it provides signal from domain walls and defects distorting the local magnetization. SEMPA simultaneously provides 2 components (projections) of surface magnetization (**M**) with a typical resolution <20 nm (ultimately full magnetization with the resolution down to 3 nm [4]). Due to its high surface sensitivity, it measures only the top tube surface and yields information on the curling sense of the flux-closure domains (Fig. 1c). Aside from the particular case of tubes, we will discuss some more general aspects regarding the use of both magnetic microscopies on 3D/curved magnetic (nano)structures.

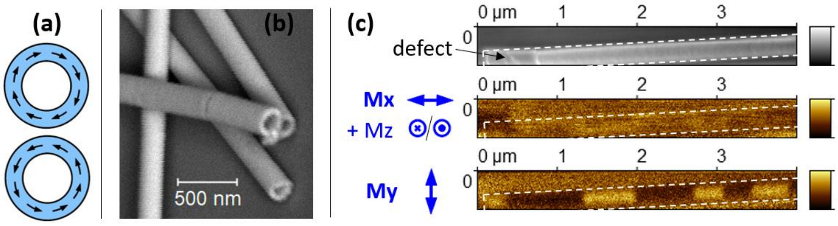

Fig. 1: *CoNiB nanotubes with azimuthal flux-closure domains.* ***(a)*** *Schematic tube cross-sections with azimuthal magnetization.* ***(b)*** *Scanning electron microscopy of a bundle of tubes on a Si substrate (sample tilt 45°).* ***(c)*** *Electron micrograph and SEMPA on an isolated nanotube. SEMPA sensitivity / magnetization projection is depicted by blue arrows. Weak out-of-plane projection (sin 19°~0.33 Mz) is caused by the sample being tilted ~19° vs the SEMPA detector plane. Transverse (My) projection has maximum close to the tube axis (center) and minimum at edges, consistent with the azimuthal* ***M****.*

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Abstract ID: 337

FLUXON COUNTERS AND VELOCIMETERS UPON NANOENGINEERED SUPERCONDUCTORS

B. Budinská[1,2], S.O. Shpilinska[3], C. Schmid[1], V.M. Bevz[4], M. Yu. Mikhailov[5], W. Lang[1], V.M. Fomin[6,7], O.V. Dobrovolskiy[1]

[1] University of Vienna, Faculty of Physics, 1090 Vienna, AUSTRIA
[2] University of Vienna, Vienna Doctoral School in Physics, 1090 Vienna, AUSTRIA
[3] University of Vienna, Faculty of Computer Sciences, 1090 Vienna, AUSTRIA
[4] Physics Department, V. Karazin Kharkiv National University, 61022, Kharkiv, UKRAINE
[5] B. Verkin ILTPE of the NAS of Ukraine, 61103, Kharkiv, UKRAINE
[6] Leibniz Institute for Solid State and Materials Research (IFW), 01069 Dresden, GERMANY
[7] Moldova State University, MD-2009 Chişinău, REPUBLIC OF MOLDOVA
E-mail: barbora.budinska@univie.ac.at

Nanoengineered superconductors attract great attention due to their application in quantum technologies (e.g., superconducting qubits, superconducting single-photon detectors) and various fluxonic devices. Of especial interest for the latter are non-equilibrium states, ultra-fast vortex motion at a few km/s, and emerging vortex patterns and topological transitions between them. An edge defect can locally suppress the energy barrier for vortex entry and affect the trajectories of the moving vortices [1]. Studies of single edge defects have shown that the repulsive interaction between vortices stipulates their arrangement in the form of a vortex jet (**Fig. 1a**) [2]. Considering that a defect at the opposite edge attracts vortices [3], two single edge defects placed on the same straight line opposite to each other can promote a vortex-chain arrangement (**Fig. 1b**). This approach can be extended to a larger number of edge or volume defects [4] to enable a desired functionality. In this work, we use numerical modeling based on the time-dependent Ginzburg-Landau (TDGL) equation to shed light on the vortex patterns in microbridges with slits as emerging platforms for vortex counting and velocimetry. Additionally, novel approaches, such as machine learning and inverse design for the realization of fluxonic gates and vortex-pattern generators, are explored.
We thank R. O. Rezaev who contributed to the development of the original version of the code [4].

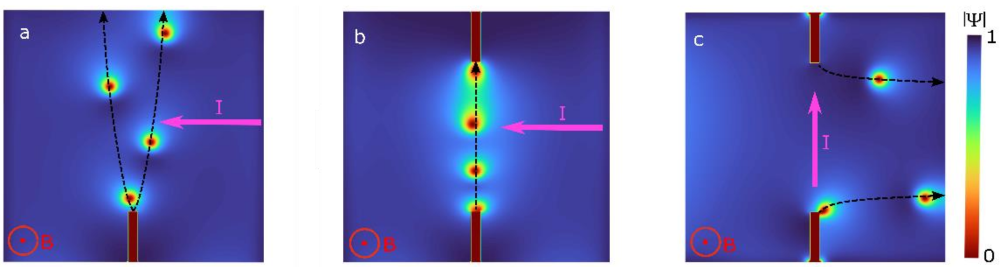

Fig. 1: *TDGL simulations of the superconducting order parameter |ψ| in films subjected to low magnetic fields with a single edge defect (a), two defects opposite each other with the current I flowing perpendicular (b) and parallel (c) to the defect line. Black arrows mark the trajectories of the vortices.*

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Abstract ID: 401

DIRECT WRITING OF THREE-DIMENSIONAL NANO-SUPERCONDUCTORS

Elina Zhakina[1], Vladimir M. Fomin[2, 3], Markus König[1], Amalio Fernandez-Pacheco[4], Claire Donnelly[1]

[1] *Max Planck Institute for Chemical Physics of Solids, Nöthnitzer Straße 40, 01187 Dresden, GERMANY*
[2] *Institute for Emerging Electronic Technologies, Leibniz IFW Dresden, Helmholtzstraße 20, D-01069 Dresden, GERMANY*
[3] *Moldova State University, strada A. Mateevici 60, MD-2009 Chisinau, REPUBLIC OF MOLDOVA*
[4] *CSIC-University of Zaragoza, C. de Pedro Cerbuna, 12, 50009 Zaragoza, SPAIN*
E-mail: zhakinaelina@gmail.com

In recent years, superconductivity and vortex matter in curved 3D nanoarchitectures have become a vibrant research avenue because of the rich physics of the emerging geometry- and topology-induced phenomena [1]. However, the realisation of such architectures is still challenging, with first demonstrations making use of multiple-step lithography or specialized ion beam deposition. To realise the full potential of 3D nanosuperconductivity, further fabrication techniques allowing the patterning of arbitrary three-dimensional (3D) nano-objects are required [2].

Here, we present the fabrication of superconducting 3D nanoarchitectures by focused electron-beam-induced-deposition [3] of tungsten, allowing for the realisation of complex 3D superconducting geometries with a critical temperature on the order of 5 K (fig 1). The geometrical effects of the 3D superconducting nanoarchitecture allow us the local control of the upper critical field of the device, which is not possible in bulk superconductors. This method unveils a wide perspective in experimental studies of the dynamics of topological defects of the superconducting order parameter in curved 3D nanoarchitectures.

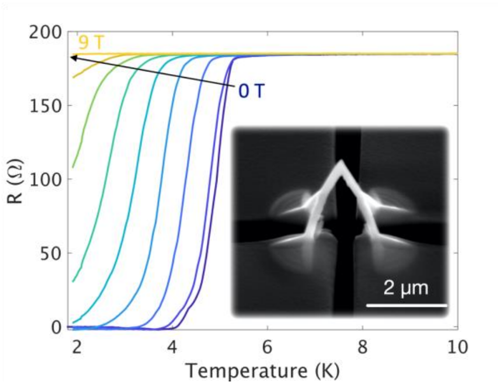

Fig. 1: *Temperature dependence of the resistance at different magnetic fields showing the superconducting transition at around 5 K of the nanostructure shown in the insert.*

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Abstract ID: 183

IN-SITU CORRELATION OF THE HALL EFFECT WITH THE OCCURRENCE OF TOPOLOGICAL MAGNETIC PHASES

S. Schneider[1,2], Y. He[3]

[1] *The University of Sydney, Sydney, AUSTRALIA*
[2] *Dresden Center for Nanoanalysis, cfaed, Technische Universität Dresden, GERMANY*
[3] *Max-Planck-Institute for Chemical Physics of Solids, Dresden, GERMANY*
E-mail: sebastian.schneider2@tu-dresden.de

Skyrmions are potential future nanoscale information carriers since they can be electrically manipulated and detected. Magnetic imaging in a transmission electron microscope (TEM) [1], has proven extremely valuable for unveiling the details of these magnetic solitons even in 3D [2,3]. Hall effect measurements are also widely used as a characterization tool to identify new materials hosting skyrmions. Their presence is hereby attributed to the occurrence of the topological Hall effect (THE). However, this THE might also arise from other microscopic non-coplanar spin structures in the lattice. Thus, the origin of the THE inevitably needs to be determined to fully understand skyrmions.

Magneto-transport measurements on such spin textures are usually conducted on samples, whose size and morphology differ substantially from those investigated in a TEM. Since the stability of skyrmions is highly sensitive to the sample geometry, the correlation of magneto-transport and TEM data is problematic if not conducted on identical samples [4].

We have therefore devised an in-situ measurement platform that bridges this gap and allows for the conduction of magneto-transport measurements in-situ in a TEM. We aim to correlate the anomalous Hall effect in skyrmionics materials with the magnetic field dependent occurrence of topologically protected magnetic phases such as the helical phase and skyrmions. In-situ Lorentz-TEM (L-TEM) investigations were conducted in a FEI Themis-Z Double-corrected microscope (300 kV, X-FEG) equipped with a fast Ceta 16M camera. A DENSsolutions Lightning holder with spring contacts connected to electrical feedthroughs was used to measure the anomalous Hall effect. TEM lamellae were cut using a focused ion beam system (FIB), positioned on a commercial measurement chip, and soldered to the modified contact pads by Pt deposition in the FIB. In Lorentz mode, the objective lens of the microscope was used to exert an external magnetic field perpendicular to the sample plane. The magnetic field of the objective lens was calibrated with an analog Hall sensor fitted into the in-situ biasing holder.

Our new setup provides the field dependence of the Hall voltage while simultaneously monitoring the magnetic phases in detail for the first time, thereby providing valuable insights into the existence and nature of an intensely debated electrical signature of skyrmionic structures.

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[5] S. Schneider gratefully acknowledges financial support through the Walter Benjamin Programme of the German Research Foundation (DFG) within project SCHN 1667/1-1.

Abstract ID: 304

MAGNONIC CONDUITS BY DIRECT WRITE NANOFABRICATION

Sebastian Lamb-Camarena[1,2], Fabrizio Porrati[3], Alexander Kuprava[3], Qi Wang[1], Michal Urbánek[4], Sven Barth[3], Denys Makarov[5], Attila Kákay[5], Michael Huth[3], Oleksandr Dobrovolskiy[1]

[1]*Nanomagnetism and Magnonics, University of Vienna, 1090, Vienna, AUSTRIA*
[2] *Vienna Doctoral School in Physics, University of Vienna, 1090, Vienna, AUSTRIA*
[3]*Physikalisches Institut, Goethe-Universität, 60438, Frankfurt am Main, GERMANY*
[4]*CEITEC BUT, Brno University of Technology, 61200, Brno, CZECH REPUBLIC*
[5]*Helmholtz-Zentrum Dresden-Rossendorf e.V, 01328, Dresden, GERMANY*
E-mail: sebastianlambcamarena@gmail.com

Magnonics is a rapidly developing domain of nanomagnetism, with application potential in information processing [1,2]. Realisation of this potential and miniaturisation of magnonic circuits requires their extension into the third dimension. However, so far magnonic conduits are limited to thin films and 2D structures. Here, we introduce 3D magnonic nanoconduits fabricated by the direct write technique of focused electron beam induced deposition (FEBID). FEBID surpasses the limitations of creating thin film or core-shell structures imposed by conventional 3D fabrication methods [3]. Magnetic alloys are a good basis for magnonics' integration in existing foundry processes due to the ease of fabrication. Curvature of nanoarchitectures induces a redistribution of the magnetisation, affecting both static and dynamic magnetisation behaviour, thus curvature is an exciting new ingredient for the engineering of magnetic properties [4,5]. We use Brillouin light scattering (BLS) spectroscopy [6] to demonstrate significant qualitative differences in spatially resolved spin-wave resonances of 2D and 3D nanostructures, which originates from the geometrically induced nonuniformity of the internal field. This work demonstrates the capability of FEBID as an additive manufacturing technique to produce magnetic 3D nanoarchitectures, and presents the first report of BLS spectroscopy characterisation of FEBID conduits.

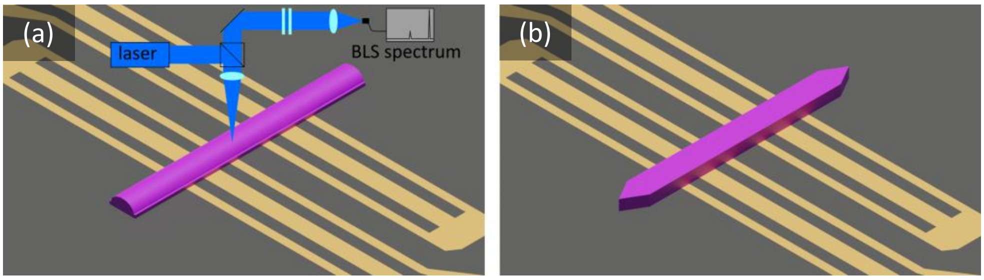

Fig. 1: *Design schematics for the bumped (a) and flat plank (b) conduits, the z dimension is stretched for visibility. Illustrative sketch of the BLS probing setup is shown in panel (a).*

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Abstract ID: 520

DESIGN MAGNETIC NANOSTRUCTURES FOR CURVILINEAR MAGNETISM STUDY

Sawssen Slimani[1,2], G. Varvaro[1], D. Peddis[1,2]

[1]University of Genova-Department of Chemistry and Industrial Chemistry (DCCI), nM2-Lab, 16146 Genova, ITALY
[2]National Research Council (CNR) – Institute of Structure of Matter (ISM), nM2-Lab, 00015 Monterotondo Scalo (Roma), ITALY

E-mail: Sawssen.Slimani@edu.unige.it

The large surface-to-volume ratio (R=S/V) of magnetic nanoparticles (MNPs) is proving to be a key factor for novel physical and chemical properties. An interesting possibility in the synthesis of nanostructures is the fabrication of hollow nanoparticles that have both internal and external surfaces, which further amplifies the value of R. The surface-driven effects in these structures have allowed research to take shape into new perspectives to explore surface magnetism at the nanoscale. Hollow spherical nanoparticles can be considered as a thin spherical shell, i.e., as one of the simplest 3D objects for studying the effect of curvature at the nanoscale level. This communication will present on overview on the design of exotic curvilinear nanoscaled structures (e.g., hollow spherical nanoparticles, nano-rings, nanotubes etc.). Then, as a case study, results about the peculiar magnetic structure in hollow nanoparticles with the highest value of R reported in literature (R ≅1.5 external diameter ~9.4 nm and shell thickness of ~1.4 nm). These hollow nanoparticles have been investigated by AC/DC magnetization measurements and using zero-field/in-field ^{57}Fe Mössbauer spectrometry. The zero-field hyperfine structure suggests some topological disorder, whereas the in-field one shows the presence of a complex magnetic structure that can be fairly described as due to two opposite pseudo-speromagnetic sublattices attributed to octahedral and tetrahedral iron sites. This corresponds to the presence of non-collinear spin structure originated from the increased surface role due to the hollow morphology. Monte Carlo (MC) simulations on a ferrimagnetic hollow nanoparticles unambiguously corroborate the critical role of the surface anisotropy on the non-collinearity of spin structure in the samples [1,2].

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Superconductors Under Extreme Conditions of Pressure and Strain I-II

07.05.2023 SUNDAY

Abstract ID: 104

EXPERIMENTAL STUDIES OF SUPERCONDUCTING HYDRIDES AT ULTRAHIGH PRESSURES

I. Troyan[1], A. Gavriliuk[1,2], I. Lyubutin[1] , V. Pudalov[3], D. Semenok[4], A. Oganov[5]

[1]*Shubnikov Institute of Crystallography, FSRC "Crystallography and Photonics", Russian Academy of Sciences, 119333, Moscow, RUSSIA*
[2]*Institute for Nuclear Research, Russian Academy of Sciences, 117312, Moscow, RUSSIA*
[3]*P.N. Lebedev Physical Institute, Russian Academy of Sciences, 119991, Moscow, RUSSIA*
[4]*Center for High Pressure Science and Technology Advanced Research (HPSTAR), Beijing 100094, CHINA*
[5]*Skolkovo Institute of Science and Technology, Skolkovo Innovation Center, 3 Nobel Street, Moscow 143026, RUSSIA*
E-mail: itrojan@mail.ru

Room-temperature superconductivity has long been an unattainable dream and the subject of speculative discussions. Recently, a record superconducting transition temperature of T_C = 203 K was discovered in H_3S at pressure of 150 GPa [1,2]. Theoretical prediction of high-temperature superconductor LaH10 with $T_C \sim$ 260 K [3] and which was subsequently confirmed experimentally [4,5] opened a new field in high-pressure physics devoted to the study of superconducting metal hydrides. Our report will present a brief overview the high-pressure synthesis of a series of lanthanum-yttrium ternary hydrides: cubic hexahydrides (La,Y)H_6 with a critical temperature T_C = 237±5 K, and decahydrides (La,Y)H_{10} with a maximum value of $T_C \sim$ 253 K and extrapolated upper critical magnetic field $B_{c2}(0)$ up to 135Tesla at a pressure of 183 GPa. This is one of the first examples of ternary high-T_C superconducting hydrides. In our experiments, the novel high-T_C ternary superconducting hydrides $Im\bar{3}m$- (La,Y)H_6 and $Fm\bar{3}m$- (La,Y)H_{10} were experimentally discovered together with $I4/mmm$ - (La,Y)H_4 at pressures of 170–196 GPa. Using the La – Y alloys (in ratio 1:1, 2:1, 3:1, 4:1, and 1:4) as a source for high-pressure synthesis, we replaced about 25% of the lanthanum atoms in the structure of LaH_{10} by yttrium. Moreover, we found that about 70% of the yttrium atoms in YH_6 can be replaced by La without decomposition of the $Im\bar{3}m$ sodalite-like structure of the hexahydride. Inclusions of Y@H_{32} with the local H environment specific for $Fm\bar{3}m$-YH_{10} can be synthesized in the $Fm\bar{3}m$-LaH_{10} superlattice, whereas fragments of La@H_{24} can be stabilized in the $Im\bar{3}m$-LaH_6 crystal structure by introducing only 30% of yttrium. Along with this, at pressure of 170–180 GPa, we successfully synthesized a series of ternary polyhydrides (La,Nd)H_{10} containing 8–20 at% of Nd. We found that the addition of magnetic neodymium leads to a significant suppression of superconductivity in LaH_{10}: each atomic % of Nd causes a decrease in T_C by 10–11 K. Partial replacement of La atoms by magnetic Nd atoms results in a decrease in the upper critical magnetic field, can be obtained by existing pulse magnets. Using the data obtained in strong pulsed magnetic fields up to 68 T, we plotted the magnetic $T_C(H_{ext})$ phase diagram of the ternary (La,Nd)H_{10} superhydride, which appears to be surprisingly linear with $H_{C2} \propto |T - T_C|$. The pronounced suppression of superconductivity in LaH_{10} by magnetic Nd atoms and the stability of T_C with respect to nonmagnetic impurities (e.g., Y) in accordance with Anderson's theorem indicate the isotropic (*s*-wave) character of conventional electron-phonon pairing in the synthesized superhydrides.

This work is supported by the Russian Science Foundation (Project No.22-12-00163).

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Abstract ID: 244

HIGH-PRESSURE HYDRIDES AND ELECTRON-PHONON SUPERCONDUCTIVITY: QUESTIONS ABOUT THE EXPERIMENTS AND QUESTIONS ABOUT THE THEORY

Frank Marsiglio

Dept. of Physics, University of Alberta, Edmonton, AB, CANADA
E-mail: fm3@ualberta.ca

Room-temperature superconductivity was reported in October, 2020, after 5 years of discovery of superconducting hydrides in the 200 - 250 K range. This talk will first critically review the experimental evidence for superconductivity. At the time of this writing, there are big resistivity drops, but no compelling measurements of the Meissner We also provide a basic review of our current understanding of the electron-phonon interaction in relation to superconductivity. We revisit the age-old question (once thought settled) of whether or not the electron-phonon interaction can produce high-temperature superconductivity.

Abstract ID: 492

SYNTHESIS OF SUPERCONDUCTIVE LANTHANUM-BASED HYDRIDES

K. Shimizu[1], S. Matsumoto[1], N. Osaki[1], M. Sasaki[1], M. Einaga[1], Y. Nakamoto[1],S. Kawaguchi[2], N. Hirao[2], Y. Ohishi[2]

[1] *Osaka University, KYOKUGEN, 560-8531, Osaka, JAPAN*
[2] *JASRI, 679-5148, Hyogo, JAPAN*
E-mail: shimizu@stec.es.osaka-u.ac.jp

Since the high-temperature superconductivity of hydrides was reported in hydrogen sulfide H_3S [1], many superconducting hydrides have been investigated by both theory and experiment. Comprehensive theoretical studies have been made for binary hydrides consisting of a single metal element and hydrogen, and verification experiments have been conducted based on these predictions. Among them, rare-earth-based hydrides have attracted, for example, the lanthanum hydride (LaH_{10}) was found to exhibit a superconducting transition temperature (T_c) above 250 K at 150 GPa [2,3]. While higher superconducting transition temperatures are expected to be obtained by adding light elements to rare earth hydrides, a realization of high-temperature superconductivity at lower pressure (or ambient pressure) is aimed for future practical use.

We are now conducting experiments on the light-elements doping and substitution to rare earth hydrides. The lanthanum-boron hydride, $LaBH_8$ is the candidate with T_c ~ 138 K at ~ 70 GPa [4]. we have conducted experimentally verified the high-pressure synthesis of $LaBH_8$ and its superconductivity.

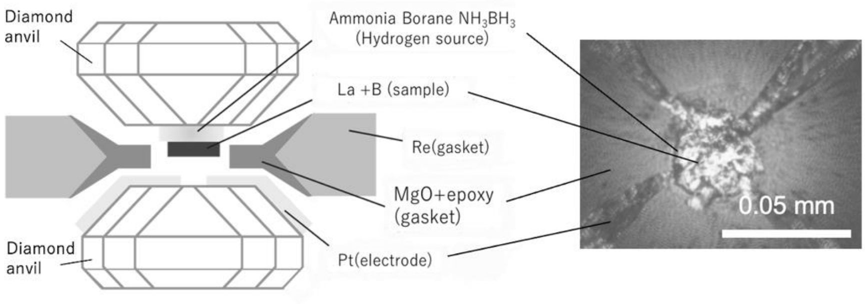

Fig. 1: *Schematic drawing of the sample set in a diamond-anvil cell (left) and the microphotograph of the sample and electrodes taken through the diamond anvil (right).*

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Abstract ID: 166

UNSPLIT SUPERCONDUCTING AND TIME REVERSAL SYMMETRY BREAKING TRANSITIONS IN Sr_2RuO_4 UNDER HYDROSTATIC PRESSURE AND DISORDER

Rustem Khasanov[1], V. Grinenko[2,3], D. Das[1], R. Guprta[1], B. Zinkl[4], N. Kikugawa[5], Y. Maeno[6], C.W.Hicks[7,8], H.-H. Klauss[2], M. Sigrist[4]

[1] *Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institut, CH-5232 Villigen PSI, SWITZERLAND*
[2] *Institute for Solid State and Materials Physics, Technische Universität Dresden, D-01069 Dresden, GERMANY*
[3] *Leibniz-Institut für Festkörper- und Werkstoffforschung (IFW) Dresden, D-01171 Dresden, GERMANY*
[4] *Institute for Theoretical Physics, ETH Zurich, CH-8093 Zurich, SWITZERLAND*
[5] *National Institute for Materials Science, Tsukuba 305-0003, JAPAN*
[6] *Department of Physics, Kyoto University, Kyoto 606-8502, JAPAN*
[7] *Max Planck Institute for Chemical Physics of Solids, D-01187 Dresden, GERMANY*
[8] *School of Physics and Astronomy, University of Birmingham, Birmingham B15 2TT, UNITED KINGDOM*
E-mail: rustem.khasanov@psi.ch

There is considerable evidence that the superconducting state of Sr_2RuO_4 breaks time reversal symmetry. In the experiments showing time reversal symmetry breaking its onset temperature, T_{TRSB}, is generally found to match the critical temperature, T_c, within resolution. In combination with evidence for even parity, this result has led to consideration of a $d_{xz} \pm id_{yz}$ order parameter. The degeneracy of the two components of this order parameter is protected by symmetry, yielding $T_{TRSB} = T_c$, but it has a hard-to-explain horizontal line node at k_z=0. Therefore, $s \pm id$ and $d \pm ig$ order parameters are also under consideration. These avoid the horizontal line node, but require tuning to obtain $T_{TRSB} = T_c$.

In this work, to test whether the order parameter of Sr_2RuO_4 is of single- or composite-representation type we perform zero-field muon spin rotation/relaxation measurements on hydrostatically pressurised Sr_2RuO_4 and on La-doped $Sr_{2-y}La_yRuO_4$. Both of these perturbations maintain the tetragonal symmetry of the lattice. If the order parameter has single-representation nature, T_{TRSB} will therefore track T_c. If the order parameter is of the composite-representation kind, with T_{TRSB} matching T_c in clean, unstressed samples through an accidental fine tuning, then perturbations away from this point should in general split T_{TRSB} and T_c, whether they preserve tetragonal lattice symmetry or not [1]. We have observed a clear suppression of T_{TRSB} at a rate matching the suppression of T_c. Our experimental results provide evidence in favour of single-representation nature of the order parameter in Sr_2RuO_4.

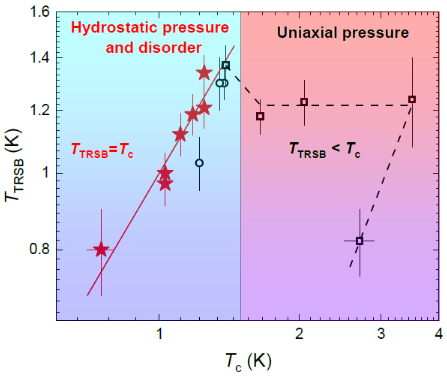

Fig. 1: *Dependence of the time-reversal symmetry-breaking temperature T_{TRSB} on the superconducting transition temperature T_c for Sr_2RuO_4 [2,3]. The colored areas represents parts with preserved tetragonal lattice symmetry (hydrostatic pressure and disorder effects) and with orthorhombic distortions in the lattice (uniaxial pressure). The red solid line corresponds to $T_{TRSB} = T_c$. The dashed line is a guide to the eye.*

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Abstract ID: 176

USING UNIAXIAL STRESS TO PROBE THE RELATIONSHIP BETWEEN COMPETING SUPERCONDUCTING STATES IN A CUPRATE WITH SPIN-STRIPE ORDER

Z. Guguchia[1], D. Das[1], C.N. Wang[1], T. Adachi[2], N. Kitajima[3], M. Elender[1], F. Brückner[4], S. Ghosh[4], V. Grinenko[4,5], T. Shiroka[1,6], M. Müller[7], C. Mudry[7,8], C. Baines[1], M. Bartkowiak[9], Y. Koike[3], A. Amato[1], J.M. Tranquada[10], H.-H. Klauss[4], C.W. Hicks[11], H. Luetkens[1]

[1]*Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institute, CH-5232 Villigen PSI, SWITZERLAND*
[2]*Department of Engineering and Applied Sciences, Sophia University, Tokyo 102-8554, JAPAN*
[3]*Department of Applied Physics, Tohoku University, Sendai 980-8579, JAPAN*
[4]*Institute for Solid State and Materials Physics, Technische Universitat Dresden, Dresden, GERMANY*
[5]*Leibniz-Institut fur Festkorper- und Werkstoffforschung (IFW) Dresden, 01171 Dresden, GERMANY*
[6]*Laboratorium fur Festkorperphysik, ETH Zurich, CH-8093 Zürich, SWITZERLAND*
[7]*Condensed Matter Theory Group, Paul Scherrer Institute, CH-5232 Villigen PSI, SWITZERLAND*
[8]*Institute of Physics, Ecole Polytechnique Fedeerale de Lausanne, CH-1015 Lausanne, SWITZERLAND*
[9]*Laboratory for Scientific Developments and Novel Materials, Paul Scherrer Institut, SWITZERLAND*
[10]*Condensed Matter Physics and Materials Science Division, Brookhaven National Laboratory, USA*
[11]*Max Planck Institute for Chemical Physics of Solids, D-01187 Dresden, GERMANY*
E-mail: zurab.guguchia@psi.ch

Cuprate high-temperature superconductors have complex phase diagrams with multiple competing ordered phases [1]. Understanding to which degree charge, spin, and superconducting orders compete or coexist is paramount for elucidating the microscopic pairing mechanism in the cuprate HTSs. In this talk, I will report some novel results of muon-spin rotation (μSR) and AC susceptibility experiments on uniaxial stress effect on the static spin-stripe order and superconductivity in the La214 cuprates [2].

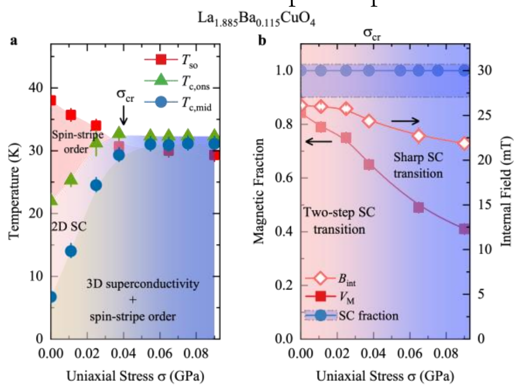

Fig. 1: *(a) The compressive stress dependence of the SC transition temperatures and of static spin-stripe order temperature T_{so} in LBCO $x = 0.115$. Black arrow marks the critical stress value, above which a sharp 3D SC transition is established. (b) The stress dependence of the base-T value (T = 3 K) of the magnetically ordered fraction V_m and the value of the internal magnetic field B_{int}.*

We find that in the cuprate system $La_{2-x}Ba_xCuO_4$ with $x = 0.115$, an extremely low uniaxial stress of 0.05 GPa induces a substantial decrease in the magnetic volume fraction and a dramatic rise in the onset of 3D superconductivity, from 10 to 32 K; however, the onset of at-least-2D superconductivity is much less sensitive to stress [2] (see Figure 1a and b). These results show not only that large-volume-fraction spin-stripe order is anti-correlated with 3D superconducting (SC) coherence, but also that these states are energetically very finely balanced. Moreover, the onset temperatures of 3D superconductivity and spin-stripe order are very similar in the large stress regime. These results strongly suggest a similar pairing mechanism for spin-stripe order, the spatially-modulated 2D and uniform 3D SC orders, imposing an important constraint on theoretical models.

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Abstract ID: 272

EXPLORATION OF NEW SUPERCONDUCTORS UNDER HIGH PRESSURES

Jinguang Cheng

Beijing National Laboratory for Condensed Matter Physics and Institute of Physics, Chinese Academy of Sciences, Beijing, 100190, CHINA

E-mail: jgcheng@iphy.ac.cn

As one of the fundamental parameters governing the states of matter, high pressure has been widely employed to explore various distinct structural and/or electronic phases that are inaccessible at ambient conditions. The application of high pressure can thus expand substantially the phase space of condensed matters and offers more opportunities to discover novel quantum materials and phenomena. The recent discovery of near-room-temperature superconductivity in the lanthanum superhydrides represents one of the most celebrated examples in this direction. In addition, unconventional magnetism-mediated superconductivity also emerges frequently near the pressure-driven magnetic quantum critical point in the strongly correlated electron systems. In this talk, I will present our recent progresses in exploring new superconductors by using high-pressure approach, including (1) a new superhydride superconductor SnH_x synthesized at about 200 GPa and 1700 K, showing transport evidences of superconductivity at $T_c \approx 70$ K with a low upper critical field $B_{c2}(0) \approx 11$ T [1]; (2) the first ternary Mn-based superconductor $A$$Mn_6Bi_5$ (A = K, Rb) with T_c up to 9.5 K achieved by suppressing its long-range antiferromagnetic order under high pressure [2, 3]; (3) a new magnetic superconductor $EuTe_2$ that shows a coexistence and concomitant enhancement of the superconducting T_c and the antiferromagnetic T_N at pressures above 6 GPa [4].

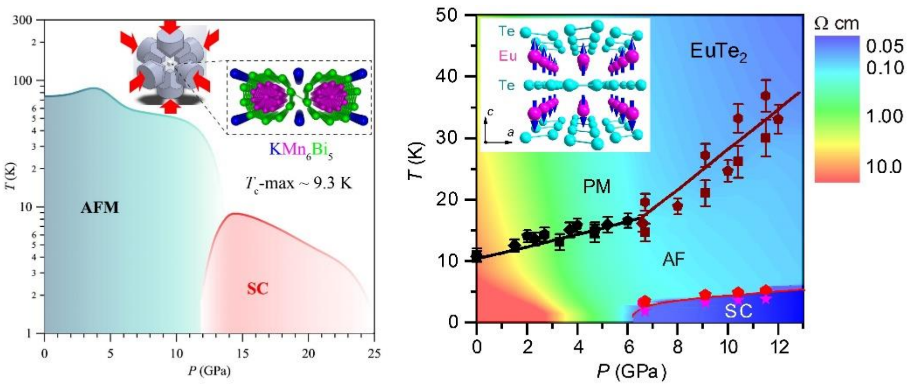

Fig. 1: *Temperature-pressure phase diagram of KMn_6Bi_5 (left) and $EuTe_2$ (right).*

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Abstract ID: 361

HIGH PRESSURE NMR OF HIGH-T_c CUPRATES

J. Haase

Leipzig University, Felix Bloch Institute for Solid State Physics, 04103 Leipzig, GERMANY
E-mail: j.haase@physik.uni-leipzig.de

Early in cuprate research, nuclear magnetic resonance (NMR) uncovered expected as well as surprising facts like spin singlet pairing and the pseudogap, anticipated for a powerful, versatile local probe. However, application of anvil cell pressure NMR remains sparse, in particular if single crystal experiments are required. About a decade ago, we began exploring new setups for higher sensitivity anvil cell NMR and began exploring cuprates. Here we will summarise our results, from today's perspective, which include the closing of the pseudogap with pressure [1], the reorientation of intra unit cell charge variation [2], as well as our most recent endeavour in which we uncover the mechanism behind the amplification of T_c with pressure [3].

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2D Atomically Thin Topological Materials

08.05.2023 MONDAY

Abstract ID: 447

ISING SUPERCONDUCTIVITY IN BERNAL BILAYER GRAPHENE WITH STRONG SPIN-ORBIT COUPLING

Ludwig Holleis[1], Yiran Zhang[2], Caitlin Patterson[1], Heun Mo Yoo[1], Haoxin Zhou[2], Takashi Taniguchi[3], Kenji Watanabe[3], Stevan Nadj-Perge[2], Andrea F. Young[1]

1: University of California, Santa Barbara, Santa Barbara, California 93106, USA
2: California Institute of Technology, Pasadena, California 91125, USA
3: National Institute for Materials Science, Namiki 1-1, Tsukuba, Ibaraki 305 0044, JAPAN
E-mail: Lholleis@ucsb.edu

Superconductivity seems to be an almost ubiquitous feature in the low temperature phase diagram of multilayer graphene allotropes – whether moire or crystalline. Famous examples include twisted bi- and tri-layer as well as Bernal bi- and rhombohedral tri-layers. While the microscopic electronic structures of these systems differ, supporting devices with monolayer WSe2 has been shown to increase superconductivity along many axes of the phase space like density, magnetic field and temperature. Here, we study two superconducting domes (SC1 and SC2) in Bernal Bilayer graphene on WSe2 as prototypical examples of the enhancement of superconductivity. Using transport and penetration field capacitance measurement, we investigate the effect of the proximity induced Ising spin-orbit coupling (SOC) on the underlaying phase diagram. While SC1 appears in a symmetry unbroken phase, quantum oscillation measurements show that the normal state of SC2 is nematic, breaking C3 symmetry. Despite the difference in symmetries of the normal state, both superconductors violate the Pauli limit consistent with spin singlet pairing between opposite valleys protected from de-pairing by Ising SOC – the magnitude of which we confirm by independently from Landau level transitions. Our results suggest that the induced SOC is central to the observed enhancement of superconductivity in many graphene multilayer systems - favoring pairing between time reversal symmetric partners.

Abstract ID: 558

NOVEL CREATION METHODS OF 2D TOPOLOGICAL INSULATING STATES ON ATOMICALLY THIN LAYERS

J. Haruyama[1,2]

[1]*Faculty of Science and Engineering, Aoyama Gakuin University, 5-10-1 Fuchinobe, Sagamihara, Kanagawa 252-5258, JAPAN*

[2]*Institute for Industrial Sciences, The University of Tokyo, 4-6-1 Komaba Meguro-ku, Tokyo 153-8505, JAPAN*

E-mail: J-haru@ee.aoyama.ac.jp

Topological insulating (TI) states are attracting large attentions from various perspectives. In the two-dimensional (2D) TI state, the quantum spin Hall (QSH) phase with a half-integer quantum value of resistance (R_Q) emerges thanks to the gapless helical edge spin states protected by time-reversal symmetry, namely, opposite-phase and counter-propagating spin pairs forming a Kramers doublet that flows along one-dimensional edges. 2D TI states have been researched in various materials, such as semiconductor quantum wells, graphene, and atomically thin transition metal dichalcogenides.

In the talk, I will demonstrate novel creation methods of 2D TI phases; *i.e.*, (1) Bi_2Te_3 nanoparticle decoration (only within a few %) on graphene [1], (2) laser-beam irradiation to few-layer MoS_2 [2,3], and (3) placing graphene on $SrTiO_3$ subtrate with extremely high di-electric constant [4]. In indivisual systems, the R_Q-related values in resitance peaks or plateaus are confirmed depending on back-gate voltages and number and patterns of metal electrodes on the helocal edge path. These methods open the feasible application to room-temperature topological quantum devices.

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Abstract ID: 605

DESIGN AND CONTROL OF TOPOLOGICAL PHASES IN QUASI-1D STACKED MATERIALS INVESTIGATED BY ARPES

Takeshi Kondo

Institute for Solid State Physics, The University of Tokyo, JAPAN
E-mail: kondo1215@issp.u-tokyo.ac.jp

Materials with quantum spin Hall insulator layers weakly coupled and stacked on top of each other form Z_2 weak topological insulator (WTIs) [1,2], the sides of which are topologically non-trivial and flow a highly directional, non-dissipative spin current. The same concept holds for higher-order topological insulators (HOTIs), which are similarly constructed from stacking quantum spin Hall insulators but, in this case, yield topologically protected one-dimensional helical hinge states. HOTI is a new class of topological insulators predicted in compounds previously thought to as trivial insulators under the Z_2 criterion by expanding the topological categorization to the Z_4 topological index. The material first proposed to be in the higher-order topological phase is Bulk bismuth [3], which is, however, a semimetal and cannot be made insulating by a simple parameter tuning like carrier doping. The experimental realization of a higher-order topological insulator in a 3D material has been anticipated in materials science. If achieved, it will allow for exploring many quantum phenomena, such as spin currents around hinges and quantized conductance under external fields.

In my talk, I will introduce that the quasi-1D bismuth halides Bi_4X_4 (where X is either I or Br) provide an excellent platform to realize various topological phases that can be selected by different ways the chain layers are stacked. Bi_4X_4 with single-layered chains per unit cell consisting of A-stacking develops a WTI state, where quasi-1D topological surface states are realized on the crystal side surface. In contrast, a simple insulator phase is formed in Bi_4I_4, where the chains adopt a double-layered structure consisting of AA'-stacking. Bi_4Br_4 is a HOTI candidate in the form of double layers, one of which is flipped by 180 degrees in the unit cell (AB-stacking). Using this material design concept and angle-resolved photoemission spectroscopy, I will demonstrate that Bi_4Br_4 is a higher-order topological insulator in its three-dimensional bulk state [4].

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Abstract ID: 630

TIME-REVERSAL SYMMETRY BREAKING SUPERCONDUCTIVITY BETWEEN TWISTED CUPRATE SUPERCONDUCTORS

S.Y. Frank Zhao[1], Xiaomeng Cui[1], Pavel A. Volkov[2], Hyobin Yoo[3], Sangmin Lee[4], Jules A. Gardener[5], Austin J. Akey[5], Rebecca Engelke[1], Yuval Ronen[1], Ruidan Zhong[6], Genda Gu[6], Stephan Plugge[7], Tarun Tummuru[7], Miyoung Kim[4], Marcel Franz[7], Jedediah H. Pixley[3], Nicola Poccia[8,1], Philip Kim[1]

[1] *Dept. of Physics, Harvard University, Cambridge, MA, USA*
[2] *Dept. of Physics & Astronomy, Center for Materials Theory, Rutgers University, Piscataway, NJ USA*
[3] *Dept. of Physics, Inst. Of Emergent Materials, Sogang University, Seoul, KOREA*
[4] *Dept. of Materials Science and Engineering, Seoul National University, Seoul, KOREA*
[5] *Center for Nanoscale Systems, Harvard University, Cambridge, MA USA*
[6] *Dept. of Condensed Matter Physics and Materials Science, Brookhaven National Laboratory, Upton, NY, USA*
[7] *Dept. of Physics and Astronomy & Stewart Blusson Quantum Matter Institute, University of British Columbia, Vancouver, BC, CANADA*
[8] *Institute for Metallic Materials, IFW Dresden, Dresden, GERMANY*

E-mail: zhao02@mit.edu

Twisted interfaces between stacked van der Waals cuprate crystals present a platform for engineering superconducting order parameters by adjusting stacking angles [1, 2]. Employing a novel cryogenic assembly technique, we construct twisted van der Waals Josephson junctions (JJ) at atomically sharp interfaces between $Bi_2Sr_2CaCu_2O_{8+x}$ crystals with quality approaching the limit set by intrinsic JJ [3]. Near 45^0 twist angle, we observe fractional Shapiro steps and Fraunhofer patterns revealing an emergent $d_{x^2-y^2} \pm id_{xy}$ superconducting order parameter, leading to two degenerate Josephson ground states related by time-reversal symmetry (TRS) [4]. By programming the JJ current bias sequence, we controllably break TRS to place the JJ into either of the two ground states, realizing reversible Josephson diodes without external magnetic fields and demonstrating a path to engineered emergent topological superconductivity at high temperature [1].

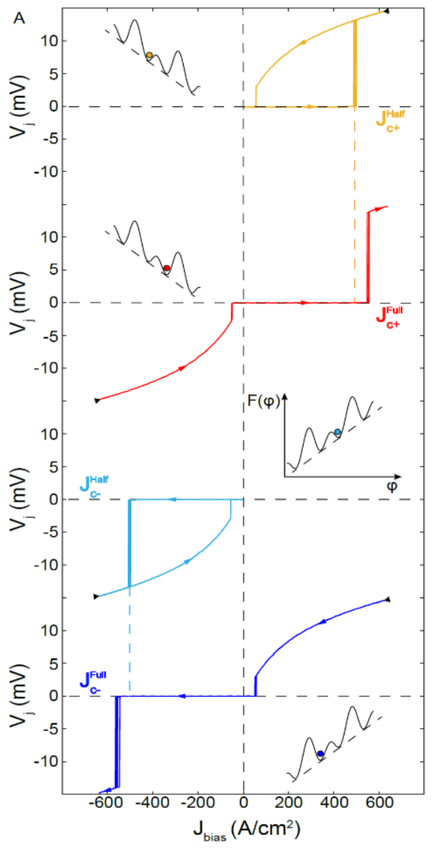

Fig. 1: *Reversible nonreciprocal critical currents in twisted BSCCO JJ near 45.*

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Advances In Current-Induced Magnetization Control I-II-III-IV

08.05.2023 MONDAY

Abstract ID: 431

UNIVERSALITY IN THERMALLY-ACTIVATED CURRENT-DRIVEN SKYRMION MOTION

M. Song[1], M. You[1], S. Yang[2], T.-S. Ju[2], K.-W. Moon[2], C. Hwang[2], K.-W. Kim[3], A. M. G. Park[1], K.-J. Kim[1]

[1] *Department of Physics, Korea Advanced Institute of Science and Technology, Daejeon 34141, REPUBLIC OF KOREA*
[2] *Quantum Spin Team, Korea Research Institute of Standards and Science, Daejeon 34113, REPUBLIC OF KOREA*
[3] *Center for Spintronics, Korea Institute of Science and Technology, Seoul 02792, REPUBLIC OF KOREA*
E-mail: kabjin@kaist.ac.kr

A scaling law elucidates the universality in nature, presiding over many physical phenomena which seem unrelated. Thus, exploring the universality class of scaling law in a particular system enlightens its physical nature in relevance to other systems and sometimes unearths an unprecedented new dynamic phase. Here, we investigate the dynamics of weakly driven magnetic skyrmions and compare its scaling law with the motion of a magnetic domain wall (DW) creep. We find that the skyrmion does not follow the scaling law of the DW creep in 2-dimensional space but instead shows a hopping behavior similar to that of the particle-like DW in 1-dimensional confinement. In addition, the hopping law satisfies even when a topological charge of the skyrmion is removed. Therefore, the distinct scaling behavior between the magnetic skyrmion and the DW stems from a general principle beyond the topological charge. We demonstrate that the hopping behavior of skyrmions originates from the bottleneck process induced by DW segments with diverging collective lengths, which is inevitable in any closed-shape spin structure in 2-dimension. This work reveals that the structural topology of magnetic texture determines the universality class of its weakly driven motion, which is distinguished from the universality class of magnetic DW creep.

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Abstract ID: 507

CURRENT-INDUCED CONTROL OF NONCOLLINEAR ANTIFERROMAGNETIC Mn_3Sn

S. Fukami[1,2,3,4,5]

[1] *Research Institute of Electrical Communication, Tohoku Univ., Sendai, JAPAN*
[2] *Center for Science and Innovation in Spintronics, Tohoku Univ., Sendai, JAPAN*
[3] *Center for Innovative Integrated Electronic Systems, Tohoku Univ., Sendai, JAPAN*
[4] *Center for Innovative Integrated Electronic Systems, Tohoku Univ., Sendai, JAPAN*
[5] *Inamori Research Institute for Science, Kyoto, Japan*
E-mail: shunsuke.fukami.c8@tohoku.ac.jp

Electrical control of magnetic materials is an ever-evolving field in spintronics. Earlier studies focused on ferromagnetic materials and demonstrated magnetization switching, magnetic phase transition, oscillation, resonance, and so on [1]. Among them, the spin-transfer torque induced magnetization switching has evolved into an essential ingredient in magnetoresistive random access memory technology, and other phenomena are also expected to open various opportunities of functional electronics. In 2016, electrical control of collinear antiferromagnet CuMnAs was also demonstrated, where staggered spin-orbit torque was utilized [2]. Besides, a recent study [3] reported an electrical switching of non-collinear antiferromagnet, another type of antiferromagnets with chiral-spin structure exhibiting intriguing properties that was believed to be observed only in ferromagnets such as the anomalous Hall effect [4].

Here I show a chiral-spin rotation in non-collinear antiferromagnet Mn_3Sn driven by the spin-orbit torque [5]; the phenomenon has no parallel in the history of spintronics research. We prepare cross-shaped Hall devices made of an epitaxial W/Ta/Mn_3Sn/Pt stack [6] and investigate the response of Hall resistance to the lateral current. We observe a characteristic fluctuation of the Hall resistance above a certain threshold, which can be consistently explained by considering persistent rotation of chiral-spin structure induced by the spin-orbit torque. We also find that the efficiency to manipulate the spin structure in this scheme is much higher than that in ferromagnet and collinear antiferromagnet. If time allows, I will also present our recent studies on the domain structure [7] and thermal stability [8] of Mn_3Sn thin film and nanodot.

The work has been carried out under a collaboration with Y. Takeuchi, Y. Yamane, J.-Y. Yoon, H. Ohno et al., and have been financially supported by JSPS Kakenhi 19H05622, 19J13405, and 20K22409 and RIEC Cooperative Research Projects.

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Abstract ID: 527

NUCLEATION AND DYNAMICS OF CHIRAL SOLITONS IN TOPOLOGICAL MATERIALS

O.A. Tretiakov

School of Physics, University of New South Wales, 2052, Sydney, AUSTRALIA
E-mail: o.tretiakov@unsw.edu.au

Skyrmions are topologically protected chiral solitons [1], which may serve as elements of future spintronic memory and logic devices. Therefore, skyrmion nucleation in topological systems such as topological insulator (TI)/ferromagnet is important to study, especially as in these systems the skyrmions are shown to move much faster. I will discuss skyrmion nucleation induced by spin-transfer torques specific for a TI interface with a ferromagnetic insulator based on micromagnetic simulations and diagrammatic techniques [2]. I will show that the nucleation time is inversely proportional to the applied electric field and will identify temperature dependences of the critical nucleation field. Furthermore, I will discuss the effect of the Dzyaloshinskii-Moriya interaction and demonstrate that the temperature dependence can be explained by the reduction of a magnon excitation gap due to the self-energy corrections. I will also discuss topological chiral solitons in numerous in-plane magnetized materials. These solitons are called bimerons and they are in-plane analogues of skyrmions as they have the same topological charge. I will first describe their stability, static and dynamics properties in ferromagnets [1]. Then I will turn to antiferromagnets, where I will show that in analogy with skyrmions [3], these topological solitons possess no skyrmion Hall effect, and among other exciting properties demonstrate chaotic behaviour when driven by ac currents.

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Abstract ID: 415

ORBITAL TORQUE AND ORBITAL MAGNETORESISTANCE IN 3*d* TRANSITION METALS

G. Sala

Department of Materials, ETH Zürich, 8093 Zürich, SWITZERLAND
E-mail: giacomo.sala@mat.ethz.ch

Recent theories have shown that orbital moments play a pivotal role in current-induced effects in transitional-metal thin films [1-2]. In particular, electric currents in 3*d* elements can induce an orbital Hall effect (OHE) that is comparable to or even stronger than the spin Hall effect (SHE) in 4*d* and 5*d* elements. The orbital accumulation can exert spin-orbit torques on ferromagnets and can lead to magnetoresistance effects in multi-layered samples [3-4]. Yet, in contrast to spins, non-equilibrium orbitals do not couple directly to the magnetization, which makes the identification of orbital effects difficult.

Here, we present a comprehensive study of the interplay between OHE and SHE by performing systematic measurements of spin-orbit torques in structures combining different light (Cr, Mn), ferromagnetic (Co, Ni), heavy-metal (Pt) and rare-earth (Gd, Tb) elements [5]. We provide robust support for the OHE in Mn, Cr, and even Pt, and establish a framework to analyze and efficiently exploit the interplay of spin and orbital currents. In addition, we extend the spin drift-diffusion model to include orbital effects and the interconversion of spin and orbital moments. This generalized model accounts for both the thickness and material dependence of the SOTs generated by the interplay of the OHE and SHE.

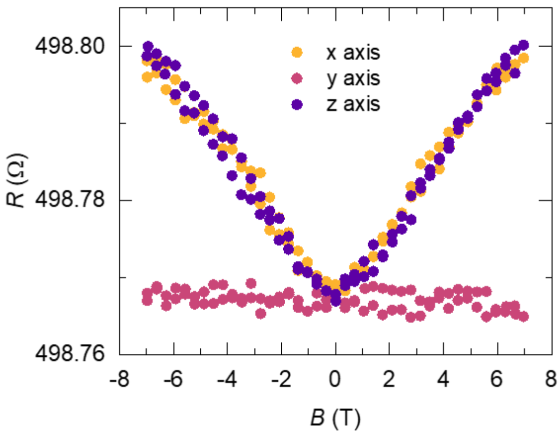

Fig. 1: *Hanle magnetoresistance in single layers of Mn. Dependence of the longitudinal resistance of a Mn(9 nm) Hall bar device on a magnetic field oriented along three orthogonal directions; the electric current flows along x.*

Finally, we present measurements of the orbital Hanle magnetoresistance in single Mn layers with variable thickness. We shows that magnetic fields orthogonal to the orbital accumulation cause a modulation of the longitudinal and transverse resistance of the order of $6.5 \cdot 10^{-5}$ and $2 \cdot 10^{-5}$ respectively, which is comparable in magnitude to the spin Hall and Hanle magnetoresistance measured in Pt-based heterostructures [6].

Overall, our results provide a useful framework to maximize the orbital-to-spin conversion efficiency, interpret experimental results, and address open fundamental questions about the orbital transport.

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Abstract ID: 611

RARE-EARTH IRON GARNETS WITH PERPENDICULAR MAGNETIC ANISOTROPY FOR EFFICIENT SPINTRONICS

Can Onur Avci

Institut de Ciència de Materials de Barcelona (ICMAB-CSIC), Campus de la UAB, 08193 Bellaterra, SPAIN
E-mail: cavci@icmab.es

Spintronics, the concept of harnessing electron spin as an active variable in electronic circuits, has evolved into a broad and interdisciplinary research field at the intersection of physics, materials science, and nanotechnology. Our improved understanding of transport phenomena and magnetic interactions in solid-state, along with the discoveries of new materials and experimental techniques, enabled rapid progress. Current-induced control of magnetization lies at the heart of the research efforts as it will ultimately lead to efficient nonvolatile solid-state memory, logic, and signal transmission devices. These devices can boost the capabilities of the contemporary CMOS technologies and potentially offer beyond-CMOS concepts leading to paradigm shifts in the microelectronic industry [1].

In the first part of the talk, we will discuss current-induced magnetic manipulation and detection experiments in insulating magnetic garnet systems mainly enabled by spin-orbit torques, spin Hall magnetoresistance, and other emerging spin transport phenomena. We will first present the fundamentals and symmetry of spin-orbit torques [2] and how they are accurately characterized magnetic insulator/platinum bilayers [3] and used to switch magnetization with high efficiencies [4]. We will then show how interfacial chiral magnetism stabilizes homochiral Neel domain walls in some perpendicularly magnetized iron garnets, which can be propelled as fast as 800 m/s with moderate current densities of the order of 10^8 A/cm^2 [5].

In the second part of the talk, we will present recent advances in the optimization of various rare-earth iron garnets by magnetron sputtering and pulsed laser deposition methods for efficient spintronics applications. We will show how their properties can be conveniently engineered for different experimental purposes [6]. We will conclude by providing some suture directions in spintronics that may benefit from the research progress in perpendicular ferrimagnetic insulators.

Acknowledgements

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Abstract ID: 612

HARNESSING ORBITAL TORQUE FROM ORBITAL-TO-SPIN CONVERSION THROUGH AN ANTIFERROMAGNETIC INSULATOR

Shilei Ding, Paul Noël, Gunasheel Kauwtilyaa Krishnaswamy, Giacomo Sala, Pietro Gambardella

Department of Materials, ETH Zürich, 8093 Zürich, SWITZERLAND
E-mail: shilei.ding@mat.ethz.ch

Orbital transport describes the flow of orbital angular momentum perpendicular to the orientation of the external electrical field, the injection of the orbital current into a ferromagnetic with a finite spin-orbit coupling can result in efficient torques on the magnetization, analogous to the spin torque scenario [1]. However, the current study is limited to ferromagnetic metals [2,3]. We hereby report the large orbital torque from the orbital-to-spin conversion through an antiferromagnetic insulator layer CoO. The polarity of the orbital torque efficiency in Co/CoO/naturally oxidized Cu (Cu*) is negative compared with the value in Co/Cu*, and the torque efficiency is greatly enhanced at low temperatures in Co/CoO/Cu*. The formation of the CuOx layer between CoO/Cu* plays a role for the negative torque, where the inversed oxygen gradient in Cu gives rise to the orbital angular momentum with negative polarization. The results indicate that the antiferromagnetic insulator can be an efficient orbital-to-spin converter, the locally converted spin current carried by magnons is further transported through CoO and exert the torque on the Co layer. We also find out that the orbital torque reaches a minimum absolute value at the magnetic ordering temperature of the CoO and the orientation of the antiferromagnetic Néel vector does not affect the efficiency of the orbital-to-spin conversion. Our finding opens the possibility of utilizing the antiferromagnetic insulator for spin-orbitronic devices based on orbital torque, it provides insight into a potential way for orbital engineering with antiferromagnetic ordering materials.

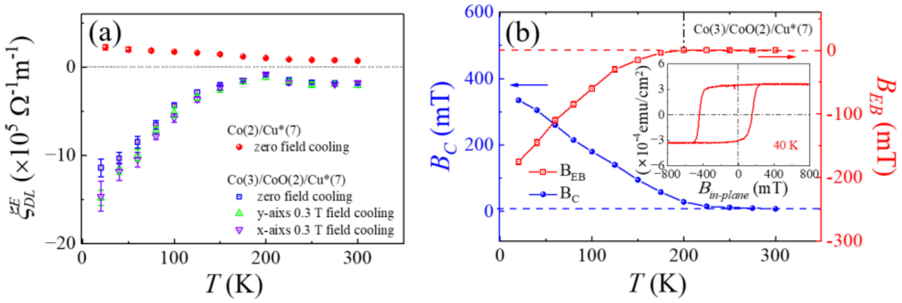

Fig. 1: *(a) Temperature dependence of the orbital torque efficiency for Co(2)/Cu*(7) and Co(3)/CoO(2)/Cu*(7). (b) Temperature dependence of the exchange bias field (B_EB) and coercive field (B_C) for Co(3)/CoO(2)/Cu*(7) after field cooling in a 0.3 T field. The inset shows the magnetic hysteresis loop at 40 K after field cooling.*

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Abstract ID: 444

ANATOMY OF SPIN-ORBIT EFFECTS AT INTERFACES COMPRISING METALS, OXIDES AND 2D MATERIALS

M. Chshiev[1,2]

[1] *Univ. Grenoble Alpes, CEA, CNRS, Spintec, Grenoble, FRANCE*
[2] *Institut Universitaire de France, 75321 Paris, FRANCE*
E-mail: mair.chshiev@cea.fr

Spin-orbit coupling based phenomena at interfaces comprising ferromagnetic (FM) metal, oxide (O) and nonmagnetic metal (NM) have been of great interest for spintronics including spin-orbitronics [1]. A major attention of scientific community has been also devoted to developments of emerging field of 2D spintronics [2]. Here we provide theoretical insights into perpendicular magnetic anisotropy (PMA) [1,3-9], Dzyaloshinskii-Moriya interaction (DMI) [9-13] at interfaces comprising transition metals, insulators and 2D materials. First, mechanisms of PMA [1,3-6] and of its variation under applied electric field (VCMA) [7] or via ionic migration [8] at FM/O interfaces are unveiled using first-principles approaches. Strong enhancement of the surface anisotropy of Co films at Co/graphene interfaces is also discussed [9]. Next, microscopic mechanisms of DMI behavior at FM/NM [10], FM/O [11,12] and FM/2D [13,14] interfaces are elucidated. Several approaches for DMI enhancement using trilayers with different FM/NM or FM/O interfaces [11] important for observation of room temperature skyrmions [12] are proposed. Possibilities of controlling DMI by electric field (VCDMI) at NM/FM/O [11] or by hydrogenation at FM/graphene interfaces [15] are discussed. Finally, DMI mechanisms and possibility of inducing skyrmions in 2D magnetic materials and in the films with composition gradient are introduced [16-18].

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Abstract ID: 470

REDUCED FIELD-FREE SPIN-ORBIT TORQUE SWITCHING USING OUT-OF-PLANE SPIN-POLARIZED SPIN CURRENT

Byong-Guk Park

Dept. of Materials Science and Engineering, 34141, Daejeon, KOREA
E-mail: bgpark@kaist.ac.kr

Spin-orbit torque (SOT) arising from spin-orbit coupling has gained much attention because it promises efficient magnetization switching in spintronic devices [1]. However, in order to develop actual devices utilizing SOT, it is important to switch perpendicular magnetization without an external magnetic field. In addition to field-free switching, reducing SOT switching current density is another essential requirement for device applications with low energy consumption.

In this talk, I will present two approaches to reducing field-free SOT switching current by exploiting out-of-plane spin-polarized spin current. First, we report that the Rashba effect in Pt/Co/AlOx structures is laterally modulated by electric voltages, generating out-of-plane SOTs. This enables field-free switching of the perpendicular magnetization and electrical control of the switching polarity [2]. Furthermore, it is shown that the field-free switching current density gradually reduces when the gate voltage is increased. Second, we demonstrate that spin currents with three different spin polarizations can be exploited in a ferromagnet/non-magnet/ferromagnet trilayer by controlling the magnetization direction of the bottom ferromagnet. It is found that the field-free SOT switching current in the trilayer is minimized when the magnetization of the bottom ferromagnet deviates from the current direction by 30~45 degrees [3].

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Abstract ID: 496

UNCONVENTIONAL SPIN-ORBIT TORQUES IN FERROMAGNETIC TRILAYERS

K.D. Belashchenko[1], G.G. Baez Flores[1], A.A. Kovalev[1], V.P. Amin[2]

[1]*University of Nebraska—Lincoln, Department of Physics and Astronomy, 68588 Lincoln, NE, USA*
[2]*Indiana University Purdue University Indianapolis, Department of Physics, 46202, Indianapolis, IN, USA*
E-mail: vpamin@iu.edu

We demonstrate using ab-initio and semiclassical transport calculations that unconventional spin-orbit torques arise in ferromagnetic trilayers that cannot be described using spin diffusion models. The unconventional nature of these spin-orbit torques comes both from novel spin current generation in single ferromagnetic layers and nonlocal interactions between the ferromagnetic layers. Spin-orbit torques in Co/Cu/Co, Co/Pt/Co, and Py/Cu/Py trilayers are studied using the first-principles non-equilibrium Green's function method with supercell disorder averaging. Trilayers with a Cu spacer exhibit strong current-in-plane giant magnetoresistance, and the torques exhibit features that cannot be captured by the spin-diffusion model. In the parallel configuration there is strong disorder-dependent dampinglike torque which can greatly exceed the torque in bilayers with Pt. This torque is strongly reduced in the antiparallel configuration. We also consider the case where the magnetizations in the two layers are orthogonal to each other. In addition to dampinglike and fieldlike torque components, we find a new torque with the angular dependence $(\mathbf{s}\cdot\mathbf{m}_2)\mathbf{m}_1$ where $\mathbf{s} = \mathbf{E} \times \mathbf{z}$ while $\mathbf{m}_1$ and $\mathbf{m}_2$ are the magnetizations in the spin-orbit source and detector layer, respectively. For further insight, we develop a semiclassical model based on the Boltzmann equation. Numerical calculations show that spin torques on one ferromagnetic layer are modulated by the other through interlayer scattering. Thus, in contrast to ferromagnet/heavy-metal bilayers, ferromagnetic trilayers can exhibit unconventional torques that cannot be captured by the spin-diffusion model.

Abstract ID: 436

OBSERVATION OF CHARGE-TO-SPIN CONVERSION IN FERROMAGNETS BY MEANS OF SPIN-ORBIT TORQUE

M. Aoki[1,2], E. Shigematsu[1,2], R. Ohshima[1,2], T. Shinjo[1,2], M. Shiraishi[1,2], Y. Ando[1,2,3]

[1]*Kyoto University, Dept. of Electronic Science and Engineering, 615-8510, Kyoto, JAPAN*
[2]*Center for Spintronics Research Network, Institute for Chemical Research, Kyoto University, 611-0011, Kyoto, JAPAN*
[3]*PRESTO, Japan Science and Technology Agency, 332-0012, Saitama, JAPAN*
E-mail: aoki.motomi.53r@st.kyoto-u.ac.jp

In a nonmagnet (NM)/ferromagnet (FM) bilayer structure, electric current in the NM layer generates spin current via charge-to-spin conversion such as the spin Hall effect (SHE), resulting in a spin-current injection into the FM layer [Fig. 1(a)]. Injected spin current exerts torque on the magnetization of the FM layer, which is called spin-orbit torque (SOT). Since SOT enables us to control and even switch the magnetization, it has been attracted much attention for application to a non-volatile memory device. Therefore, SOT has been investigated in various kinds of NM/FM bilayers such as heavy metal/FM, topological insulators/FM, and 2D material/FM structures to maximize the torque efficiency. Whereas most of SOT experiments have focused on the SHE in NMs, spin-current outflow from the FM to NM layer also exerts torque on the magnetization of the FM itself [1]. Therefore, we must consider the SHE in the FM layer when analyzing the SOT in the NM/FM bilayer systems [Fig. 1(b)]. However, most of previous works have neglected such self-induced SOT (SI-SOT) so far.

In our research, we observed anomalous sign inversion of the SOT in Ta/Co bilayer structure as increasing the thickness of Co layer as shown in Fig. 2, which originates from the competition between SOT via the SHE in Ta and the SI-SOT via the SHE in Co [1]. Thickness dependence of the SOT efficiency is well described by the spin-diffusion equation. We estimated contribution of the SI-SOT to be -43 % and 27 % of the measured SOT for Ta/Co and permalloy/Pt, respectively, which induces serious misestimation of the spin Hall angle (SHA) because the measured SOT has been considered to be close to the value of the SHA of the NM layer in the conventional understanding. Moreover, our calculation based on the spin-diffusion model indicates that the influence of the SI-SOT becomes significant when the resistivity of the NM layer is high, indicating that revisiting of SOT research is needed especially when a high-resistive NM layer such as the topological insulators is used.

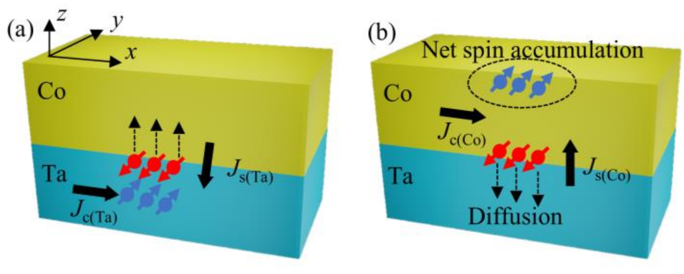

Fig. 1: *(a) Injection of spin current via the SHE in Ta and (b) absorption of spin current via the SHE in Co. J_c and J_s are the electric and spin current, respectively.*

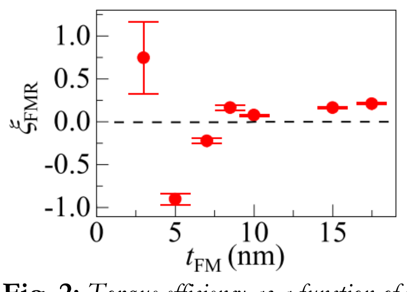

Fig. 2: *Torque efficiency as a function of the thickness of the Co layer.*

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Abstract ID: 437

COEXISTENCE OF LOW-FREQUENCY SPIN-TORQUE FERROMAGNETIC RESONANCE AND UNIDIRECTIONAL SPIN HALL MAGNETORESISTANCE IN SPIN TORQUE FERROMAGNETIC RESONANCE SIGNALS

Y. Ando[1,2,3], M. Aoki[1,2], M. Shiraishi[1,2]

[1]*Kyoto University, Dept. of Electronic Science and Engineering, 615-8510, Kyoto, JAPAN*
[2]*Center for Spintronics Research Network, Institute for Chemical Research, Kyoto University, 611-0011, Kyoto, JAPAN*
[3]*PRESTO, Japan Science and Technology Agency, 332-0012, Saitama, JAPAN*
E-mail: ando.yuichiro.5s@kyoto-u.ac.jp

Spin torque ferromagnetic resonance (ST-FMR) [1] is a powerful tool for estimating the spin Hall angle (SHA) of the nonmagnetic metal (NM) in an NM/ferromagnetic metal (FM) bilayer structure. Figure 1 shows a schematic of the measurement for the ST-FMR. When we plot rectification voltage under microwave irradiation, V_{DC}, as a function of external magnetic field, B_{ext}, the V_{DC}-B_{ext} plot is composed of Lorentzian and anti-Lorentzian functions. Since the SHA can be estimated by taking the ratio between the magnitudes of these two Lorentzian functions, less attention has been paid to the signal other than the resonance curve, e.g., offset voltage.

In this study, we found the spin-dependent unidirectional spin Hall magnetoresistance (SD-USMR) [2], which originates from the spin Hall effect in the NM and spin-dependent electron mobility in the FM, also contributes to non-zero V_{DC} [3]. Figure 2 shows the V_{DC}-B_{ext} plot for Ta/Co sample, where microwave frequency, f, was 12 GHz and microwave power, P, was 5 dBm. l, w, and θ defined as shown in Fig. 1 are 5 μm, 5 μm, and 45°, respectively. In addition to the conventional Lorentzian functions, magnetization-dependent background (BG) signal was also observed. We investigated B_{ext}, θ, f, P, NM material, and temperature dependences of the BG signal, and we concluded the BG signal is generated by the SD-USMR. In addition, we estimated the SHA of Ta to be -0.084±0.012 from the value of the BG signal, which is consistent with the previous work [4]. The ST-FMR spectrum composed of Lorentzian functions is produced by the spin orbit torque, whereas the BG signal is produced by the spin accumulation. Therefore, this experiment provides an effective cross check of the SHA from two different physical origins by using only one V_{DC}-B_{ext} plot.

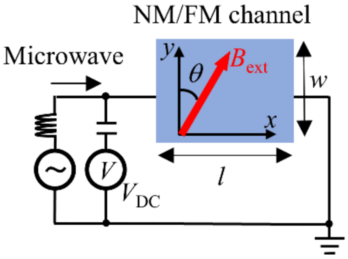

Fig. 1: *A schematic of the device and the electrical circuit used in the ST-FMR measurement.*

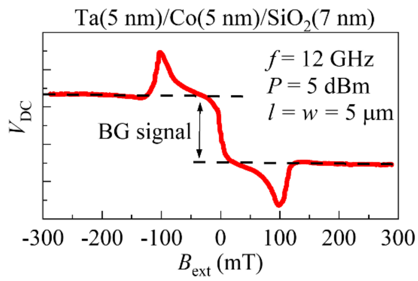

Fig. 2: *ST-FMR spectra with the BG signal originating from the SD-USMR for Ta/Co.*

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GEOMETRIC MANIPULATION OF SPIN POLARIZATION AND SPIN ORBIT TORQUE

Chang Pan[1], Yijie Lin[1], Yumeng Yang[2], Xuepeng Qiu[1]

[1]*Tongji University, School of Physics Science and Engineering, 200092, Shanghai CHINA*
[2]*ShanghaiTech University, School of Information Science and Technology, 201210, Shanghai, CHINA*
E-mail: xpqiu@tongji.edu.cn

In normal metal/ferromagnet heterostructures, transport of spin current generates spin orbit torque and drives efficient magnetization switching [1]. However, the spin current, arising from either the spin Hall effect or interface Rashba-Edelstein effect, is normally polarized along the y direction, i.e., in the film plane and transverse to the electric current direction as a σ_y component. This restriction fundamentally hinders the efficiency and requires external magnetic field for SOT switching of perpendicular magnetization. Recently, σ_z spin current has attracted particular attention as it has been proven more capable for efficient and field-free perpendicular magnetization switching [2]. Here, we demonstrate the generation of both σ_x, σ_y, σ_z spin currents through geometric rotation of spin transport plane by wedge thickness or anisotropic shutting layer. The corresponding spin orbit torque has been found of distinctly different vector symmetry and magnetization switching dynamics. The continuous tunning of σ_z/σ_y ratio and anisotropic field-free spin orbit torque switching have been also realized.

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High Tc- Cuprates I-II-III

08.05.2023 MONDAY

Abstract ID: 194

NEW QUANTUM CRITICALITY FOR THE STRANGE METAL AND PLANCKIAN BEHAVIOR IN HIGH TEMPERATURE SUPERCONDUCTORS

C. Di Castro

Accademia dei Lincei; Department of Physics, University of Roma "Sapienza", Pazza A. Moro Roma I-00185, ITALY
E-mail: carlo.dicastro@roma1.infn.it

The recent high-resolution RIXS (resonant inelastic X-ray scattering) experiments have given a new impulse to the physics of cuprates [1]. In particular, the newly discovered short-range dynamical charge density fluctuations [2], precursors of the three-dimensional charge density waves, account for the long-standing problem of the strange metal behaviour of the cuprates [3]. Due to their broadness, charge density fluctuations mediate an almost isotropic scattering among the fermi quasiparticles. For temperatures greater than their characteristic energy (proportional to the inverse correlation length squared and to the inverse dissipation parameter), their scattering provides the famous linear-in-T resistivity [3]. The linearity and a seemingly divergent specific heath [4], are then extended to the lowest temperatures by an increase of the damping of the fluctuations while the correlation length stays finite [5], thus providing the so called Planckian behavior.

Namely in ref. [5], we are proposing a new paradigm in contrast with the standard hot-spot model. Usually, the diverging correlation length is invoked to produce quantum criticality, here the strange-metal behaviour with linear resistivity and a diverging specific heat occurring near an anomalous QCP can be attributed to and accounted for by the increase of the damping parameter only. When the damping increases by lowering the temperature, the CDFs relax at longer and longer times giving rise to a glass of islands (finite correlation length) of CDFs. We are now developing a microscopic mechanism for enhanced dissipation which would lead to this "anomalous" quantum criticality [6].

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Abstract ID: 200

IONIC EFFECTS IN CUPRATES: FROM FERMI ARCS TO SUPERCONDUCTIVITY

D.K. Sunko

Department of Physics, Faculty of Science, University of Zagreb, Bijenička cesta 32, HR-10000 Zagreb, CROATIA
E-mail: dks@phy.hr

Experimental evidence accumulated over time shows that the mobile carriers in the normal state of cuprates are a Fermi liquid with practically the same transport parameters for all compounds and dopings [1, 2]. Here, a comprehensive theoretical framework is laid out to explain how such an outcome is possible despite the large Coulomb scales affecting the mobile carriers, and despite the superconducting planes being two-dimensional. Its key ingredients are:

1. Conduction occurs via the O *2p* [3] and Cu *4s* [4] orbitals, not the Cu *3d* orbital.
2. Fermi arcs are a simple kinematic projection effect [6] of the ionic doping mechanism in cuprates [5], and have nothing to do with carrier interactions at the Fermi energy.
3. The observed crossover [1,7,8] in the delocalization of a hole on the Cu *3d* orbital is a first-order orbital transition, with the *d-p* bond changing from ionic to covalent [9].
4. The assumed role of the localized hole as a superconducting glue [7,8,9] does not require going beyond the BCS framework, but does imply a drastically different physical regime than the textbook one.
5. The material-dependent tuning of the superconducting T_c is due to varying degrees of sharing of the localized hole between the Cu *3d* and O *2p* orbitals [9].
6. The Hohenberg-Mermin-Wagner theorem is irrelevant for 2D superconductivity, because it requires sample sizes larger than the observed universe [10].

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Abstract ID: 488

HIGH-T_c SUPERCONDUCTIVITY IN STRONGLY OVERDOPED CUPRATES

A. Gauzzi[1], Y. Klein[1], D. Hrabovsky[2], A. Hemmatzade[1], L. Delbes[1], B. Baptiste[1], L. Sederholm[3], M. Karppinen[3], G. Allodi[4], R. De Renzi[4], G. Baldinozzi[5], E. Gilioli[6], S.D. Conradson[7,8]

1IMPMC, Sorbonne Université, CNRS and MNHN, 4, Place Jussieu, Paris, FRANCE
2Department of Physics, Sorbonne Université, 4, Place Jussieu, Paris, FRANCE
3Department of Chemistry and Materials Science, Aalto University, 00076 Aalto, FINLAND
4Dpt of Mathematical, Physical and Computer Sciences, Univ. of Parma, 43124 Parma, ITALY
5CNRS CentraleSupélec, Université Paris-Saclay, 91192 Gif-sur-Yvette, FRANCE
6CNR, Institute of Materials for Electronics and Magnetism, Parma, ITALY
7Department of Complex Matter, Josef Stefan Institute, 1000 Ljubljana, SLOVENIA
8Department of Chemistry, Washington State University, Pullman, WA 90164, USA
E-mail: andrea.gauzzi@sorbonne-universite.fr

It is widely accepted that, in the overdoped region, $p > 0.27$ hole/Cu, where superconductivity disappears, the properties of cuprates are conventional, i.e. Fermi-liquid like. In fact, until recently, such conventional scenario for overdoped cuprates has never been verified experimentally owing to the difficulty of overdoping the CuO_2 plane.

Here we report on the successful synthesis of high-purity polycrystalline samples of strongly overdoped $YBa_2Cu_3O_{7+x}$ and $Cu_{0.75}Mo_{0.25}Sr_2YCu_2O_{7+x}$ [1] with oxygen content, x, up to 0.4 (i.e. $p > 0.5$ hole/Cu, well beyond the superconducting dome) using a high-pressure oxygenation method at 4-6 GPa. Surprisingly, all samples exhibit bulk superconductivity in the 80-90 K range with little variations of T_c as a function of x. This result is confirmed by the observation of a nearly x-independent superfluid density by muon-spin-relaxation spectroscopy. Remarkably, a common feature of both systems is a record short apical distance between the apical oxygen and the planar Cu atom, which points at a partial occupancy of both Cu $d_{x^2-y^2}$ and d_{z^2} orbitals [2,3]. Low-temperature specific heat measurements suggest the existence of a significant fraction of unpaired electrons, consistent with a picture of electronic phase separation. Finally, a study of the local structure by means of Extended X-ray Absorption Fine Structure (EXAFS) spectroscopy unveils huge (~1 Å) dynamical distortions of the lattice at T_c that involve the apical oxygen [4,5], which reflects a lattice-driven change of the electronic structure in the superconducting state. The above unexpected results put into question the validity of the current phenomenological description of cuprates. Specifically, we discuss the possibility of multi-orbital superconductivity and the implications of the nonadiabatic scenario suggested by our experiments on the electron-lattice dynamics.

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Abstract ID: 155

THE BREAKDOWN OF SUPERCONDUCTIVITY IN QUANTUM MATERIALS

Milan P. Allan

Leiden University, THE NETHERLANDS
E-mail: milan.allan@gmail.com

Many quantum materials are superconducting: below the critical temperature T_C, they enter a phase with zero electrical resistance. Often it is not known what causes superconductivity, and what kind of superconductivity occurs. One might understand the issue better by turning the question around: what causes superconductivity to disappear at T_C?

In my talk, I will present two case studies: First, I will show how in the disordered superconductor titanium nitride, superconductivity breaks down even though pairs exist above T_C. For this, I will introduce new instrumentation that can unambiguously and quantitatively detect electron pairs: the *electron pair microscope* [1-3]. Using it, we discover a state where almost all electrons are paired up to temperatures much higher than T_C [4]. At the same time, this material exhibits no spectroscopic gap. Our results thus demonstrate the existence of a novel quantum state above T_C that, much like an ordinary metal, has no (pseudo)gap, but carries charge entirely via paired electrons. Second, I will discuss the situation in the overdoped high-temperature superconductors, where we found that superconductivity breaks down because of the formation of nanometer-sized puddles of metallic regions. This shows that superconductivity is again not limited by the pairing interaction [5].

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Abstract ID: 159

TEMPERATURE AND DOPING DEPENDENT SHORT RANGE ANTIFFEROMAGNETIC ORDER AND PSEUDOGAP FORMATION IN HOLE-DOPED CUPRATES

S.G. Ovchinnikov[1,2], V.I. Kuzmin[1], S.V. Nikolaev[2], M.A. Visotin[1]

[1]*Kirensky Institute of Physics, Federal Research Center KSC SB RAS, 660036, Krasnoyarsk, RUSSIA*
[2]*Siberian Federal University, 660041, Krasnoyarsk, RUSSIA*
E-mail: sgo@iph.krasn.ru

Cluster perturbation theory is applied to the two-dimensional Hubbard $t - t' - t'' - U$ model to obtain doping and temperature-dependent electronic spectral function and spin correlation function with 4×4 and 12-site clusters. It is shown that evolution of the pseudogap and electronic dispersion with doping and temperature is similar and in both cases it is significantly influenced by spin-spin short-range correlations. When short-range magnetic order is weakened by doping or temperature and Hubbard-I-like electronic dispersion becomes more pronounced, the Fermi arc turns into a large Fermi surface and the pseudogap closes. It is demonstrated how static spin correlations impact the overall dispersion's shape and how accounting for dynamic contributions leads to momentum-dependent spectral weight at the Fermi surface and broadening effects. With increasing doping or temperature we have found strong pseudogap regime, weak pseudogap regime, and almost normal Fermi liquid regime (fig.1) with smooth crossovers between them.

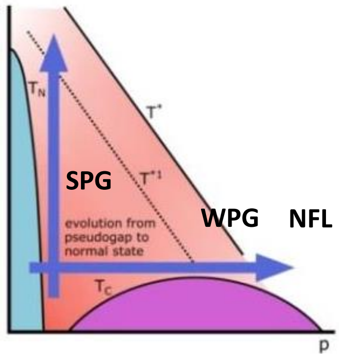

Fig.1: *Temperature - doping phase diagram with near Fermi-liquid (NFL), weak pseudogap (WPG) and strong pseudogap (SPG) states. Crossovers between these states are related to the changes in the short order spin correlation function.*

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Abstract ID: 189

ELECTRON FRACTIONALIZATION IN THE PSEUDOGAP STATE OF CUPRATES DETECTED BY RIXS

A. Fujimori[1,2,3], A. Singh[2], H. Y. Huang[2], T. Watanabe[4], M. Imada[5,6], D. J. Huang[1,2]

[1]*Center for Quantum Science and Technology, Department of Physics, National Tsing Hua University, Hsinchu 30013, TAIWAN*
[2]*National Synchrotron Radiation Research Center, Hsinchu 30076, TAIWAN*
[3]*Department of Physics, University of Tokyo, Tokyo113-0033, JAPAN*
[3]*Graduate School of Science and Technology, Hirosaki University, Aomori 036-8561, JAPAN*
[5]*Research Institute for Science and Engineering, Waseda University, Tokyo 169-8555, JAPAN*
[6]*Toyota Physical and Chemical Research Institute, Aichi 480-1192, JAPAN*
E-mail: fujimori@phys.s.u-tokyo.ac.jp

The origin of the pseudogap in cuprates has been hotly debated for decades, but remains enigmatic up to now. In this talk, we demonstrate that the concept of electron fractionalization starting from the Mott-insulating state explains recent spectroscopic data of hole-doped cuprates related to the pseudogap formation. Upon hole doping, the lower Hubbard band (LHB) fractionalizes into a coherent LHB below the Fermi level (E_F) and an in-gap band (IGB) above E_F with a pseudogap in between [1]. Electron-hole pair excitation from the LHB to the IGB is observed using resonant x-ray inelastic scattering (RIXS) at the Cu L_3 edge, and the excitation exhibits a characteristic enhancement below T_c as predicted by the theory of fractionalized electrons [2].

ARPES studies on electron-doped cuprates have also shown that the upper Hubbard band (UHB) is fractionalized into a coherent UHB and an IGB with a pseudogap in between [3].

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POSSIBLE MANIFESTATIONS OF Q-BALL MECHANISM OF HIGH T_c SUPERCONDUCTIVITY IN X-RAY DIFFRACTION AND DIAMAGNETIC RESPONSE

Sergei I. Mukhin

NUST MISIS, Dept. of Theoretical Physics and Quantum Technologies, 119049, Moscow, RUSSIA
E-mail: i.m.sergei.m@gmail.com

Recently proposed Q-ball mechanism of pseudogap state and high-Tc superconductivity in cuprates [1-3] has experimental manifestations. Q-ball charge Q gives the number of condensed elementary bosonic excitations in a CDW fluctuation of finite amplitude. Attraction between these excitations inside Euclidean Q-balls is self-consistently triggered by simultaneous condensation of Cooper/local pairs below pseudogap (PG) transition temperature T*. Euclidean Q-balls charge Q is conserved in Matsubara time due to global invariance of the effective theory under the U(1) phase rotation of the Fourier amplitudes of the short-range CDW fluctuations. Conserved 'Noether charge' Q equals ~ TM^2V, where temperature T, Q-ball's volume V, and fluctuation amplitude M enter. Several predictions follow from this picture. Conservation of the charge Q leads to inverse proportionality between volume V and X-ray scattering intensity A ~ M^2 (Fig. 1a) of the Q-balls. Besides, the theory predicts, that superconducting condensate forms at T* inside the Q-balls starting from vanishingly small superconducting density. Then it follows from the Ginzburg-Landau theory, that there should be a sharp inflation of the Q-ball volume when temperature approaches T* from below, since the radius of superconducting sphere increases in the vicinity of the transition temperature T_c, which for an individual Q-ball coincides with T*. This behaviors are already found in micro X-ray scattering experiments [4]. Also, a diamagnetic moment of the Q-ball gas as function of magnetic field above T_c is calculated and favourably compares with experimental plots in cuprates [5] (Fig. 1b).

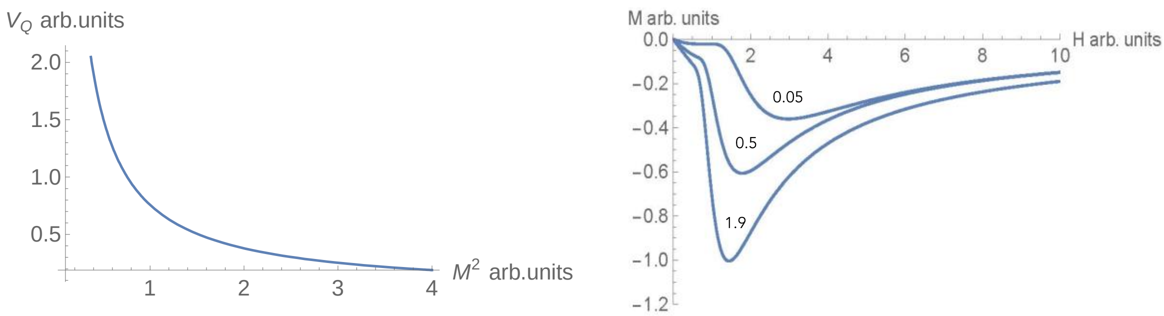

Figure 1: **(a)** *Q-ball volume V_Q as function of the CDW amplitude squared M^2.* **(b)** *Density of diamagnetic moment of the Q-balls gas in the PG phase at different temperatures T*-T indicated in arb. units.*

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Abstract ID: 344

SPIN EXCITATIONS COUPLED WITH CHARGE AND LATTICE DYNAMICS IN HOLE-DOPED CUPRATE

M. Fujita

Institute for Materials Research, Tohoku University, 980-8577 Miyagi, JAPAN
E-mail: fujita@tohoku.ac.jp

The relationship between spin correlations and superconductivity in Mott insulators remains a fascinating issue in condensed matter physics. In the hole-doped $La_{2-x}Sr_xCuO_4$ (LSCO), a spin excitation spectrum shows an hour-glass shape in the energy (ω)-momentum space. Such characteristic spectrum can be seen in superconducting $YBa_2Ca_3CuO_{6+d}$, suggesting a common nature of spin excitations in doped Mott insulators. Here we present the result of neutron scattering studies on the hourglass spin excitations of LSCO, which shows a coupling among spin fluctuations, itinerant electrons, and phonons.

1. Hierarchical energy structure in the spin excitation spectrum [1]

We collected high-quality data of spin excitations for LSCO with x = 0.10 and 0.16 using the neutron spectrometer installed at the Materials and Life Science Facility in J-PARC, Japan. The analysis based on the two-component picture, which considers the coexistence of commensurate and incommensurate (IC) components, well reproduced the spin excitation spectra in the wide energy range, including the waist energy of the hourglass. The temperature dependence of excitations suggests the different origins of the two components; the contribution of itinerant electron spins to the appearance of low-energy IC component.

2. Enhanced amplitude of spin fluctuations due to spin-phonon coupling [2]

We clarified the intensity enhancement of the IC component at the energy of 16 – 19 meV, where the spin excitations intersect optical phonon branches. The intensity shows the dome-shaped x dependence with the maximum value at $x \sim 0.15$, similar to the x dependence of superconducting transition temperature. We confirmed that the optical branes at ~19 meV correspond to the out-of-plane vibration of Cu or O of the CuO2 planes that could stabilize stripe alignment of charge. Since the intensity enhancement was not seen in the insulating La_2CuO_4, $La_{5/3}Sr_{1/3}NiO_4$, and non-superconducting LSCO with x = 0.30, the results indicate the interplay among spin, charge, and lattice dynamics.

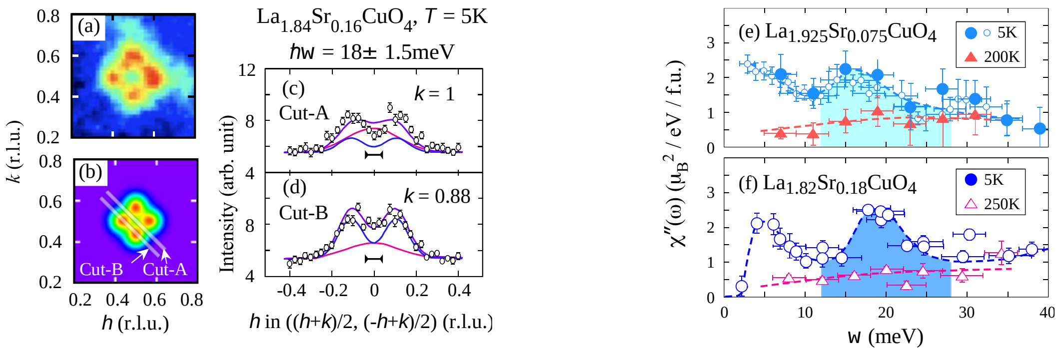

Fig. 1: (a), (c), (d) *Measured and (b) calculated spin excitation spectra for* $La_{2-x}Sr_xCuO_4$ *with* $x = 0.16$ *at 18 meV. Energy dependence of the momentum-integrated intensity of (e)* $x = 0.075$*, and (f)* $x = 0.18$.

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Abstract ID: 549

DENSITY CONTROLLED BCS-BEC CROSSOVER AND VORTEX DYNAMICS IN 2D SUPERCONDUCTORS

Y. Iwasa

Department of Applied Physics & QPEC, University of Tokyo, Tokyo 113-8656, JAPAN
RIKEN Center of Emergent Matter Science, Wako 351-0198, JAPAN
E-mail: iwasay@riken.jp

The Bardeen-Cooper-Schrieffer (BCS) condensation and Bose-Einstein condensation (BEC) are the two limiting ground states of paired Fermion systems, and the crossover between these two limits has been a source of excitement for both fields of high temperature superconductivity and cold atom superfluidity [1]. Here we report the two-dimensional (2D) BCS-BEC crossover realized in a gate-controlled superconductor, electron doped layered material ZrNCl, and the vortex dynamics across the crossover. To observe this phenomenon, we utilized an ionic gating method, which is well known as a powerful tool to control the carrier density in a large scale and induced 2D superconductivity [2].

We have succeeded in controlling the carrier density in ZrNCl devices by nearly two-orders of magnitude, and establishing an electronic phase diagram through the simultaneous experiments of resistivity and tunneling spectra [3]. We found T_c exhibits dome-like behavior, and more importantly, a wide pseudogap phase in the low doping regime. In the low carrier density limit, T_c scales as $T_c/T_F = 0.12$, where T_F is the Fermi temperature, which shows fair agreement with the theoretical prediction for the 2D BEC-BEC crossover [4,5]. Furthermore, through the systematic Hall effect measurements, we have clarified the evolution of vortex dynamics along the crossover combined with the time-dependent Ginzburg-Landau theory. These results demonstrate that the Li intercalated ZrNCl and its gate-controlled superconductivity are ideal platforms towards investigations of unexplored properties in BEC superconductors such as vortex dynamics in BEC superconductors [6].

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Large Scale Applications of Superconductors and their fundamental technologies I-II-III

08.05.2023 MONDAY

Abstract ID: 321

LOSS EVALUATION OF A SUPERCONDUCTING CABLE AND ITS TERMINATIONS FOR A DC RAILWAY NETWORK

G. Hajiri[1], K. Berger[1], J. Lévêque[1], H. Caron[2]

[1]*Université de Lorraine, GREEN, F-54000 Nancy, FRANCE*
[2]*Département de la Traction Électrique, SNCF Réseau, F-93418 La Plaine Saint-Denis, FRANCE*
E-mail: ghazi.hajiri@univ-lorraine.fr

In recent years, there have been an increasing number of projects to use superconducting cables to address industrial challenges. In particular, the integration of superconducting cables into the network can be a solution to the challenges of increasing traffic on the railway network and regulatory issues. In this paper, we study the behavior of a single-pole superconducting cable and the losses of the whole installation, including terminations, in a daily scenario in the Paris area. To this end, we present a comprehensive approach to coupling a finite element (FE) model and an electrical circuit (EC) of the railway network with Simulink. The FE model is based on a cable model with a nominal current of 3.5 kA and a nominal voltage of 1.5 kV. This is the world's first cable project that will be installed on a commercial line of a railway network, near the Montparnasse station. The power law $E(J)$ and the temperature and magnetic field dependence of the critical current density $J_c(B,\theta)$ will be considered. The current flowing through the superconducting cable and terminations shown in Fig. 1 is simulated using a dynamic model of the railway network presented in [1] which includes an electrical model of the substation, a mechanical model to determine the traction force and train displacement and a variable line impedance model for the network. Finally, an energy balance will be presented, detailing the choice of the cooling system to ensure the proper functioning of the entire superconducting installation.

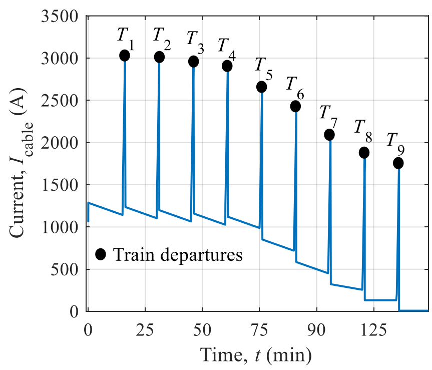

Fig. 1: *Current flowing in the superconducting cable as a function of time, where T1, T2, T3, T4, T5, T6, T7, T8, T9 represent the departure of trains during the day.*

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Abstract ID: 428

SUPERCONDUCTING UNDULATORS – FROM UNLIKELY TO UNLIMITED

Y. Ivanyushenkov

Argonne National Laboratory, Advanced Photon Source 9700 S. Cass Ave., Lemont, IL 60439, USA
E-mail: yury@anl.gov

For a long time, superconducting undulators (SCUs) have been considered as a desirable step forward in undulator technology and at the same time unlikely due to concerns of quenches and possible excessive liquid helium consumption due to a substantial heat load by the electron beam. These and other misconceptions have been debunked by the SCU team at the Advanced Photon Source (APS) over the last two decades. Since 2013, SCUs have operated reliably at the APS, demonstrating no effect on the APS storage ring and zero consumption of liquid helium. In addition, a helical superconducting undulator was also built and became a part of the undulator portfolio at the APS. The concept for a universal superconducting undulator SCAPE was also suggested and successfully prototyped; it is now being developed. The feasibility study for a high-temperature superconductor (HTS) undulator clearly indicated the great potential for an HTS to achieve undulator fields not reachable with NbTi and even Nb_3Sn superconductors. Yet another attractive feature of SCUs is that, due to the compactness of SCU magnets, several SCUs can be mounted inside a single cryostat forming a multi-line undulator. This option might be very attractive for FELs. Details of these and other projects are given in this presentation. In summary, the combination of SCU's high undulator field, numerous magnetic field configurations, and variety of undulator architectures offers nearly unlimited technological capabilities.

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Abstract ID: 521

A STUDY OF MAGNETIZATION ANISOTROPY OF HIGH TEMPERATURE SUPERCONDUCTING TAPE

I. Rudnev[1,2], S. Pokrovskii[1,2], S. Veselova[1,2] , I. Martirosian[1,2], R. Batulin[2]

[1] *National Research Nuclear University MEPhI, 115409, Moscow, RUSSIA*
[2] *Kazan Federal University, 420008, Kazan, RUSSIA*
E-mail: iarudnev@mephi.ru

The creation of second-generation HTSC wires in the form of thin tapes with high critical currents has led to the growing use of such wires in the design of magnetic systems for various purposes. In such magnetic systems, individual sections of the HTSC tape experience magnetic fields of different orientations with respect to the plane of the tape, which leads to the differences in such important characteristics as the critical current, magnetization, and hysteresis losses, along the tape length. The anisotropy effect may depend on temperature and the value of applied magnetic field. The study of anisotropy of HTSC tapes is complicated by the fact that the YBCO compound itself is strongly anisotropic and the anisotropy of the critical current of the tape is determined by several contributions: the anisotropy of the compound, the anisotropic system of pinning centers, and the anisotropy of the tape shape. Many works have been published on measuring the anisotropy of HTSC tapes from different manufacturers by the resistive method at liquid nitrogen temperature. Considerably fewer works consider critical currents and their anisotropy of HTSC tapes at liquid helium temperature. A separate area of research is aimed at studying the anisotropy of magnetization and hysteresis losses.

In this report, we present new experimental data concerning the dependence of magnetization of HTS tape samples on the direction of applied magnetic field with respect to the tape plane. The measurements were carried out in the temperature range 5–100 K and in magnetic fields up to 8 T using the PPMS-9 system with the set of special sample holders which provided different angles between the direction of the field and the plane of the tape.

As a result of experimental studies, we obtained the magnetization curves M(H) for different temperatures and directions of the magnetic field and found that at, the angles close to zero (when the magnetic field is parallel to the tape plane), the M(T) curves have noisy shapes at the low temperature (see as example on the **Fig.1** the curves at T=30 K) . We explained this phenomenon in terms of thermal-magnetic instabilities.

The results obtained will be useful in designing systems in which superconductors are in magnetic fields of different directions: superconducting inductive energy storage devices, magnetic levitation systems, superconducting bearings.

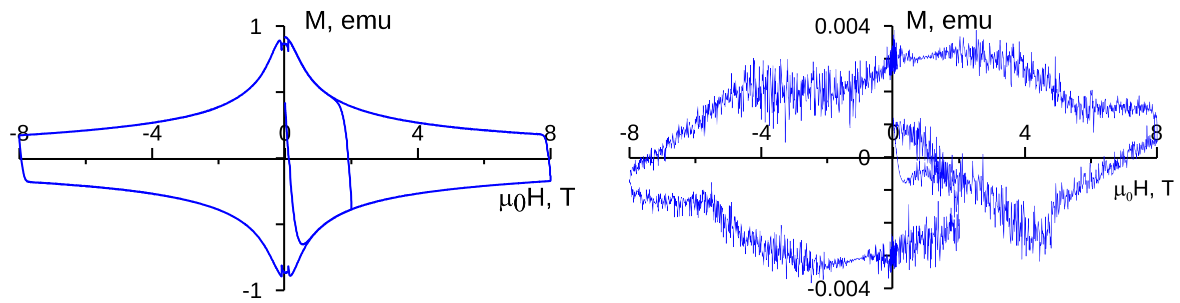

Fig. 1: *On the left: hysteresis loops of sample in a magnetic field perpendicular to the plane tape. On the right: hysteresis loops of samples in a magnetic field parallel to the plane tape. T=30 K.*

Abstract ID: 286

BULK SUPERCONDUCTORS FOR TOROIDAL MAGNETIC FIELD CONFINEMENT: APPLICATION TO FUSION MAGNETS

Jaume Cunill-Subiranas, Natanael Bort-Soldevila, Alvaro Sanchez

Departament de Física, Universitat Autònoma de Barcelona, 01893, Bellaterra, Barcelona, Catalonia, SPAIN
E-mail: jaume.cunill@uab.cat

The creation and confinement of magnetic fields in toroidal topology is fundamental for several current applications, such as the techniques for obtaining a clean and essentially unlimited future energy source: nuclear fusion. Much progress is currently being made in magnetic confinement fusion (using high magnetic fields) as well as inertial fusion (using powerful lasers). Tokamaks and stellarators are the two main types of reactors that use confined toroidal magnetic fields to generate the plasma necessary for fusion. However, some of the main problems hindering controlled fusion are the imperfect magnetic confinement and the associated plasma instabilities. Here, we theoretically present how to obtain complete and robust magnetic field confinement for toroidal fusion magnets. This is achieved in a toroid made of bulk superconducting material that has a cavity carved along the toroidal direction and a set of poloidal coils embedded in the poloidal one. The field created by the coils is confined in the cavity and its shape which is crucial for the fusion reaction results directly from the cavity shape, independently of the configuration of the coils. By magnetostatic theory, we demonstrate that the present strategy can lead to exactly generate the fully-confined fields required in two of the most advanced stellarators, LHD and W7-X, using simple round coils as magnetic sources.

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Abstract ID: 293

LOSSES IN LARGE SCALE NON-INDUCTIVE HIGH TEMPERATURE SUPERCONDUCTING COILS

S. Fawaz, H. Menana, B. Douine

Université de Lorraine, GREEN, F-54000 Nancy, FRANCE
E-mail: sara.fawaz@univ-lorraine.fr

The characterization of high temperature superconducting (HTS) coils is essential for their integration in electrical power applications as they are designed to operate in both DC and AC conditions [1, 2]. One key aspect of this characterization is evaluating the hysteresis losses, that occur during both steady and transient state operations, which is crucial for determining the performance of the coil and optimizing its design [3].

The aim of this work is to develop a fast-integral modeling approach for the design and characterization of a large scale non-inductive superconducting coils made of first-generation (1G) HTS tapes. The modeling approach is based on integral equations combined with a strategy of far tape approximation allowing to model a successive reduced set of consecutive tapes instead of modeling the entire coil.

The numerical AC losses dissipated in the HTS coil at a frequency of 40 Hz are presented in Fig. 1, compared to measurements and losses calculated using the Norris formulas [4], which can be used for AC losses evaluation such coils due to their non-inductive behavior. As we can notice, the numerical results show a good agreement with the experimental results and those obtained with the Norris ellipse formula, emphasizing the importance of considering the elliptical section of the superconductor in the tape. It was observed that the computation time for the modeling strategy based on dividing the coil into sectors for an applied current is around 30 min, while modeling the entire coil with the same discretization requires 12h.

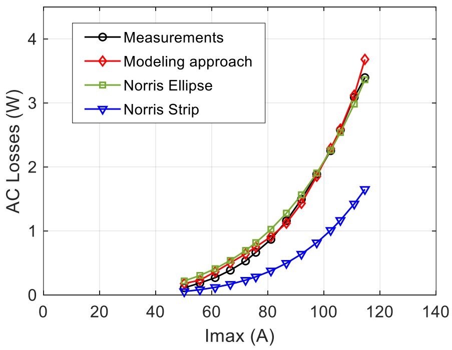

Fig. 1: *Comparison between the numerical and experimental AC losses and the losses calculated with Norris's formulas for a frequency of 40 Hz.*

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Abstract ID: 515

PERFORMANCE DEGRADATION OF MULTI-LAYER SPIRAL CABLE DURING MANUFACTURING PROCEDURE

Jie Sheng[1], Junjie Jiang[1], Yue Zhao[1], Zhuyong Li[1], Xuan Zhou[1], Yuchao Yuan[2]

[1]*Shanghai Jiao Tong University, School of Electronic Information and Electrical Engineering, 200240, Shanghai, CHINA*
[2]*Shanghai Jiao Tong University, School of Naval Architecture, Ocean and Civil, Engineering, 200240, Shanghai, CHINA*
E-mail: sjl@sjtu.edu.cn

Multi-layer spiral compact cable based on high temperature superconducting tapes is a potential candidate for large scale superconducting applications. Accurate prediction of critical current is very important for functionality and safety of superconducting equipment. And predict strain in the tapes properly is an important prerequisite. The straight cable is selected as research object. The stress and strain distribution of the tapes inside the straight cable are only related to the production and the winding process. In this paper, the critical current of straight multilayer spiral superconducting cable under 77K self-field is predicted by numerical simulation. Then corresponding test samples were prepared through the winding machine. The critical current is measured at 77K with 4-probe method. We study interlayer interaction during the preparation of multilayer cable by FEM, focus on the change of pressure on tapes, the section profile of the cable, and influence of above factors on the axial strain of the tape. They are possible explanations of the critical current degradation of the multilayer straight cable according to simulation results. The influence of tensile force and winding angle is also studied. This research is informative for the selection of design parameters of multi-layer cables and the performance prediction of subsequent cable bending.

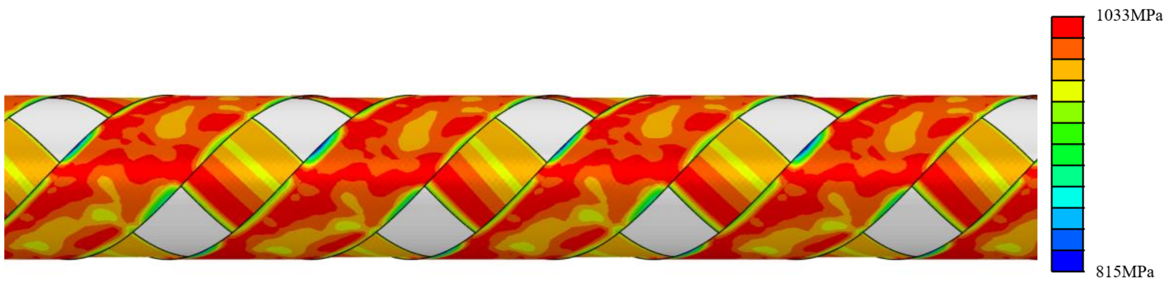

Fig. 1: *Initial stress distribution of multi-layer straight cable after manufacturing*

Abstract ID: 607

DEVELOPMENT OF SPIRAL COPPER-PLATED STRIATED COATED CONDUCTOR CABLES (SCSC CABLES)

N. Amemiya[1], Y. Sogabe[1], R. Nakasaki[2], S. Yamano[2], H. Sakamoto[3]

[1]Kyoto University, 6158510, Kyoto, JAPAN
[2] Furukawa Electric Co., Ltd., 3211493, Nikko, JAPAN
[3] SuperPower Inc., 12302, Grenville, U.S.A.
E-mail: amemiya.naoyuki.6a@kyoto-u.ac.jp

In various advanced applications of high Tc superconductors (HTSs) such as light-weight motors for electric aircraft propulsion, hydrogen turbine generators, compact fusion devices, and very high field magnets for particle accelerators, we need conductors that can carry several kilo amperes through several tens of kilo ampere of currents. In case of conventional low Tc superconductors (LTSs), which are with round cross-sectional shape, high-current cable concepts such as CICC and Rutherford cable, in which many superconductor wires are assembled to attain a high current capacity, have been established. In case of HTSs, most of which are with tape shape, these cable concepts cannot be adapted. Instead, various new concepts of high current cable, in which tape shaped HTSs are assembled, have been proposed. However, a drawback of such HTS cables and, indeed, HTSs themselves, is the monofilament structure of HTSs. It causes large ac losses in time-dependent magnetic fields and large shielding-current-induced fields (SCIFs), which deteriorate field qualities of magnets and might lead to the delamination of coated conductors with layered structure.

We proposed a novel HTS cable concept, in which copper-plated multifilament (striated) coated conductors are wound spirally on a round metal core. We named it SCSC cable standing for spiral copper-plated striated coated conductor cable. In SCSC cables, high current capacities can be attained by assembling coated conductors in multiple layers. The spiral geometry of multifilament coated conductors play an equivalent role to the twist geometry in LTSs in order to decouple filaments and, then, to reduce ac losses and SCIFs effectively.

In the presentation, ac loss characteristics, current transport characteristics, and the fabrication of SCSC cable using reel-to-reel cabling machine will be reported.

This work was supported by JST-Mirai Program Grant Number JPMJMI19E1, Japan.

Abstract ID: 287

REMOVING FORCES BETWEEN CURRENT WIRES IN ELECTROMAGNETS USING BULK SUPERCONDUCTORS

Natanael Bort-Soldevila, Jaume Cunill-Subiranas, Alvaro Sanchez

Departament de Física, Universitat Autònoma de Barcelona, 08193 Bellaterra, Barcelona, Catalonia, SPAIN
E-mail: natanaeljose.bort@uab.cat

Some of the most important technological challenges of today's society, such as fusion reactors for future unlimited energy, particle accelerators, or ultra-high field magnets for scientific and industrial uses require precise spatial shapes of strong magnetic fields. Some of the main limitations for achieving these kinds of fields are the huge forces between cables of the system and the fact that the desired field always should be obtained as a superposition of fields created by current wires. Here we introduce a way by which bulk superconductors (SC) can be used as scaffolds for building the desired magnetic field, with current-carrying wires embedded in them. The bulk SC directly shapes the magnetic field, as the magnetic field lines will always appear parallel to its surface, providing a larger freedom on how to shape the magnetic field by shaping the SC surface. By placing wires on different holes of the bulk SC one can remove the force between them. All of this is demonstrated by finite-element numerical simulations and proof-of-concept experiments. These ways of creating magnetic fields and removing the forces between the field sources can be applied to present-day ultra-high field magnets, by lowering their internal tensions. Also, with this strategy one could gain freedom on the design of strong magnetic fields.

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Abstract ID: 347

THE RESEARCH STATUS OF YBCO AND Bi2212 CICC FOR FUTURE FUSION REACTOR

Jinggang Qin, HTS group

Institute of Plasma Physics, Chinese Academy of Sciences, PO Box 1126, Hefei Anhui230031, CHINA
E-mail: qinjg@ipp.ac.cn

High magnetic field is one of the important conditions required for lots of scientific researches. High temperature superconducting (HTS) materials have the potential to generate a magnetic field beyond the level obtainable with low temperature superconducting (LTS) materials. According to the commercial production technology development of the high temperature superconducting materials, the ReBCO and Bi2212 are the promising candidates. The maximum field of CFETR magnet will be higher than 15T. In order to achieve the magnet field of CFETR, the ReBCO and Bi2212 conductor/coil technology was developed at ASIPP. To maximize their advantages and overcome the shortcomings, concepts of cable design and lots of research activities were proposed and carried out in recent years. Here, the new research results obtained at ASIPP recently were reported.

Firstly, the full size YBCO CICC was designed, and R&D achieves good progress. One new YBCO cable with 316L spiral inside was proposed as one petal for full size conductor. The first sample achieves 12kA at 20T back field, and no degradation after about 20 EM cycles with 150kN/m and 10 WUCD cycles. The coil shows good stable performance under EM and temperature cycles. These are good basis for YBCO full size CICC for fusion reactor, which was planned to finish in June 2022.

Secondly, the Bi2212 cable obtained good progress. One new sample with pre-high pressure and 5MPa heat treatment was finished, which took 1 year to solve the problem. The testing results shows good performance, and critical current achieves 35.7kA@5.8T, 4.2K.

These results are good reference for development of HTS conductor of high field magnet for CFETR, accelerator, and so on. The future research plan of HTS conductor will be also described.

Abstract ID: 547

AC LOSS MODELLING IN HTS TRANSFORMERS BY ARTIFICIAL NEURAL NETWORKS

A. Cardoso[1], J. Murta-Pina[1,2], M. Ardestani[1], N. Vilhena[1,2], J. Rosas[1,2]

[1]*NOVA School of Science and Technology – FCT NOVA, Dept. of Electrical and Computers Engineering, 2829-516 Caparica, PORTUGAL*
[2]*UNINOVA, Centre of Technology and Systems, 2829-516 Caparica, PORTUGAL*
E-mail: jmmp@fct.unl.pt

High-temperature superconducting (HTS) materials are foreseen as enablers and promoters of the Energy Transition. HTS technologies can be integrated into any of the links of the electrical energy chain, namely generation, transmission and distribution, use, and storage, allowing for the development of new or improved solutions. The proper design of an HTS device requires a priori knowledge of AC losses under distinct operation conditions, as these dictate the rating of the cryogenic system. This is typically performed through highly computational-intensive numerical techniques, particularly the finite element method. Yet, other approaches, from the field of Artificial Intelligence, are arising. Among them, highlights the ones based on data-driven paradigms, able to learn the complex relations between the multiple subsystems and materials of the devices from operational data. In this work, such a methodology, based on Artificial Neural Networks (ANNs) is proposed and used to model AC losses in HTS transformers. A hierarchical methodology, based on the characterisation of losses on tapes, coils, and devices, is designed and assessed, with data obtained from experiments. The methodology is compared with the commonly used numerical methods, where a particular focus is given to the need for high volumes of varied data, which is discussed. A solution for this challenge is also proposed in the work.

Magnetic shape memory alloys and magnetocaloric I-II

08.05.2023 MONDAY

Abstract ID: 377

CROSS-COUPLING CONTRIBUTION TO THE MULTICALORIC EFFECT IN MAGNETIC MATERIALS

Lluís Mañosa[1], Enric Stern-Taulats[1], Adrià Gràcia-Condal[1,2], Antoni Planes[1]

[1]*Universitat de Barcelona, Dept. Física de la Matèria Condensada, 08028 Barcelona, Catalonia*
[2]*CELLS-ALBA Synchrotron, 08290 Cerdanyola del Vallès, Catalonia*
E-mail: lluis.manosa@fmc.ub.edu

Multicaloric effects result from the application or removal of diverse external fields and they are enhanced in materials with strong coupling between different degrees of freedom. Such a response is synergic when the monocaloric effects are both conventional (or both inverse) while it is non-synergic when one of the monocaloric effects is conventional and the other is inverse. Importantly, in all cases the multicaloric properties do not result from the simple addition of the monocaloric data because there is a contribution from the interplay between degrees of freedom (cross-coupling term). We will analyse the contribution of such a cross-coupling term to the multicaloric isothermal entropy change in both synergic and non-synergic materials. We will first discuss several model examples and then we will illustrate the realistic situation for prototype magnetostructural materials with synergic and non-synergic magnetocaloric and mechanocaloric effects [1-4].

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Abstract ID: 398

TUNING OF MAGNETIC PROPERTIES OF HEUSLER-TYPE GLASS-COATED MICROWIRES

V. Zhukova[1,2,3], M. Ipatov[1,2], P. Corte-León[1,2,3], J. Gonzalez[1,2], A. Zhukov[1,2,3,4]

[1]*Dept. Advanced Polymers and Materials: Physics, Chemistry and Technology, Univ. Basque Country, UPV/EHU San Sebastián 20018, SPAIN*
[2]*Dept. Appl. Phys., Univ. Basque Country EIG, UPV/EHU, 20018, San Sebastian, SPAIN*
[3]*IKERBASQUE, Basque Foundation for Science, 48011 Bilbao, SPAIN*
[4]*EHU Quantum Center, University of the Basque Country, UPV/EHU, SPAIN*
E-mail: arkadi.joukov@ehu.es

Studies of Heusler alloy have attracted considerable interest owing to a number of interesting features such as large magnetic field-induced strain, the ferromagnetic shape-memory effect, magnetic field induced martensitic transition, a substantial magnetocaloric effect (MCE) and the half-metallic behaviour [1].The conventional method for preparation of Heusler alloys is arc-melting followed by long high temperature annealing [1,2]. For increasing of the heat exchange rate the use of either thin wires or thin films is beneficial [1,2].

Glass-coated Ni-Mn-Ga microwires with a metallic nucleus diameter of d≈ 22μm and total diameter of D≈62 μm, respectively, have been prepared using master alloy with a nominal composition of $Ni_{50}Mn_{25}Ga_{25}$ (at.%) by a Taylor-Ulitovsky technique described elsewhere [1]. The preparation method (commonly referred to as the modified Taylor-Ulitovsky method or the quenching and drawing method) involves the simultaneous rapid melt quenching of a composite microwire (a metallic nucleus inside a glass capillary) when it passes through a stream of coolant (water). As-prepared Ni-Mn-Ga microwires at room temperature exhibit a very weak magnetization, M (see Fig1a). As-prepared samples additionally present magnetoresistance, MR, effect and considerable dependence of M(H) dependences (particularly M-values) on magnetic field values attributed to the magnetic and atomic disorder.

Annealing conditions strongly affect the temperature dependence of magnetization and Curie temperature of prepared microwires. A ferromagnetic ordering with Curie temperature near room temperature and features that can be interpreted as the first order phase transformation are observed in annealed samples (see Fig.1b). Aforementioned interpretation is confirmed by change of hysteresis loops measured at different temperatures: hysteresis loops measured at 260K and at T< 180K are rather different. Consequently we report on the preparation and processing of Heusler-type glass-coated Ni_2MnGa microwires exhibiting first order phase transition at heating after appropriate annealing.

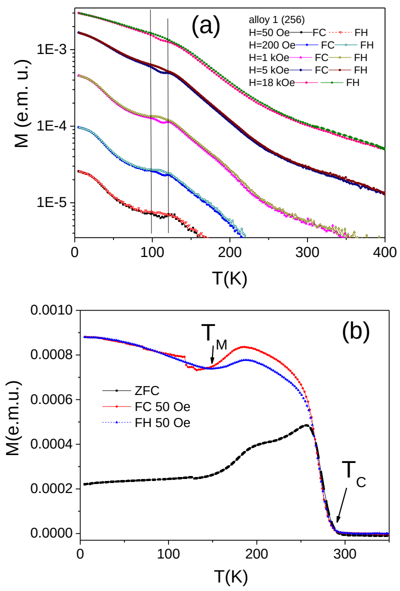

Fig. 1: *Temperature dependence of magnetic moment of as-prepared (a) and annealed (b) NiMnGa.*

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Abstract ID: 461

NATURE OF THE FREQUENCY DEPENDENCE OF THE ADIABATIC TEMPERATURE CHANGE NEAR T_C IN HEUSLER ALLOYS

Adler Gamzatov, Sh.K. Khizriev, A.M. Aliev

Amirkhanov Institute of Physics, DFRC, RAS, 367003, Makhachkala, RUSSIA
E-mail: gamzatov_adler@mail.ru

In recent years, the emergence of new types of materials with a giant magnetocaloric effect has greatly contributed to the development of magnetic cooling technology at room temperature. Heusler alloys Ni–Mn–Z (Z = In, Sn, Sb, and Ga) are of particular interest among such materials from both fundamental and applicable points of view, especially those alloys that do not contain expensive rare earth elements. The optimal operating frequencies of the magnetic refrigerating machines existing today are in the frequency range f=1-20 Hz and at these frequencies, magnetocaloric materials should retain their functional properties.

This paper presents the influence of magnetic field frequency (up to 20 Hz) and the long-term cyclic effect of magnetic fields (0.62 and 1.2) on the magnetocaloric performance of $Ni_{50}Mn_{28}Ga_{22-x}(Cu, Zn)_x$ (x=0; 1,5) and $Ni_{47}Mn_{40}Sn_{13}$ alloys by directly measuring the adiabatic temperature change (ΔT_{ad}).

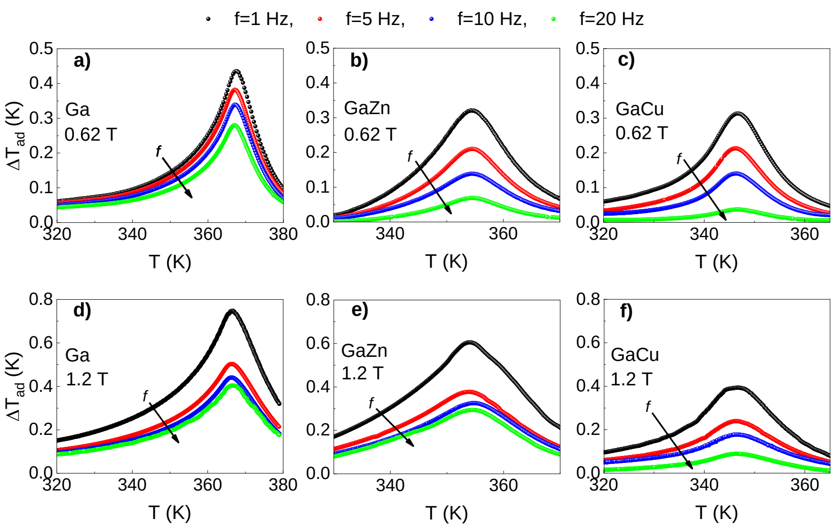

Fig. 1: *Temperature dependences of ΔT_{ad} for $Ni_{50}Mn_{28}Ga_{22-x}(Cu, Zn)_x$ alloys in magnetic fields of 0.62 and 1.2 T at frequencies of 1, 5, 10, and 20 Hz.*

As the frequency of the cyclic field increases, a monotonic decrease in ΔT_{ad} is observed (Fig.1(a-f)). Doping of the initial state with Zn and Cu leads both to a decrease in the value of ΔT_{ad} and to a stronger frequency dependence. The relative weak frequency dependence observed in the initial composition is a consequence of the inhomogeneous microstructure of the sample. We attribute the strong frequency dependence $\Delta T_{ad}(T,f)$ for compositions with Cu and Zn to a combination of two mechanisms: 1) heat dissipation at grain boundaries, 2) coexistence of martensite-austenite phases.

The study was supported by the Russian Science Foundation grant No. 22-19-00610.

Abstract ID: 264

MAGNETIC AND MAGNETOCALORIC PROPERTIES IN LOW TEMPERATURE ORDERED LAVES PHASE COMPOUNDS

J. Ćwik[1], Y. Koshkid'ko[1], K. Kowalska[1], B. Weise[2], N. de Oliveira[3]

[1]*Institute of Low Temperature and Structure Research, PAS, Okólna 2, 50-422 Wrocław, POLAND*
[2]*Leibniz IFW Dresden, Institute for Complex Materials, D-01069, Dresden, GERMANY*
[3]*Instituto de Física Armando Dias Tavares–Universidade do Estado do Rio de Janeiro, Rua São Francisco Xavier 524, 20550-013 Rio de Janeiro, RJ, BRAZIL*
E-mail: j.cwik@intibs.pl

The magnetocaloric effect (MCE) is an exciting topic of investigation in the field of condensed matter physics due to the link between magnetic and thermal properties of magnetic materials and their applicability in refrigeration technology. According to the literature data, some Laves phase compounds can become a potential magnetic refrigerants for low temperature applications such as hydrogen liquefaction. The magnetic properties of the $DyNi_2$ and $ErNi_2$ compounds have been studied intensively in [1]. The high MCE values of the compounds are strongly influenced by crystalline electric fields. Theoretical data show that some of Laves phase compounds exhibit high MCE [2,3]. Unique physical properties of RNi_2 compounds result from the high localized magnetic moments, which are derived from the incompletely filled 4*f*-electron shell of lanthanide atoms. The non-magnetic state of Ni atoms in these compounds results in low magnetic ordering temperatures because the wave functions derived from the lanthanides have a small range as compared to interatomic distances, and 4*f*-4*f* interactions are weak. Due to these features, some of the RNi_2 compounds exhibit high MCE and, therefore, show promise as ideal materials-refrigerants at low temperatures. In this work, the behaviour of magnetocaloric effect of polycrystalline $Dy_{1-x}Er_xNi_2$ solid solutions with x = 0.25, 0.5 and 0.75 at both low and high magnetic-field changes has been studied experimentally. The employment of direct measurements over a wide field range along with indirect methods allowed us to find high-field regularities of MCE in studied compounds, which was estimated as the adiabatic temperature and isothermal magnetic entropy changes. Temperature dependencies of isothermal magnetic entropy change were obtained using magnetization and heat capacity measurements, while the adiabatic temperature changes were determined directly using a measuring device designed and constructed by the authors and were derived from the experimental data on the heat capacity as well. The magnetocaloric parameters obtained for the phase-transition temperature range are discussed in the framework of Landau theory for the second-order phase transitions. Precise experimental characterization of the structure and magnetic properties of the $Dy_{1-x}Er_xNi_2$ solid solutions was also performed.

The work was supported by the National Science Center, Poland through the OPUS Program under Grant No. 2019/33/B/ST5/01853.

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Abstract ID: 453

THE PHASE DIAGRAMS OF Mn_2YSn HEUSLER ALLOYS WITH Y = Sc, Ti, V: INSIGHTS FROM *AB INITIO*

V. Sokolovskiy, M. Zagrebin, D. Baigutlin, V. Buchelnikov

Chelyabinsk State University, 454001, Chelyabinsk, RUSSIA
E-mail: vsokolovsky84@mail.ru

Half-metallic ferro- and ferrimagnetic alloys are the most interesting class of materials, since in them one direction of the spin has a metallic behavior, while the other shows a semiconductor character. In recent years, Mn_2-based Heusler alloys are especially attractive due to their interesting half-metallic properties and potential applications in the fields of spintronics and spin caloritronics [1, 2].

In the present work, we investigate the structural, magnetic and thermodynamic properties of Mn_2YSn (Y = Sc, Ti, and V) Heusler alloys under applied hydrostatic pressure within the density functional theory and the projected augmented wave method implemented in the VASP code [3]. For the exchange-correlation energy, the GGA-PBE functional was applied. We find that two magnetic reference states with low and high magnetic moment at the low and high crystal lattice volume, which are denoted as LMS and HMS. The LMS is characterized by the half-metallic behavior, while the HMS is distinguished by the metallic behavior. Both phases can coexist together due to the almost equal energy under applied pressure of 3.4, -2.9 and -3.25 GPa for Mn_2ScSn, Mn_2TiSn, and Mn_2VSn, correspondingly (see Fig. 1(a)). It is obvious from Fig. 1(b), that both phases LMS with 1.98 μ_B and HMS with 4.1 μ_B can coexist together at 700 K and 0 GPa. However, the lattice contraction under 2 GPa leads to the phase coexistence at 300 K.

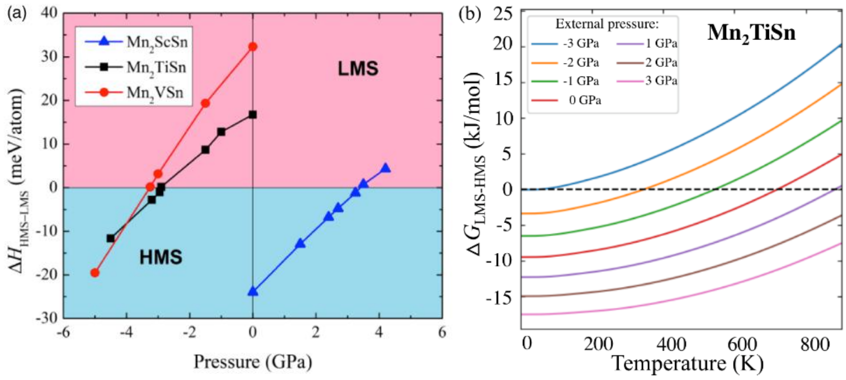

Fig. 1: *(a) Enthalpy difference ΔH as a function of applied pressure for Mn_2YSn at zero temperature. (b) Gibbs energy difference ΔG as a function of temperature for Mn_2TiSn at various pressures.*

This work was supported by the RSF-Russian Science Foundation No. 22-12-20032.

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Abstract ID: 530

INVESTIGATION OF THE CONTRADICTORY ROLE OF TEMPERATURE AND MAGNETIC FIELD IN META-MAGNETIC SHAPE MEMORY ALLOY VIA FRACTION METHOD

S. Yuce[1], E. Kavak [2], O. Yildirim[3], N. M. Bruno[4], B. Emre[2]

[1]*Department of Physics, Science and Literature Faculty, Ondokuz Mayis University, Kurupelit 55139, Samsun, TURKEY*
[2]*Department of Engineering Physics, Faculty of Engineering, Ankara University, Ankara, 06100, TURKEY*
[3]*Empa-Swiss Federal Laboratories for Material Science and Technology, CH, 8600, Dübendorf, SWITZERLAND*
[4]*South Dakota School of Mines and Technology, Department of Mechanical Engineering, Rapid City, SD 57701, USA*
E-mail: syuce@omu.edu.tr

Caloric effect of materials refers to the temperature change resulting from the applied external field [1]. This response is called magnetocaloric, barocaloric, elastocaloric, and electrocaloric when the applied external field is magnetic, pressure, stress, and electric, respectively [1]. Among them, magnetocaloric effect is the superstar in the caloric effect community. The magnetocaloric community scientist have spent time working on the correct determination magnetic entropy change. In the literature there are some works which describes the methods to correct determination of magnetocaloric effect from the isothermal magnetization curves. In this study, we examine a magnetic shape memory alloy (MSMA) in order to illustrate the nature of the of inverse magnetocaloric materials. We calculated the magnetic entropy change of MSMA by two methods: the fraction method and the Maxwell relation. We show that the dilemma of inverse magnetocaloric materials can be depicted by the contradictory roles of the temperature and magnetic field.

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Abstract ID: 532

DEMONSTRATION OF THE DILEMMA OF INVERSE MAGNETOCALORIC MATERIALS IN A MAGNETIC SHAPE MEMORY ALLOY (MSMA)

B. Emre[1], S. Yuce[2], E. Kavak[1], M.M. Cicek[1,3], O. Yildirim[4], E. Duman[5], F. Albertini[6], S. Fabbrici[6]

[1]*Department of Engineering Physics, Faculty of Engineering, Ankara University, Ankara, 06100, TURKEY*
[2]*Department of Physics, Science and Literature Faculty, Ondokuz Mayis University, Kurupelit, 55139 Samsun, TURKEY*
[3]*REHIS LTCC and Thin Film Dept., Aselsan Inc., Ankara 06830, TURKEY*
[4]*Empa-Swiss Federal Laboratories for Material Science and Technology, CH, 8600, Dübendorf, SWITZERLAND*
[5]*Department of Energy Eng., Faculty of Engineering, Ankara University, Ankara, TURKEY*
[6]*Institute of Materials for tute of Materials for Electronics and Magnetism, National Research Council (IMEM-CNR), Parco Area delle Scienze 37/A, I-43124 Parma, ITALY*
E-mail: bemre@eng.ankara.edu.tr

Refrigeration has become one of the main demands of the human being's daily life. The universal spread of refrigerators, air conditioners, however, leads to an enormous energy consumption. In addition, according to the report of International Energy Agency (IEA) the use of energy for space cooling is growing faster than for any other end used in buildings [1, 2]. The rapid increase of energy demand for refrigeration will lead to energy crisis called 'cold crunch' [1]. Thereby, the steps to prevent such a crisis are a hot topic for a wide range of scientist and researchers. From the point of view of material science, caloric cooling based on caloric effects is a promising step. Caloric effects occur in many materials due to entropy changes induced by external fields, moreover they are named according to these external fields. Hence, inducing the entropy changes by means of magnetic field, pressure, uniaxial stress and electric field gives rise to the magnetocaloric, the barocaloric, elastocaloric and electrocaloric effects, respectively.

In this work, we examine the nature of the inverse magnetocaloric effect. In this respect, we produced $Ni_{49}Ti_{1}Mn_{36}In_{14}$ Heusler alloy and investigate the nature of the phase transitions by thoroughly studying its thermal, magnetic, and magnetocaloric properties. By analyzing the magnetic behaviors and magnetocaloric properties, the competition of magnetic and lattice contribution to the total entropy change is investigated. At last, the mutually contradictory role of magnetic and lattice contributions is experimentally demonstrated with a simple method.

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Abstract ID: 571

ADVANCES IN ADDITIVE MANUFACTURING OF METAMAGNETIC SHAPE MEMORY ALLOYS FOR MAGNETOCALORIC APPLICATIONS

Daniel Salazar

BCMaterials, Basque Center for Materials, Applications and Nanostructures, UPV/EHU Science Park, Leioa 48940, SPAIN

E-mail: daniel.salazar@bcmaterials.net

The current social challenges demand new energy-efficient technologies and the ability of obtaining 3D structures in a green and a cost-effective way. Recent progress in caloric materials (magneto- or elasto-caloric) as part of the next generation energy saving devices open new possibilities to explore future technological developments in additive manufacturing. In this way. metamagnetic shape memory alloys are promising candidates for magnetic refrigeration due to their high entropy change around the first-order martensitic transformation, but their crystalline phase is unstable at high temperatures (>300 ºC).

In this work, we developed original inks and pastes to be implemented in extrusion printing techniques at room temperature to fabricate complex 3D structures using high performance NiMnSn-based magnetocaloric powders. Cellulose and water were used as green matrix and solvent, respectively. The ink containing more than 85 wt.% of powder was elaborated by achieving an optimum viscosity whereby a high maximum number of layers (250 layers were reached) was obtained with the highest printing resolution (0.5mm wall thickness).

The proposed technological route for the treatment of the printed structures includes: (i) special heat treatments to dry the printed structures so that the polymer is removed by calcination followed by sintering to get an all-metal structure, and (ii) nickel electrodeposition to protect the printed structure from any corrosion. We also demonstrated that any incorrectly printed workpiece can be recycled by dissolving it in water, so the material loss is significantly reduced, making printing more cost-efficient and environmentally friendly.

Magnetization Dynamics and Magnonics I-II

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Abstract ID: 116

THz-FIELD-INDUCED TRANSIENT MAGNETIZATION IN THE QUANTUM PARAELECTRIC DIAMAGNET $KTaO_3$

Filip Kadlec[1], Christelle Kadlec[1], Stanislav Kamba[1], André Maia[1], Sergey Kovalev[2], Jan-Christoph Deinert[2], Igor Ilyakov[2], Martina Basini[3], Stefano Bonetti[3,4]

[1]*Institute of Physics of the Czech Academy of Sciences, Prague, CZECH REPUBLIC*
[2]*Helmholz Zentrum Dresden-Rossendorf, GERMANY*
[3]*Stockholm University, SWEDEN*
[4]*Ca' Foscari University of Venice, ITALY*
E-mail: kadlecf@fzu.cz

The possibility that a transient magnetization appears in non-magnetic crystals was theoretically predicted by Juraschek *et al.* [1]. The proposed mechanism consists in exciting two degenerate perpendicularly polarized optical phonons with a circularly polarized THz beam. That publication, and later the one by Dunnet *et al.* [2], suggested it should be possible to induce a transient magnetoelectric multiferroicity in materials which are close to their ferroelectric quantum critical points. In fact, fluctuating electric dipoles linked to the soft phonons could induce magnetization, whereas THz pumping of the soft phonon mode would break the inversion symmetry, inducing a transient ferroelectric polarization.

No experimental confirmation of the predicted transient magnetization has been published so far. Recently, we conducted THz pump–optical probe experiments at the TELBE beamline of the free-electron laser in Dresden-Rossendorf. We studied a flat parallelepiped-shaped single crystal of the quantum paraelectric $KTaO_3$, which revealed transient magnetization and ferroelectricity.

The discovered magneto-optic Faraday effect is much stronger than expected from the theory. Moreover, the THz pump-induced transient birefringence was detected after pumping not only by a circularly polarized THz beam pump, but also using a linearly polarized beam. We explain this by the THz field-induced electro-optic Kerr effect. Since the excited phonons were polarized in the sample plane, the induced magnetization has to be perpendicular to the sample plane. Then, in theory, the magnitude of the transient birefringence should be the same after pumping using clockwise and anticlockwise circularly polarized THz radiation, which was not the case. We explain our observations by a combination of Faraday and Kerr effects, together with the directional dichroism which is allowed in non-centrosymmetric diamagnetic systems exposed to magnetic field [3]. The observed effects are most prominent at temperatures where the pump pulse is resonant with the soft phonon frequency, which confirms that the initially proposed mechanism [1] is at the origin of the detected behavior.

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Abstract ID: 465

DYNAMICS AND REVERSIBLE CONTROL OF THE VORTEX BLOCH POINT DOMAIN WALL IN SHORT CYLINDRICAL MAGNETIC NANOWIRES

Diego Caso[1], Pablo Tuero[1], Javier Garcia[1], Konstantin Y. Guslienko[2], Farkhad G. Aliev[1,3]

[1]Departamento Fısica de la Materia Condensada C03, Universidad Autonoma de Madrid, Madrid 28049, SPAIN
[2]Departamento Polımeros y Materiales Avanzados: Fısica, Quımica y Tecnologıa, Universidad del Paıs Vasco, UPV/EHU, 20018 San Sebastian, SPAIN
[3]IFIMAC and INC, Universidad Autonoma de Madrid, Madrid 28049, SPAIN
E-mail: farkhad.aliev@uam.es

Spin waves in quasi one-dimensional structures have recently attracted much attention. For example, numerical and experimental studies allowed observation of spin waves channeling along domain walls in circular [1] and triangular [2,3] dots (Winter magnons) in the ground or metastable states. These waves could be generalized for arbitrary shapes and stimulate the development of new devices such as edge spin wave interferometers, controllers or splitters [2]. Three-dimensional magnetic nanotextures belong to an emerging field in the fundamental and applied science. In contrast to the two-dimensional textures existing in thin films and dots, they significantly enhance the diversity of the possible magnetic topologies, opening the door to a radically new useful for applications effects. Fast and efficient switching of nanomagnets is one of the main challenges in the development of future magnetic memories.

Here we numerically investigate the evolution of the static and dynamic spin wave (SW) magnetization in short (50-400 nm length and 120 nm diameter) cylindrical ferromagnetic nanowires, where competing single vortex (SV) and vortex domain wall with a Bloch point (BP-DW) magnetization configurations could be formed [4]. For a limited nanowire length range (between 150 and 300 nm) we demonstrate a reversible microwave field induced (forward) and opposite spin currents (backwards) transitions between the topologically different SV and BP-DW states. By tuning the nanowire length, excitation frequency, microwave pulse duration and spin current values we show that the optimum (low power) manipulation of the BP-DW could be reached by a microwave excitation tuned to the main SW mode and for nanowire lengths around 230-250 nm, where single vortex domain wall magnetization reversal via nucleation and propagation of SV-DW takes place. An analytical model for dynamics of the Bloch point provides an estimation of the gyrotropic mode frequency close the one obtained via micromagnetic simulations. A practical implementation of the method on a device has been proposed involving microwave excitation and the generation of the opposite spin currents via spin orbit torque. Our findings open a new pathway for the creation of unforeseen topological magnetic memories.

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Abstract ID: 584

DYNAMICS OF MAGNETIZATION IN CHIRAL MAGNETIZATION TEXTURES

M. Zelent, M. Moalic, K. Kotus, P. Gruszecki, M. Krawczyk

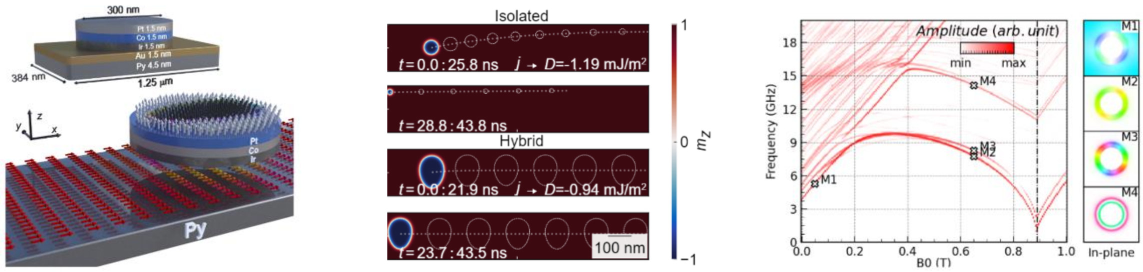
Institute of Spintronics and Quantum Information, Faculty of Physics, Adam Mickiewicz University, Poznan, PL-61-614, POLAND

E-mail: mateusz.zelent@amu.edu.pl

Nontrivial magnetization textures, such as skyrmions and vortices, have become a driving force in the field of magnetism due to their enormous potential for processing and transporting information. The ability to encode information in spin textures or spin waves can lead to the development of magnonic devices that are more space-efficient than optical devices and more energy-efficient than current electronics.

In this presentation, we will demonstrate that a Néel-type skyrmion confined within a nanodot placed on top of a ferromagnetic in-plane magnetized stripe provides a unique and compelling platform to investigate the dynamics of spin waves and magnetization textures in hybrid structures (see Fig. 1(a)). We will discuss the consequences of skyrmion stabilization in that hybrid structure and spin wave coupling between propagating modes in the stripe, and skyrmion excitations. Moreover, we will present a technique for the unconstrained transport of skyrmions along a hybrid racetrack (see Fig. 1(b)) [1].

We will also discuss the interesting properties of a magnonic crystal that utilizes a periodic array of antidots with artificially-induced patterns with vortex-like magnetization textures around them (see Fig. 1(c)). We will analyze the dynamic coupling between edge-localized and bulk modes in the film and show the collective behavior on the lattice, as well as the promising magnonic applications [2].



(a) **(b)** **(c)**

Fig. 1: *Visual representation of the Pt/Co/Ir multilayer dot is separated by a 1.5 nm thick Au layer from the 4.5 nm thick Py stripe. (b) Illustration of skyrmion moving trajectory driven by a sequence of electric current pulses in isolated and hybrid racetrack. (c) Spin-wave resonance spectra dependence on the amplitude of the external magnetic field for the ADL with vortex-like rim, and modes visualization.*

The research has received funding from the Polish National Science Centre, projects 2018/30/Q/ST3/00416 and 2020/37/B/ST3/03936.

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Abstract ID: 326

MUTUAL SYNCHRONIZATION OF ANTIFERROMAGNETIC SPINTRONIC OSCILLATORS

A. Mitrofanova[1,2], A. Safin[1,3], O. Kravchenko[1], O. Temnaya[1], S. Nikitov[1,2]

[1]*Kotel'nikov Institute of Radioengineering and Electronics, RAS, 125009, Moscow, RUSSIA*
[2]*Moscow Institute of Physics and Technology, 141701, Dolgoprudny, RUSSIA*
[3]*National Research University "MPEI", 111250, Moscow, RUSSIA*
E-mail: arsafin@gmail.com

Recent studies into the properties of spintronic oscillators have led to broadening their scope of practical application as devices for generating and processing signals [1]. The practical implementation of spintronic oscillators is, however, significantly limited by their low power capacity, thus requiring synchronization between devices. Thus, it is important to determine conditions for the implementation of the synchronous regime of two antiferromagnetic (AFM) spintronic oscillators coupled by a common current. To simplify the numerical simulation of a system of coupled resistively AFM oscillators, the method of multiple-time-scale analysis was applied [2]. This allowed a system of generalized Kuramoto equations with inertial term to be considered instead of the original system. Expressions describing the locking and synchronization band as functions of the system parameters (bias currents and sizes) were derived. The results of the numerically simulated Kuramoto model with two obtained regimes are demonstrated in Fig. 1, and they agree well with the theoretically calculated values of locking and synchronization ranges. The scheme for reducing the model of antiferromagnetic oscillators to a Kuramoto model can be further extended to the case of a larger number of coupled oscillators, which will simplify computational experiments and significantly reduce the time required for numerical simulations.

This work was supported by Russian Science Foundation (Project No. 21-79-10396.).

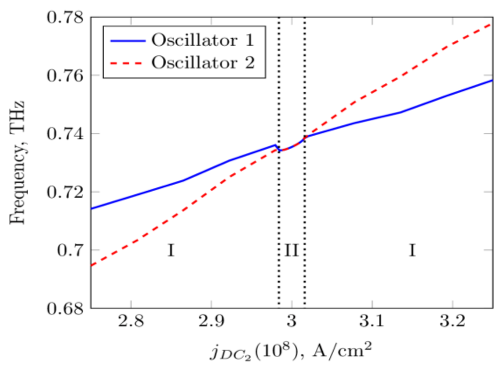

Fig. 1: *Dependence of the frequency of self-oscillations of two coupled antiferromagnetic oscillators demonstrating two possible regimes, which are asynchronous regimes I and the synchronous regime II.*

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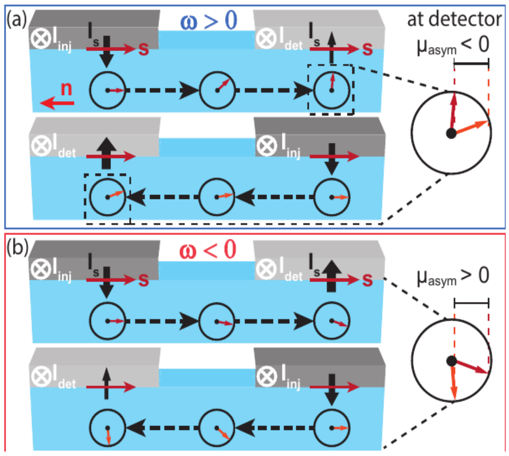
Abstract ID: 518

NONRECIPROCAL MAGNON TRANSPORT AND HANLE EFFECT IN HEMATITE

J. Gückelhorn[1,2], S. de-la-Peña[3], M. Grammer[1,2], M. Scheufele[1,2], M. Opel[1], S. Geprägs[1], J. C. Cuevas[3], R. Gross[1,2,4], H. Huebl[1,2,4], A. Kamra[3], M. Althammer[1,2]

[1]*Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, GERMANY*
[2]*Physik-Department, Technische Universität München, Garching, GERMANY*
[3]*Condensed Matter Physics Center (IFIMAC) and Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, Madrid, SPAIN*
[4]*Munich Center for Quantum Science and Technology (MCQST), München, GERMANY*
E-mail: akashdeep.kamra@uam.es

The precession of magnon pseudospin about the equilibrium pseudofield, the latter capturing the nature of magnonic eigen-excitations in an antiferromagnet, gives rise to the magnon Hanle effect. Its realization via electrically injected and detected spin transport in an antiferromagnetic insulator demonstrates its high potential for devices and as a convenient probe for magnon eigenmodes and the underlying spin interactions in the antiferromagnet. Here, we observe a nonreciprocity in the Hanle signal measured in hematite (blue) using two spatially separated platinum electrodes (gray) as spin injector/detector. Interchanging their roles was found to alter the detected magnon spin signal. The recorded difference depends on the applied magnetic field and reverses sign when the signal passes its nominal maximum at the so-called compensation field. We explain these observations in terms of a spin transport direction-dependent pseudofield. The latter leads to a nonreciprocity, which is found to be controllable via the applied magnetic field. The observed nonreciprocal response in the readily available hematite films opens interesting opportunities for realizing exotic physics predicted so far only for antiferromagnets with special crystal structures.



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Abstract ID: 581

A SPINWAVE TIME-MULTIPLEXED ISING MACHINE

A. Litvinenko[1], R. Khymyn[1], V. Gonzalez[1], A.A. Awad[1], V. Tyberkevych[2], A. Slavin[2], J. Åkerman[1,3]

[1]*University of Gothenburg, 412 96, Gothenburg, SWEDEN*
[2]*Department of Physics, Oakland University, 48309, Rochester, Michigan, USA*
[3]*Tohoku University, 980-8577, Sendai, JAPAN*
E-mail: artem.litvinenko@physics.gu.se

Here we develop a compact and power-efficient time-multiplexed Ising Machine (IM) exploiting spinwave phenomena [1]. The spinwave Ising Machine (SWIM) circuit is a ring oscillator operating in an RF pulsed regime with an additional feedback system implemented with microwave delay cables (Fig. 1). The main loop consists of linear and parametric amplifiers, a YIG spinwave delay line where the spinwave RF pulses propagate, and an RF switch that ensures the formation of RF pulses in the ring. The feedback circuit consists of two coupling delay lines implemented with microwave cables followed by a variable phase shifter and an attenuator and connected to the main loop via RF couplers. A phase-sensitive amplifier (PSA) limits conditions for stable oscillations in the SWIM ring circuit to only RF pulses at either phase 0 or π relative to a pumping reference signal ω_{ref} at 6.25 GHz.

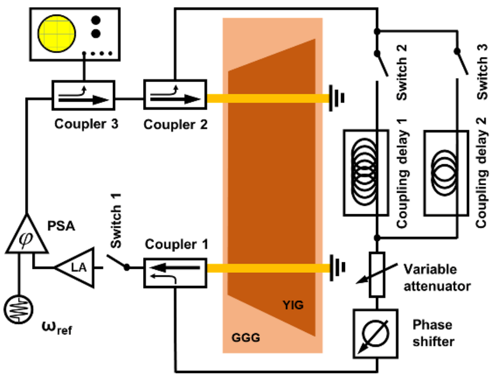

Fig. 1: *A schematic of a spinwave-based time-multiplexed Ising machine.*

We evaluated the computational performance of the SWIM with 4-spin and 8-spin MAX-CUT optimization problems. The weak coupling of –8 dB between nearest neighbour spins is implemented with coupling delay cable 1 and 2, correspondingly. It takes 3.8 μs or approximately 14 circulation periods for SWIM to evolve to a stable and optimal state for MAX-CUT optimization problem. The SWIM consumes only 2 W of power and, therefore, requires only 7 μJ to compute the solution of simple 4-spin and 8-spin MAX-CUT problems.

Our work creates a pathway for miniature low-power and commercially feasible Ising machines for solving a wide range of optimization problems.

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Abstract ID: 582

DIRECT OBSERVATION OF PROPAGATING SPIN WAVES WITH LARGE NON-RECIPROCITY

R.A. Gallardo[1], M. Weigand[2], K. Schultheiss[3], A. Kákay[3], R. Mattheis[4], J. Raabe[5], G. Schütz[6], A.M. Deac[7], J. Lindner[3], S. Wintz[6]

[1]*Universidad Técnica Federico Santa María, Valparaiso, CHILE*
[2]*Helmholtz-Zentrum Berlin für Materialien und Energie, 12489 Berlin, GERMANY*
[3]*Institute for Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, 01328, Dresden, GERMANY*
[4]*Leibniz Institut für Photonische Technologien, 07745, Jena, GERMANY*
[5]*Paul Scherrer Institut, 5232, Villigen PSI, SWITZERLAND*
[6]*Max-Planck-Institut für Intelligente Systeme, 70569, Stuttgart, GERMANY*
[7]*Dresden High Magnetic Field Laboratory, Helmholtz-Zentrum Dresden-Rossendorf, 01328, Dresden, GERMANY*
E-mail: sebastian.wintz@psi.ch

Non-reciprocal wave propagation occurs in systems with broken time-reversal symmetry, and is essential to the functionality of devices, such as circulators, in microwave, photonic and acoustic applications. In magnetic systems, spin waves were found to yield only moderate dispersion non-reciprocities so far, e.g. [1–3].

Here, we demonstrate the direct observation of propagating coherent spin waves with large non-reciprocity in a patterned element of an antiparallel ferromagnetic bilayer stack [4,5]. We use time-resolved scanning trans- mission x-ray microscopy (TR-STXM) to image the collective spin-wave dynamics at wavelengths (λ) ranging from 5 µm down to 100 nm, corresponding to frequencies between 500 MHz and 5 GHz (see Figure 1). The non-reciprocity factor of these counter-propagating waves is found to be larger than 10 with respect to both wavelengths and group velocities. Our experimental results are supported by numeric calculations solving an analytic theory that is also predicting caustic spin-wave focusing effects to emerge in the system.

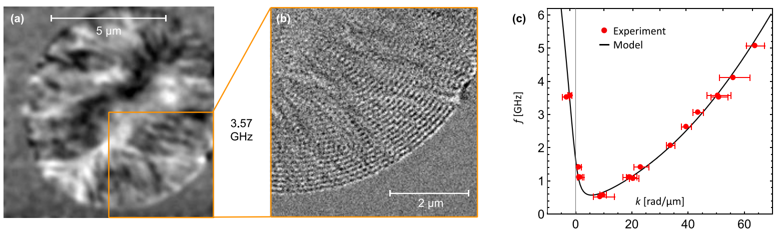

Fig. 1: *Non-reciprocal spin-wave propagation, adapted from [5]. (a,b) TR-STXM micrographs (snapshots) showing the normalized dynamic perpendicular magnetic deflection at an excitation frequency of 3.57 GHz. (a) Long-λ branch with outward phase propagation (blurred to mask short-λ waves), (b) zoom-in of short-λ branch with inward propagating phase. (c) Non-reciprocal spin-wave dispersion relation, experimental data points (red dots) and modeled curve (black line).*

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Novel Functional Magnetic Materials – Basic Approach and Applications I-II

08.05.2023 MONDAY

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ULTRA-RAPIDLY ANNEALED HIGH-Bs Fe(Co)-BASED SOFT MAGNETIC NANOCRYSTALLINE ALLOYS FOR APPLICATIONS AT ELEVATED TEMPERATURES

Ivan Škorvánek[1], Branislav Kunca[1], Jozef Marcin, Peter Švec[2]

[1]*Institute of Experimental Physics, Slovak Academy of Sciences, 040 01 Košice, SLOVAKIA*
[2]*Institute of Physics, Slovak Academy of Sciences, 842 28 Bratislava, SLOVAKIA*
E-mail: skorvi@saske.sk

The continuing interest in FeCo-based nanocrystalline alloys prepared by crystallization of metallic glass ribbons is motivated mainly due to the combination of high saturation magnetic flux density with good magnetic softness and their capability to operate at elevated temperatures. A further improvement of magnetic performance in these alloys is possible by using a careful compositional tuning as well as by employing special processing techniques resulting in optimal phase content and reduced grain sizes. Special attention of our work is focused on ultra-rapid annealing technique that utilizes a compression of samples between pair of pre-heated Cu blocks [1]. Here, very high heating rates and short processing times result in a formation of smaller nanocrystalline grains as compared to conventional furnace annealing. Selected results showing the impact of rapid annealing on the soft magnetic properties will be presented for series of high-Bs Fe-Co-B-(Cu) and Fe-(Co)-Sn-B alloys with a reduced metalloid content. Examples of testing the high temperature soft magnetic behavior in investigated alloys will be briefly discussed. These experiments revealed that ultra-rapidly annealed high-Bs Fe-Co-B-(Cu) alloys exhibit a very good thermal stability of soft magnetic characteristics in temperature range 30 – 250°C, which makes them promising soft magnetic materials for applications at elevated temperatures [2].

Acknowledgement: This work was supported by the projects APVV-19-0369 and VEGA 2/0148/23.

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Abstract ID: 413

KONDO-LIKE BEHAVIOR AND GMR EFFECT IN Co-Cu GRANULAR ALLOYS AND MULTILAYERS

R. López Antón[1], J.P. Andrés[1], J.A. Gónzalez[1], M. Ipatov[2,3], V. Zhukova[2,3,4], J. Gónzalez[2,3,4], M. Salaheldeen[2,3,4,5], A. Zhukov[2,3,4,6]

[1] *Instituto Regional de Investigación Científica Aplicada (IRICA) and Departamento de Física Aplicada, Universidad de Castilla-La Mancha, 13071, Ciudad Real, SPAIN*
[2] *Dpto. de Polímeros y Materiales Avanzados, Fac. Química, Universidad del País Vasco, UPV/EHU, 20018, San Sebastián, SPAIN*
[3] *Dpto. de Física Aplicada, EIG, Universidad del País Vasco, UPV/EHU, 20018, San Sebastián, SPAIN*
[4] *EHU Quantum Center, University of the Basque Country, UPV/EHU, SPAIN*
[5] *Physics Department, Faculty of Science, Sohag University, 82524, Sohag, EGYPT*
[6] *Ikerbasque, Basque Foundation for Science, 48011, Bilbao, SPAIN*
E-mail: ricardo.lopez@uclm.es

Co-Cu Granular alloys and multilayers have attracted considerable attention since the beginning of 1990s, due to the existence of giant magnetoresistance (GMR) effect in those materials [1,2]. Solubility of Co in Cu at room temperature is almost negligible but several preparation methods allow to obtain a metastable solid solution of a small quantity of Co in Cu. Additionally, it is also noteworthy the observation of Kondo-like resistivity minimums versus temperature in as-prepared and annealed Cu-Co microwires in the last years [3, 4]. Hence, we have studied these phenomena in granular alloys obtained by different methods (melt-spinning, sputtering and gas aggregation), also checking the effect of thermal treatments in their properties [5]. In figure 1, GMR curves are shown for samples obtained by sputtering (sp) and gas agreggation (ag). Currently, we are studying if the Kondo-like minimum also appears in multilayer system (more appropriate for GMR applications) due to interdiffusion at the interfaces.

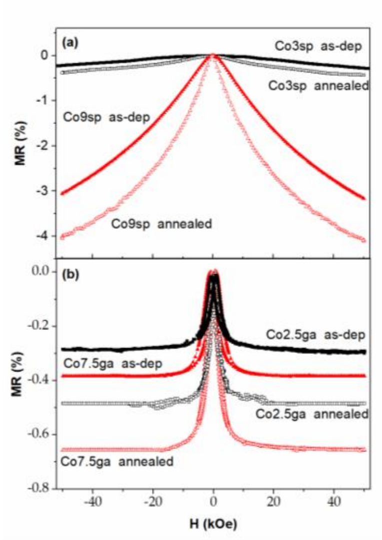

Fig. 1: *Magnetoresistance loops of the samples obtained by sputtering (a) and sputter gas aggregation (b), in both cases as-deposited and annealed. (from [5]).*

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Abstract ID: 425

XTREMED: A NEW SINGLE CRYSTAL AND POWDER DIFFRACTOMETER DESIGNED FOR MEASUREMENTS AT EXTREME CONDITIONS OF PRESSURE AND MAGNETIC FIELDS

J. Campo[1], S. Savvin[1], J.A. Rodríguez-Velamazán[2]

[1]*Instituto de Nanociencia y Materiales de Aragón, CSIC - Universidad de Zaragoza, 50009, Zaragoza, SPAIN*
[2]*Institut Laue-Langevin, 38042, Grenoble, FRANCE*
E-mail: javier.campo@csic.es

Neutron diffraction has unique capabilities for the research under extreme conditions, mainly in two large areas: crystallography/geosciences and magnetism/solid-state physics. The growing interest for these problems is attested by the quantity and quality of publications, by the number of experiments proposed at the different neutron sources and by the new instrumentation projects under development all around the world. Therefore, the project for the construction of an "eXtreme conditions Diffractometer (XtremeD)" at Institut Laue-Langevin for both single crystals and powders, operating at high pressures (> 30 GPa) and high magnetic fields (up to 15-17 Tesla), is being considered and will be presented here [1].

The scientific areas in which the projected instrument can make significant contributions and the main technical characteristics of the project are discussed in this presentation. The main idea of XtremeD is to combine a large solid-angle detector with an optional highly-focused beam on the sample, thus providing high flux while maintaining low background. The principal features of XtremeD will be the following:

- Optimisation for small samples: optional and variable focusing optics (choice of the focusing point).
- Large 2D position-sensitive detector for powders and single crystals.
- Sample environment adapted for high pressure (variety of pressure cells, up to 30 GPa for the moment, but with a goal of 50 GPa after the envisaged developments) and high magnetic fields (up to 15 Tesla in continuous mode, with the possibility of higher pulsed fields).
- Radial oscillating collimator and neutron shielding to suppress background.
- Choice of monochromators (Si, PG), take-off angles (40º-120º), and wavelengths (0.9– 4 Å).

The scientific possibilities that this instrument will provide and the main technical characteristics of the instrument performance in different conditions will be the focus of this presentation.

The Scientific Advisory Committee and the Working Team of XtremeD are acknowledged for the preparation of the scientific case and for the realization of the technical project, respectively.

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Abstract ID: 397

ADVANCED FUNCTIONAL MAGNETIC MICROWIRES FOR TECHNOLOGICAL APPLICATIONS

A. Zhukov[1,2,3,4], M. Ipatov[1,2], P. Corte-León[1,2,3,], A. Gonzalez[1,2,3], A. García- Gomez[1,2,3], J.M. Blanco[2,3], V. Zhukova[1,2,3]

[1]*Dept. Advanced Polymers and Materials: Physics, Chemistry and Technology, Univ. Basque Country, UPV/EHU San Sebastián 20018, SPAIN*
[2]*Dept. Appl. Phys., Univ. Basque Country EIG, UPV/EHU, 20018, San Sebastian, SPAIN*
[3]*IKERBASQUE, Basque Foundation for Science, 48011 Bilbao, SPAIN*
[4]*EHU Quantum Center, University of the Basque Country, UPV/EHU, SPAIN*
E-mail: arkadi.joukov@ehu.es

Amorphous magnetic wires have attracted great attention owing to their superior soft magnetic, mechanical and corrosion properties. Excellent magnetic properties such as magnetic bistability or Giant Magnetoimpedance (GMI) effect are suitable for various technological applications [1]. Recent tendency in devices miniaturization stimulated development of thin (few μm diameters) microwires. Generally, better magnetic softness and higher GMI effect have been observed in Co-rich amorphous microwires (Fig1b), while Fe-rich amorphous microwires present spontaneous magnetic bistability related to remagnetization process through fast domain wall propagation (see Fig.1a). Less expensive Fe-rich microwires are preferable for the applications, but exhibit rather high magnetostriction coefficient, λ_s, and hence present quite low GMI effect. We designed the post- processing allowing remarkable optimization of magnetic properties of Fe- and Fe-Co based glass-coated microwires [1,2]. Stress annealing of Fe-rich microwires allows considerable magnetic softening (Fig.1c), GMI effect enhancement and remarkable improvement of domain wall dynamics. In Co-rich microwires stress-annealing allows better magnetic softness (Fig.1d), GMI effect improvement due to induction of transverse magnetic anisotropy at high enough annealing temperature.

Observed versatile properties of properly processed glass-coated amorphous microwires with enhanced and tuneable soft magnetic properties make them suitable for various applications.

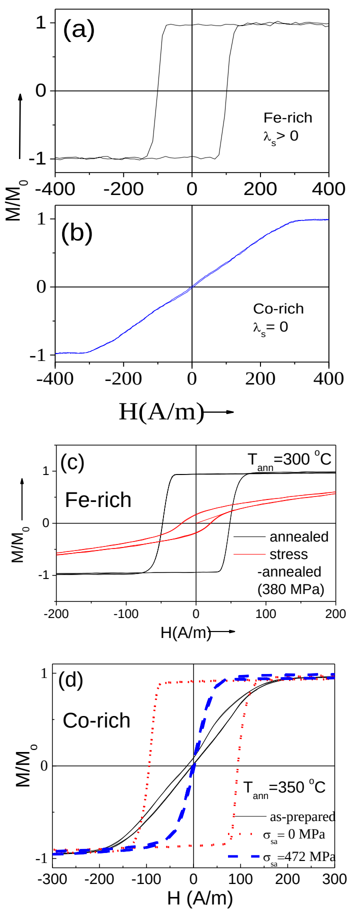

Fig.1: *Typical hysteresis loops of as-prepared (a,b) and processed (c,d) Fe- and Co-rich amorphous microwires.*

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Abstract ID: 405

FIELD TUNING SPIN SWITCHING AND SPIN REORIENTATION TRANSITION IN (Er,Pr)FeO_3 SINGLE CRYSTALS

Shixun Cao, Xiaoxuan Ma, Baojuan Kang, Rongrong Jia, Qianying Yu, Wei Ren, Junyi Ge

Department of Physics, Materials Genome Institute and International Center for Quantum and Molecular Structures, Shanghai University, Shanghai 200444, CHINA

E-mail: sxcao@shu.edu.cn

Rare-earth orthoferrite ($RFeO_3$, R=Y or rare-earth elements), as a canted antiferromagnetic material, have a variety of interesting and rich magnetic properties such as spin reorientation (SR) transition, magneto-optical effect, ultrafast spin switching, and multiferroicity, thus attracting intense interest from researchers in different fields. In this work, high-quality $Er_{1-x}Pr_xFeO_3$ (x=0, 0.1, 0.3, 0.5) series single crystals were successfully grown using the optical floating zone method, and the crystal structure analysis and related magnetic characterization were carried out. The SR transition from Γ_4 (G_x, A_y, F_z) to Γ_2 (F_x, C_y, G_z) still exists in the sample Pr^{3+} doping up to x=0.3, and the increase of Pr^{3+} doping shifts the SR transition temperature region to the higher temperature, indicating stronger Er^{3+}/Pr^{3+}-Fe^{3+} anisotropic symmetry interaction factor than the undoped $ErFeO_3$. Interestingly, when the Pr^{3+} doping amount reaches x=0.5, shows a double SR transition of Γ_4 (G_x, A_y, F_z)-Γ_1 (A_x, G_y, C_z)-Γ_2 (F_x, C_y, G_z), and the SR transition temperature region slightly moves toward the lower temperature. The triggering temperature of both types of spin switching in $Er_{0.7}Pr_{0.3}FeO_3$ is closely related to the magnitude of the applied magnetic field, similar to the process by which the magnetic field transmits enough momentum of the spin system to overcome the potential barrier and thus redirect the ionic magnetic moments from the metastable state to a steady state. An in-depth understanding of the magnetic coupling and competition between the R^{3+} and Fe^{3+} magnetic sublattices, within the $RFeO_3$ system, has important implications for advancing the practical applications of the relevant spin switching materials.

Abstract ID: 450

MAGNETIC PROPERTIES OF Mn_2ScSn HEUSLER ALLOYS: INSIGHTS FROM FIRST PRINCIPLES

M. Obambi, M. Zagrebin, V. Sokolovskiy, V. Buchelnikov

Chelyabinsk State University, 454001, Chelyabinsk, RUSSIA
E-mail: miczag@mail.ru

At present, the study of new solid-state compounds and alloys with multifunctional properties is becoming increasingly popular in the scientific community around the world. This interest is due to the potential application as material for spintronics, where the spin degree of freedom of an electron plays a significant role in encoding, faster transfer and processing of data as compared to a charged based equivalent transistor [1]. The spintronic devices mostly consist of a non-magnetic layer sandwiched between two ferromagnetic electrodes like giant-magnetoresistance [2], tunneling magnetoresistance [3] and magnetic tunnel junction [4] devices. One of such compounds are Heusler alloys which having multifunctional properties such as exchange bias, magnetocaloric effect and magnetic shape memory alloys Among the Heusler alloys, Mn_2YZ based members (Y being a 3d or 4d transition element and Z a sp element) are of significant interest due to high electron-spin polarization with high T_C and efficient spin-transfer torque are responsible a promising material in future spintronic devices [5]. So, this work is devoted to the ab initio study of the magnetic properties of the Mn_2ScSn alloy depending on the applied external pressure.

In order to investigate the magnetic properties of Mn_2ScSn alloy, we used the Korringa–Kohn–Rostoker Green's function method as implemented in SPR-KKR (spin-polarized-relativistic Korringa–Kohn–Rostoker code) [6], respectively. The exchange correlation effects were described by the Perdew–Burke–Ernzerhof (PBE) formulation of the generalized gradient approximation (GGA) [7]. For these calculations equilibrium lattice parameters obtained for different external pressure has been used. For lattice parameters definition the VASP (Vienna ab initio simulation program) [8], [9] with GGA-PBE exchange correlation approximation and has been used. Obtained magnetic exchange parameters has been used for thermomagnetic curves calculations via classical Heisenberg model and Monte Carlo simulations. From this curves Curie temperature were estimated.

As a result, dependence on external pressure of magnetic moments (total and partial), magnetic exchange parameters and Curie temperatures for Mn_2ScSn alloy are obtained.

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Abstract ID: 452

PHONON THERMAL CONDUCTIVITY OF $Mn_2V(Al,Si)$ HEUSLER ALLOYS

V. Buchelnikov[1], V. Sokolovskiy[1,2], D. Baigutlin[1], O. Miroshkina[1]

[1]*Chelyabinsk State University, 454001, Chelyabinsk, RUSSIA*
[2]*National University of Science and Technology 'MISiS', 119049, Moscow, RUSSIA*
E-mail: buche@csu.ru

In the recent years, ferromagnetic half-metallic (HM) materials attract a significant interest for scientific research and industrial applications due to their promising applications in the smart magnetoelectronic and spintronic devices. HM materials are characterized by an energy gap at the Fermi level (EF) for one of two spin channels, while the other channel has a metallic character. As a result, a high spin polarization in such materials is observed at EF as predicted by de Groot et al. [1] in the earlier 1980s, who considered an electronic structure of NiMnSb and PtMnSb half-Heusler alloys. Among various HM materials, ferromagnetic Heusler alloys are highly attractive for applications as they can be synthesized easily and reveal a structural similarity to traditional binary semiconductors such as GaAs, InP, etc. For example, well-known Co2FeSi displays a lattice match with GaAs within 0.08% [2]. Moreover, Co-based alloys possess high spin polarization, magnetic moment, and Curie temperature. These features make ferromagnetic HM highly promising for various practical applications. The aim of this work is to provide a theoretical description of $Mn_2V(Al,Si)$ alloys, which demonstrate a switchable behavior between low magnetic state (LMS) and high magnetic state (HMS) [3]. We investigate the influence of the exchange-correlation effects on the structural and magnetic properties, and calculated transport properties within GGA. For spintronic applications it is important to know the electronic and lattice thermal conductivities. In this work we calculated lattice conductivity $Mn_2V(Al,Si)$ alloys (Fig.1) with the help of AICON2 program code [4].

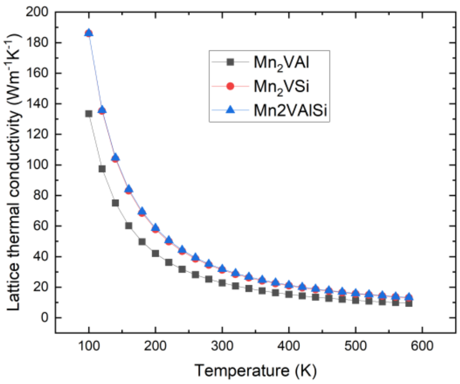

Fig. 1: *The lattice conductivity of $Mn_2V(Al,Si)$ alloys.*

This work was supported by RSF-Russian Science Foundation No. 22-12-20032

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Abstract ID: 468

CONTROLLING THE RELAXATION OF A Er^{3+} SINGLE-ION MAGNETS USING FERROMAGNETIC MICROPARTICLES

E. I. Kunitsyna, R.B. Morgunov

Federal Research Center of Problems of Chemical Physics and Medicinal Chemistry RAS, 142432, Chernogolovka, RUSSIA

E-mail: kunya_kat@mail.ru

The development of molecular magnetism is moving towards the use of magnetic molecules in molecular spintronics, quantum technologies, and organometallic frameworks. In molecular spintronics, the goal is to develop next-generation devices based on molecular materials or one molecule. In the field of quantum technologies, the efforts of researchers are focused on the development of molecular spin qubits with a long quantum coherence time and in the implementation of quantum operations. The most promising materials at the moment in these areas are single-ion magnets (SIM). In SIM, relaxation often is fast, so it cannot be measured with a SQUID magnetometer and does not meet the quantum decoherence conditions required for quantum calculations. The solution to this problem is the use of an external magnetic field (electromagnet), which shifts the relaxation time to the desired frequency range. In our work, we propose to use the residual field of a ferromagnetic particle to create an external magnetic field. We used ferromagnetic PrDyFeCoB microparticles with a given conserved magnetization to control the rate of spin relaxation in Er^{3+} complexes covering microparticles.

In this work, we studied the frequency dependences of the magnetic susceptibility of individual microparticles, an individual SIM powder, and also their composite. A comparative analysis of the obtained relaxation times for the pure complex and in the presence of microparticles was carried out. As part of a composite, the Er^{3+} complex demonstrates slow magnetic relaxation in the absence of an external field, although the pure complex did not exhibit slow relaxation in the absence of a field. The stray field of PrDyFeCoB microparticles turned out to be sufficient to observe slow spin relaxation in the SIM complex. Two processes that affect relaxation in the complex are considered: orbital hybridization due to the chemical interaction of the compound with the metal surface and magnetic dipole interaction provided by residual magnetization of the matrix. It has been established that the magnetic relaxation of the Er^{3+} complex can be controlled using a preliminarily applied external magnetic field.

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Theory of Magnetism- Ab-Initio Callculations and Nanomagnetism

08.05.2023 MONDAY

Abstract ID: 486

QUANTUM MUON EFFECTS IN SOLIDS AND FRUSTRATED MAGNETS

M. Gomilšek[1,2], F. Hotz[3], H. Luetkens[3], F.L. Pratt[4], S.P. Cottrell[4], S.J. Clark[5], T. Lancaster[5]

[1]*Jožef Stefan Institute, SI-1000, Ljubljana, SLOVENIA*
[2]*University of Ljubljana, Faculty of Mathematics and Physics, SI-1000 Ljubljana, SLOVENIA*
[3]*Paul Scherrer Institute, Laboratory for Muon Spin Spectroscopy, CH-5232, Villigen PSI, SWITZERLAND*
[4]*Science and Technology Facilities Council (STFC), ISIS Muon Group, OX11 0QX, Didcot, UNITED KINGDOM*
[5]*Durham University, Department of Physics, DH1 3LE, Durham, UNITED KINGDOM*
E-mail: matjaz.gomilsek@ijs.si

Implanted muons serve as exquisite and unique local probes of magnetism at the atomic scale in the technique of muon spectroscopy (μSR), which proved indispensable in establishing some of the most highly visible results in the field of quantum magnetism and quantum spin liquids [1]. However, for unambiguous interpretation of experimental data, a thorough understanding of quantum behaviour (zero-point motion; ZPM) of muons inside materials is essential. Namely, while ZPM of light nuclei like hydrogen is known to strongly affect the structure and dynamics of many materials [2], quantum effects of muons in solids can be even stronger due to the low mass of muons (~1/9 the mass of a proton) [3], which can qualitatively change the measured μSR signal.

I will present our recent results on state-of-the-art *ab initio* simulations of quantum muons in select materials based on our novel, unified description of different light-particle ZPM regimes [4], which is crucial for making such computations feasible on many materials of interest, from frustrated magnets to superconductors. I will present our proof-of-concept results on solid nitrogen, α–N_2, where we demonstrated strong, many-body quantum entanglement between the position of an implanted muon and those of the surrounding nuclei, strong anharmonic effects, and the formation of a novel type of electric-dipole polaron [4]. I will also present preliminary results on quantum muon effects in a quantum spin liquid candidate, the frustrated kagome antiferromagnet Zn-barlowite, where strong muon ZPM that impacts the measured μSR signal can be seen.

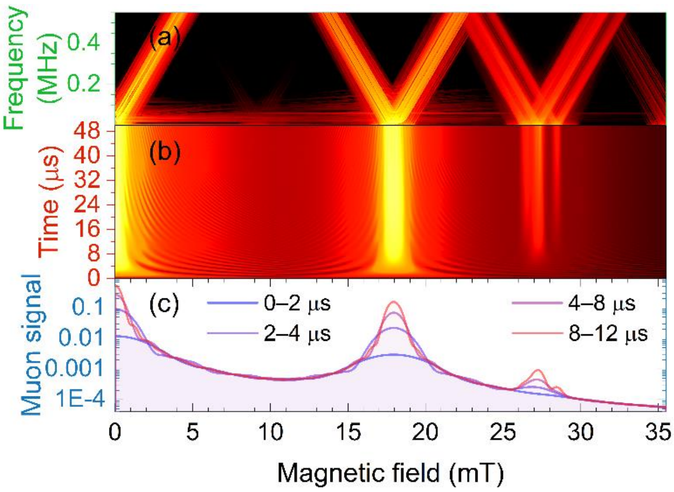

Fig. 1: *Quadrupolar level crossing resonance μSR spectra from ab initio simulations of quantum muons in solid nitrogen, α–N_2 [4].*

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Abstract ID: 489

QUANTUM PROPERTIES OF THE TOROIDAL DIPOLE

D.V. Anghel[1,2], M. Dolineanu[1,3]

[1] Institutul National de C&D pentru Fizica si Inginerie Nucleara – Horia Hulubei, 077125, Măgurele, ROMANIA
[2] BLTP, JINR, Dubna, Moscow Region 141980, RUSSIA
[3] University of Bucharest, Faculty of Physics, 077125 Magurele, ROMANIA
E-mail: dragos64@gmail.com

The toroidal dipole is the lowest order toroidal moment and, for a current distribution $\mathbf{j(r)}$ has the expression $\mathbf{T} = \frac{1}{10}\int_V [\mathbf{r}\,(\mathbf{r}\cdot\mathbf{j}) - 2r^2\mathbf{j}]d^3\mathbf{r}$. The quantum operator corresponding to $\mathbf{T}$ has the components $\hat{T}_i = \frac{1}{10m_p}\sum(x_i x_j - 2r^2\delta_{ij})\,\hat{p}_j$, with $\hat{T}_3 = -\frac{i\hbar}{10m_p}\left[z\rho\frac{\partial}{\partial\rho} - (2\rho^2+z^2)\frac{\partial}{\partial z}\right]$, where $\rho = \sqrt{x^2+y^2}$ and $r = \sqrt{\rho^2+z^2}$. In the whole $\mathbb{R}^3$ space, the $\hat{T}_i$ operators are hypermaximal [1], but when they are defined on curvilinear coordinates on closed paths, they become self-adjoint (because of the periodic boundary conditions satisfied by the wavefunctions) [2]. Being self-adjoint, the operators may correspond to observables. In Ref. [3] we solved the eigenvalues and eigenvectors problem for $\hat{T}_3$ for a quantum particle confined on a thin torus and we found an interesting situation. The eigenvectors have infinite norms and therefore they cannot belong to the Hilbert space of wavefunctions. Such eigenvectors are kernels of distributions on the Hilbert space of wavefunctions.

The eigenvalues t_3 of $\hat{T}_3$ are discrete and equidistant. This offers an opportunity of observing them, using the interaction of the toroidal dipole with external charge and displacement current densities, $\mathbf{J}$ and $\dot{\mathbf{D}}$, respectively, described by the Hamiltonian $\hat{H}_I \equiv -\mu_0 q[\mathbf{J}+\dot{\mathbf{D}}]\cdot\hat{\mathbf{T}}$. If $\dot{\mathbf{D}} = 0$ and $\mathbf{J}$ is along the z axis, such an interaction, proportional to Jt_3, would produce a splitting of the energy levels which may be observed experimentally.

The mathematical tools presented here are necessary for the study of the toroidal dipoles in nanosystem, as well as the toroidization in macroscopic systems and in metamaterials with nanoscopic metaparticles.

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Abstract ID: 580

A QUASIPARTICLE PICTURE OF ATTEMPT FREQUENCY AND MAGNETOCRYSTALLINE ANISOTROPY

R.A. Lawrence, S.J. Donaldson, M.I.J. Probert

School of Physics, Electronics and Technology, University of York, York, YO10 5DD, UNITED KINGDOM
E-mail: matt.probert@york.ac.uk

Two key material properties to describe magnetoelectric RAM (MERAM) are the magnetocrystalline anisotropy energy (MAE), which controls the long term thermal stability of an individual bit, and the attempt frequency, which controls the speed at which a bit may be written, and therefore the upper limit to the clock speed of an MERAM device. These two properties are linked via the Neel-Arrhenius equation, and accurate evaluations of the MAE from experimental data require the attempt frequency to be known. Within experimental literature, however, this value is typically assumed to lie anywhere within three orders of magnitude, which can have a significant impact on the achievable thermal stability of bits made from a given material.

Several studies have considered attempt frequency within the classical limit using the Landau-Lifshitz-Gilbert equation. However, to our knowledge, this property has not been studied using *ab initio* techiques. These classical simulations also require the MAE as an input parameter, and are therefore incapable of calculating it directly. By using *ab initio* techniques - which require only the input of atomic positions and the laws of quantum mechanics - it is possible to access both of these properties directly, thereby enabling a theoretical search for novel high-performance materials as well as providing insight to further guide the experimental search for these materials.

By describing the MAE of the system in terms of the creation energy of long-wavelength quasiparticles, it is possible to both evaluate the MAE for a given system directly, and to perform lifetime calculations to directly access a theoretical value of the attempt frequency for any given material. In this talk we will outline this new approach[1] to calculating attempt frequency and highlight the physical meaning behind it, which has implications for materials design of new, high-frequency MERAM devices. We will discuss the difference in attempt frequency between ferromagnetic and antiferromagnetic materials within this new paradigm as a way of rationalising the observed high attempt frequency seen in antiferromagnetic systems.

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Abstract ID: 636

THE EFFECT OF FUNCTIONALIZATION ON MAGNETIC ANISOTROPY OF 2D MAGNETIC MATERIALS

R. Caglayan[1], Y. Mogulkoc[2], A. Mogulkoc[1], M. Modarresi[3] A.N. Rudenko[4]

[1] *Ankara University, Dept. of Physics, 06100, Ankara, TURKEY*
[2] *Ankara University, Dept. of Physics Engineering, 06100, Ankara, TURKEY*
[3] *Ferdowsi University of Mashhad, Dept. of Physics, Mashhad, IRAN*
[4] *Radboud University, Institute for Molecules and Materials, Heyendaalseweg 135, 6525 AJ Nijmegen, THE NETHERLANDS*
E-mail: rcaglayan@ankara.edu.tr

Functionalization of 2D magnetic materials is the modification of their surface to change their electronic, optical, mechanical, and magnetic properties. Altering the magnetic anisotropy of these materials by functionalization can lead to tunable magnetic properties for applications in magnetic data storage, spintronics, and magnetic sensors. We have investigated the effects of adsorbing fluorine and chlorine on the magnetic anisotropy properties of a monolayer of ferromagnetic CrN using first-principles calculations and a spin Hamiltonian. The results show that the magnetization axis of the monolayer shifts towards the in-plane direction due to the suppression of the orbital moment. We have also found that half-coverage of CrN is dynamically stable and has ferromagnetic ordered at room temperature.

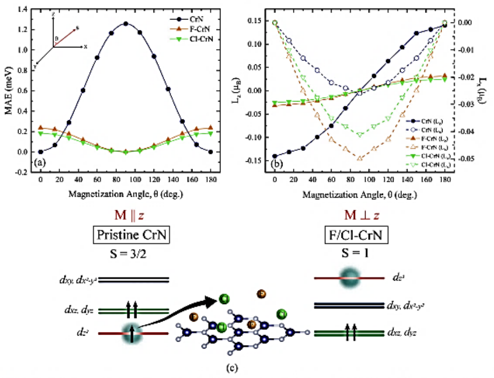

Fig. 1: *(a) Variation of the magnetic anisotropy energy, (b orbital moment as a function of the magnetization angle. (c) schematic diagram with the crystal-field splitting of the d states.*

These findings suggest that the magnetic properties of two-dimensional magnets can be modified by adsorbing F and Cl, which could be useful for detecting these gases using magnetic or optical measurements [1].

Acknowledgement

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Theory of Superconductivity I-II

08.05.2023 MONDAY

Abstract ID: 198

STRIPES IN THE EXTENDED *t-t'* HUBBARD MODEL: A VARIATIONAL MONTE CARLO ANALYSIS

Vito Marino[1], Antonio Lechiara[1], Federico Becca[2], Luca F. Tocchio[1]

[1]*Institute for Condensed Matter Physics and Complex Systems, DISAT, Politecnico di Torino, I-10129 Torino, ITALY*
[2]*Dipartimento di Fisica, Università di Trieste, Strada Costiera 11, I-34151 Trieste, ITALY*
E-mail: luca.tocchio@polito.it

The dualism between superconductivity and charge/spin modulations (the so-called stripes) dominates the phase diagram of many strongly-correlated systems, as in the case of the Hubbard model. By using variational quantum Monte Carlo techniques, we investigate the instauration of stripes (i.e., charge and spin inhomogeneities) in the Hubbard model on the square lattice at different hole dopings, with both nearest-(t) and next-nearest-neighbor hopping (t'). Stripes with different wavelengths λ (denoting the periodicity of the charge inhomogeneity) are stabilized for sufficiently large values of the electron-electron interaction U/t, without significant differences between bond- or site-centered character. The general trend is that λ increases going from negative to positive values of t'/t and decreases both by increasing U/t and by increasing the hole doping. A uniform state is obtained for large values of $|t'/t|$ and at large hole doping. At doping $\delta = 1/8$, pair-pair correlations are highly suppressed with respect to the uniform state suggesting that striped states are not superconducting, while stripes may coexist with superconductivity at different dopings[1,2].

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Abstract ID: 330

COLLECTIVE EXCITATIONS OF CHARGED SUPERFLUIDS IN THE BCS-BEC CROSSOVER

S.N. Klimin[1], J. Tempere[1,2], T. Repplinger[3], H. Kurkjian[3]

[1] *Theorie van Kwantumsystemen en Complexe Systemen (TQC), Universiteit Antwerpen, B-2610 Antwerpen, BELGIUM*
[2] *Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02138, USA*
[3] *Laboratoire de Physique Théorique, Université de Toulouse, CNRS, UPS, 31400, Toulouse, FRANCE*
E-mail: sergei.klimin@uantwerpen.be

We present a review of our recent theoretical investigation of collective excitations in charged superfluid and superconducting systems. The theoretical treatment is based on a unified method using the random phase approximation and path-integral Gaussian fluctuation approach, which is suitable for both neutral [1-3] and charged [4,5] superfluids and is straightforwardly extended to superfluid/superconducting systems in different dimensions.

The study of the plasma branch of homogeneous electron gas in the superconducting state focuses on the regime when the plasma frequency is comparable to the superconducting gap. This regime has been experimentally realized in high-temperature superconductors and is promising to be observed in strong-coupling superconductors at the BCS-BEC crossover. The dispersion and lifetime of plasmons are strongly influenced by the presence of a pair condensate, especially at energies close to the pair-breaking threshold. When the plasma frequency is sufficiently close to the pair-break threshold, the plasma branch exhibits an anomalous, negative dispersion with a minimum at the finite wavelength, in contrast to the plasma dispersion in the normal state. At nonzero temperature and for plasma frequencies above the threshold, we calculate in a non-perturbative way the coupling of plasmons to fermionic continua of quasiparticles and show that a broadened plasma resonance inside the continuum coexists with a non-damped solution in the band gap.

When the plasma frequency is much larger than the superconducting gap, which is typical for three-dimensional superconductors, specific branches of collective excitation, such as Carlson-Goldman modes, can appear. We focus on the behavior of these modes at different coupling strengths and demonstrate that strong coupling promotes the survival of the Carlson-Goldmann modes deep below the transition temperature, in contrast to the weak-coupling BCS regime.

The collective excitation spectra considered in our study can be the subject of experimental testing in spectral measurements of the density and pair-field response of superconductors and charged superfluids.

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Abstract ID: 441

QUANTITATIVE ANALYSIS OF QUASIPARTICLE TUNNELING SPECTRA OF *d*-WAVE SUPERCONDUCTORS USING PSEUDO-VOIGT FUNCTION

O.K. Ganiev[1,2,3]

[1]*Institute of Nuclear Physics, 100214 Tashkent, UZBEKISTAN*
[2]*Akfa University, Milliy Bog' Street, Tashkent 111221, UZBEKISTAN*
[3]*National University of Uzbekistan, 100174 Tashkent, UZBEKISTAN*
E-mail: orif.ganiev@gmail.com

The high-energy spectral features across the gap are still a matter of debate, although some good theoretical fits have been worked out. However, some spectral characteristics of tunneling spectra observed in the experiments [1-6] are still not clear. Moreover, one of the main features of tunneling spectra, the "peak-dip-hump" structure observed in the superconducting state near the antinode, is considered to be a hallmark of electron mode coupling in cuprate superconductors. Thus, the origin of the so-called "dip-hump" feature observed in the experiment beyond the limits of the tunneling conductance coherence peak remains unclear. Indeed, the process of quasiparticle tunneling through *d*-wave superconductor-insulator-normal metal (*d*SC-I-N) junctions is of great interest due to the unusual spectral behavior, and further research is very important.

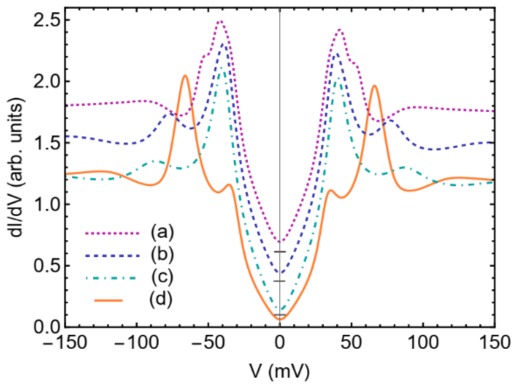

Fig.1: *Tunneling conductance curves with pronounced V-shaped, which exhibit several features such as double hump (a) and double dip (or peaked hump) (b), dip-hump (c), and subgap (d) structures, respectively.*

Here we study the main characteristics of the tunneling spectra, in particular, the peak-dip-hump structure in *d*SC-I-N junctions. To demonstrate the peak-dip-hump structure and other features of the tunneling spectra, a pseudo-Voigt function was applied as a function of the energy-dependent gap. In Fig. 1, the model reproduces various characteristic spectral features, such as double hump (a), double dip (b), diphump (c), and subgap (d) structures, respectively) of the tunneling spectra of cuprate superconductors observed in experiments [1-6].

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Abstract ID: 117

TIME-REVERSAL-SYMMETRY-BREAKING IN MULTIBAND SUPERCONDUCTORS, WITH AND WITHOUT INVERSION

Igor Herbut

Simon Fraser University, Burnaby, CANADA
E-mail: iherbut@sfu.ca

I will discuss how spontaneous breaking of time reversal symmetry in multiband superconductors leads quite generally to the formation of mini surfaces of Bogoliubov excitations with zero energy, irrespective of whether inversion symmetry is absent or present in the superconducting state. In the latter case the inversion symmetry is susceptible to being dynamical broken at low temperatures by the residual interactions. A lattice model of this process will be discussed, time permitting. Its final result is a reduced, but still finite Bogoliubov surface.

Abstract ID: 171

MISLEADING WEAK COUPLING BEHAVIOUR OF CRITICAL TEMPERATURE OF Pb/Ag, Pb/Cu AND Pb/Al NANOCOMPOSITES EXPLAINED BY PROXIMITY ELIASHBERG THEORY

G. A. Ummarino[1,2]

[1]*Dipartimento di Scienza Applicata e Tecnologia, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, ITALY*
[2]*National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashira Hwy 31, Moskva 115409, RUSSIA*
E-mail: giovanni.ummarino@polito.it

The experimental critical temperature of systems of nanoparticles superconducting (Pb) and normal (Ag, Cu and Al) with a random distribution and sizes less than their respective coherence lengths, is governed by proximity effect as the experimental data shown. At first glance the behaviour of the critical temperature in function of the ratio of the volume fraction of the superconducting and the normal metal components seems suggest a weak coupling behaviour. In reality, upon a more careful analysis using Eliashberg's theory for the proximity effect, the system instead shows a strong coupling nature. The most interesting thing is that the theory has no free parameters and perfectly explains the behavior of the experimental data just with the assumption, in the cases of nanoparticles of Ag and Cu, that the value of the density of states at the Fermi level of silver and copper is equal to value of lead.

Abstract ID: 178

A FL* SOLUTION TO THE FL /NFL DICHOTOMY IN HOLE-DOPED CUPRATES

P.A. Marchetti[1,2]

[1] *Dipartimento di Fisica e Astronomia, Università di Padova, Padova, ITALY*
[2] *INFN, Sezione di Padova, Padova, ITALY*
E-mail: marchetti@pd.infn.it

Using the terminology of [1] we denote by FL* an exotic FL satisfying a suitable version of Luttinger theorem related to topological order, in which, besides standard electrons (or better holes for hole-doped cuprates) carrying charge and spin, the quasi-particle excitations are the holons carrying only charge and the spinons carrying only spin. The electron or the hole (as in the cuprates) is then a bound state, or in general a resonance, made of holon and spinon and the corresponding Landau quasi-particle is the true low-energy excitation, holon and spinon being well defined particle-like excitations only far away from the region of small energy close to the electron Fermi surface.

One amazing characteristic of hole-doped cuprates is that some of their physical quantities qualitatively behaves almost like in a Fermi liquid (FL), especially at sufficiently large doping and temperature, whereas in the same range of parameters other quantities behave in a completely non-FL (NFL) fashion.

We show that in our FL* formalism [2] for hole-doped cuprates, based upon a 2D t-t'-J model expressed in terms of gapped spinons and semionic holons with Fermi surface smaller than that of the hole, many experimental dichotomies FL/NFL are qualitatively well reproduced [3] and the NFL features appear when the response is dominated by spinons whereas the FL features appear when the response is dominated by the hole resonance. In particular this approach can explain 1) why the uniform spin susceptibility at moderate doping approaches an almost FL behaviour at high temperature whereas the spin-lattice relaxation rate on the Cu sites does not, thus violating Korringa law [3] 2) why in spite of the gapless Fermi arcs in the pseudogap region of the phase diagram the in-plane resistivity exhibits a metal-insulator crossover and, suitably normalized, a universal behaviour [4] 3) why in spite of a BCS-like behaviour of the superconducting gap in the nodal region for small dopings, the superfluid density is not BCS-like, satisfies Uemura relation and, suitably normalized, exhibits a universal behaviour [5].

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Abstract ID: 491

THE ARCHIMEDES EXPERIMENT: USING SUPERCONDUCTIVITY TO INVESTIGATE THE COUPLING BETWEEN GRAVITY AND QUANTUM VACUUM

L. Errico[1,2]

[1]*University of Napoli "Federico II", Dept. of Physics, Naples, ITALY*
[2]*Istituto Nazionale di Fisica Nucleare (INFN) - Naples Section, ITALY*
E-mail: lerrico@na.infn.it

One of the most original predictions of General Relativity is the coupling between gravity and any physical entity described by a stress-energy tensor. In this picture, even quantum fields should warp space-time and be affected by its curvature. Nonetheless, interaction between quantum fields and gravity is still debated and the gravitational interaction of the quantum vacuum energy has not been observed yet.

Archimedes is an experiment designed to measure the weight of the vacuum, i.e. the coupling of vacuum energy with gravity. Using a high precision cryogenic balance, specifically designed for this experiment, we will measure the weight of a multi-layered superconductive crystal. In such a system, the Casimir energy of the electromagnetic vacuum can be modulated triggering the superconductive phase transition.

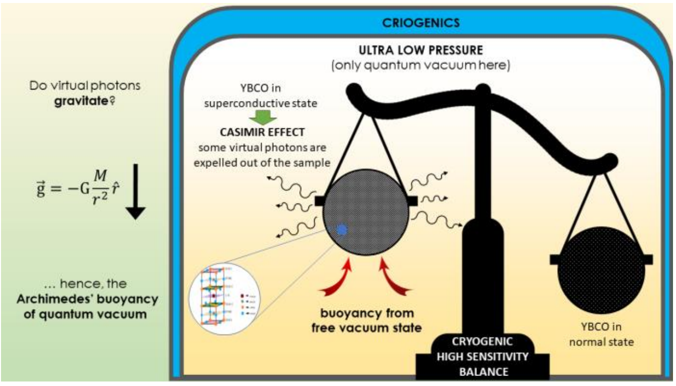

Fig. 1: *A brief schematics of the measurement strategy in Archimedes experiment.*

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Topological Quantum Magnets

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Abstract ID: 133

KITAEV MAGNETS AS A MAJORANA PLATFORM

Y. Motome

Department of Applied Physics, The University of Tokyo, JAPAN
E-mail: motome@ap.t.u-tokyo.ac.jp

The Kitaev model provides a canonical example of quantum spin liquids in more than one dimension, with the exact solution of the ground state and fractional Majorana excitations [1]. Since the proposal by Jackeli and Khaliullin [2], tremendous efforts have been made to realize it in materials and to identify the spin liquid nature [3]. While the discovery of half quantization of the thermal Hall conductivity in a candidate α-$RuCl_3$ supports the existence of Majorana excitations [4], further exploration of the platform of the Kitaev spin liquid and the manipulation of fractional excitations is crucial for not only deeper understanding of quantum spin liquids but also their application to topological quantum computation. In this talk, we will highlight our recent efforts on the exploration of the Kitaev magnets as a Majorana platform, both in the search for other candidate materials to extend the family of Kitaev magnets and in theoretical proposals for the identification and control of fractional Majorana excitations.

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Abstract ID: 226

INVESTIGATION OF QUANTUM MAGNETS IN TETRABORIDES BY SCANNING TUNNELING MICROSCOPY

S. Gabáni[1], K. Flachbart[1], O. Onufriienko[1], Mat. Orendáč[1], G. Pristáš[1], J. Bačkai[1, 2], K. Siemensmeyer[3], N. Shitsevalova[4], T. Samuely[5], D. Volavka[5], S. Wirth[6]

[1]*Institute of Experimental Physics, Slovak Academy of Sciences, Košice, SLOVAKIA*
[2]*Faculty of Electrical Engineering, Technical University, SLOVAKIA*
[3]*Institute of Quantum Materials, Helmholtz-Zentrum Berlin, Berlin, GERMANY*
[4]*Institute for Problems of Materials Science NASU, Kiev, UKRAINE*
[5]*Faculty of Science, P.J. Safarik University, Košice, SLOVAKIA*
[6]*Max Planck Institute for Chemical Physics of Solids, Dresden, GERMANY*
E-mail: gabani@saske.sk

Rare earth tetraborides crystallize in the Shastry-Sutherland lattice (SSL) which consists of orthogonal dimers. The SSL in principle is a two-dimensional structure and one of the few cases where the phase diagram has been exactly solved [1]. Surprisingly, the first compound showing this structure, $SrCu_2(BO_3)_2$ exhibited exotic quantum states in form of fractional magnetization plateaus that have been explained in terms of topological physics [2]. Tetraborides with Ho, Er and Tm ions show similar phenomena and are in contrast to $SrCu_2(BO_3)_2$ with critical field and temperature in a well accessible range ($T_c \approx$ 6-16 K, $B_c \approx$ 4-5 T, depending on the RE ion). Bulk properties of HoB_4, ErB_4 and TmB_4 were investigated in great detail (see e.g. [3, 4]). The zero-field ordering of all three compounds can be described by the dimer spin configuration, for HoB_4 and ErB_4 they are antiparallel, the dimers in TmB_4 are ferromagnetic with antiferromagnetic nearest neighbour dimers. In a magnetic field these structures break up into fractionalized magnetization states with magnetization plateaus at 1/3, 4/9, 3/5 in HoB_4 and 1/7, 1/8, 1/9 in TmB_4. For TmB_4 the corresponding structure is fully solved by neutron diffraction [3], in the fractional phase one observes stripe like structures with q-spacings of 1/7, 1/8, unit cells that resemble domains walls, but strictly ordered. In higher field always a ½ plateau is reached, and the magnetic ordering again extends over 8 unit cells in TmB_4. The large, commensurate magnetic unit cells are difficult to explain with near neighbour interactions and not understood to date.

Results from bulk measurements show exotic behavior that despite numerous theoretical approaches to date is unexplained and it appears that new theoretical directions are necessary there. On the experimental side, one shortcoming so far is that all results are received from bulk samples, mostly single crystals. To move the experimental insight forward, it is essential to study the 2D behavior, ideal on thin films. To start such investigations, however, the use of clean, cleaved surfaces from bulk samples with surface sensitive methods like scanning tunneling microscopy (STM) methods appears as a more realistic starting point [5].

In this contribution, the first investigation of bulk TmB_4 as well as ErB_4 systems by STM and SP-STM (SP – spin polarized), respectively, down to 1 K and up to 3 T is presented.

This work was supported by European Microkelvin Platform.

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CURRENT STATUS IN THE FIELD OF THE INTRINSIC MAGNETIC TOPOLOGICAL INSULATORS OF THE $MnBi_2Te_4$ FAMILY

M.M. Otrokov[1,2]

[1]*Centro de Física de Materiales (CFM-MPC), Centro Mixto CSIC-UPV/EHU, 20018, Donostia-San Sebastián, Basque Country, SPAIN*
[2]*IKERBASQUE, Basque Foundation for Science, 48011, Bilbao, SPAIN*
E-mail: mikhail.otrokov@gmail.com

Magnetic topological insulators (MTIs) are narrow gap semiconductor materials that combine non-trivial band topology and magnetic order. They host a number of exotic phenomena having potential applications. Previously, MTIs were only created by means of doping nonmagnetic TIs such as $(Bi_{1-x}Sb_x)_2Te_3$ with Cr or V atoms, however such an approach leads to strongly inhomogeneous magnetic and electronic properties of these materials, restricting the observation of important effects to very low temperatures. Recently, a stoichiometric compound $MnBi_2Te_4$ was theoretically predicted and then experimentally confirmed to be the first intrinsic antiferromagnetic TI (AFMTI) [1-4].

The discovery of $MnBi_2Te_4$ opens a new field that focuses on intrinsically magnetic stoichiometric compounds: several $MnBi_2Te_4$-derived MTIs were synthesized right away [5,6], such as $(MnBi_2Te_4)\cdot n(Bi_2Te_3)$, $MnBi_{2-x}Sb_xTe_4$, $(MnSb_2Te_4)\cdot n(Sb_2Te_3)$, $Mn_2(Bi,Sb)_2Te_5$, and $MnBi_2Se_4$, that will also be discussed in the talk. As a result, $MnBi_2Te_4$ has been predicted to be a platform for realizing high-order topological insulator and superconductor states, Weyl semimetal phase, skyrmions, quantized magnetoeletric coupling, and Majorana fermions. Moreover, $MnBi_2Te_4$-based systems are predicted and/or observed to show 11 different types of Hall effect, some of them are fundamentally new, such as the layer Hall effect [7]. In $MnBi_2Te_4$/hBN van der Waals heterostructures, a stack of n $MnBi_2Te_4$ films with $C = 1$ intercalated by hBN monolayers gives rise to a high Chern number state, characterized by $C = n$ chiral edge modes [8], this number being as large as allowed by the van der Waals heterostructures growth technology.

Concerning current challenges of this field, we will discuss in detail the issue of the Dirac point gap in the $MnBi_2Te_4$ topological surface state that caused a lot of controversy [9,10]. While the early experimental measurements reported on large Dirac point gaps, in agreement with ab initio calculations, a number of further studies claimed to observe a gapless dispersion of the $MnBi_2Te_4$ Dirac cone. A number of possible theoretical explanations of this unexpected behavior have been put forward, which we will discuss in the context of the available experimental data.

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Various Superconducting Quantum Phases

08.05.2023 MONDAY

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NON-HERMITIAN PT-SYMMETRIC ISING SPIN CHAINS: NOVEL QUANTUM PHASES AND QUANTUM PHASE TRANSITIONS

Mikhail Fistul, Grigory Starkov, Leander Tetling, Ilya M. Eremin

Institut für Theoretische Physik III, Ruhr-Universität Bochum, Bochum GERMANY
E-mail: Mikhail.Fistoul@ruhr-uni-bochum.de

A theoretical study of quantum phases and quantum phase transitions occurring in non-Hermitian PT-symmetric transverse-field Ising spin model is presented. A non-Hermitian part of the Hamiltonian is implemented via imaginary staggered longitudinal magnetic field corresponding to a local staggered gain and loss terms, γ. Using a numerical diagonalization of the Hamiltonian for spin chains of a finite size N accompanied by a scaling procedure for the coherence length ξ, a complete quantum phase diagram γ-J (J is an adjacent spins interaction strength) is established. We obtain two quantum phases for $J < 0$, i.e., PT-symmetry broken antiferromagnetic state and PT-symmetry preserved paramagnetic state, and the quantum phase transition line is the line of exception points. For $J > 0$ the PT-symmetry of the ground state is retained in a whole region of parameter space of J and γ, and a system shows two intriguing quantum phase transitions between ferromagnetic and paramagnetic states for a fixed parameter $\gamma > 1$.

The qualitative quantum phase diagram is derived in the framework of the Bethe-Peierls approximation that is in a good accord with numerically obtained results. The quantum phase diagram can be verified in the microwave transmission experiments allowing to identify the transitions between the first excited and the ground states.

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Abstract ID: 331

MANIPULATION OF THE CURRENT-CARRYING STATES IN SUPERCONDUCTOR RINGS BY CIRCULARLY POLARIZED RADIATION

M.D. Croitoru[1,2], S.V. Mironov, B. Lounis[3,4], A.I. Buzdin[1,5]

[1]LOMA, UMR-CNRS 5798, University of Bordeaux, Talence F-33405, FRANCE
[2]National Research University Higher School of Economics, Moscow 101000, RUSSIA
[3]LP2N, Université de Bordeaux, Talence F-33405, FRANCE
[4]LP2N, Institut d'Optique and CNRS, Talence F-33405, FRANCE
[5]World-Class Research Center "Digital biodesign and personalized healthcare" Sechenov First Moscow State Medical University Moscow 119991, RUSSIA

E-mail: mikhail.croitoru@uni-bayreuth.de

Recently, it has been qualitatively shown that the inverse Faraday Effect (IFE) in superconductors can arise from the light-induced gap modulation due to the concentration dependence of the superconducting gap function [1]. The light-induced magnetic moment is strongly affected by the non-dissipative oscillatory contribution to the dynamics of the superconducting order parameter, which arises from the nonzero imaginary part of the Ginzburg-Landau relaxation time. It has been experimentally demonstrated that illumination of the toroidal Bose-Einstein atomic condensate by a twisted light carrying nonzero angular momentum produces DC persistent supercurrents [2, 3]. Similar light-stimulated persistent currents can be expected in conventional solid-state superconductors.

We present a study of a basic device consisting of a small superconducting ring brought to a temperature below the critical temperature and subjected to a constant magnetic field. It is shown that illumination of the ring by radiation with circular polarized radiation makes it possible to switch, on demand, between two ground states of a superconductor. We study the evolution of the probabilities of the final superconducting state as a function of the applied magnetic field, the size of the ring and its temperature dynamics, as well as a function of the emission parameters of the emission (polarization, frequency, intensity, and switching time) [4]. These results predict a new reliable switching effect between superconducting current-carrying states based on IFE, which may pave the way for superconducting optoelectronics.

Moreover, in the absence of an external magnetic field, irradiation of the ring with circularly polarized electromagnetic radiation during rapid quenching strongly promotes the generation of current-carrying states through IFE with rotation directions controlled by the helicity of the radiation [5].

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PECULIAR ASPECTS OF THE BCS THEORY OF SUPERCONDUCTIVITY WHY DO WE HAVE MULTIPLE SOLUTIONS?

Dragoş-Victor Anghel

Institutul National de C&D pentru Fizica si Inginerie Nucleara – Horia Hulubei, 077125, Măgurele, ROMANIA
E-mail: dragos64@gmail.com

Not long time ago, a peculiar aspect of the BCS theory of superconductivity was revealed [1]. It was shown that the formalism may lead to several solutions for the energy gap and for the quasiparticle population. To obtain this, we started from the typical BCS pairing Hamiltonian $H_{BCS} = \sum_{\mathbf{k}\sigma} \epsilon_{\mathbf{k}}^{(0)} n_{\mathbf{k}\sigma} + \sum_{\mathbf{kl}} V_{\mathbf{kl}} c_{\mathbf{k}\uparrow}^{+} c_{-\mathbf{k}\downarrow}^{+} c_{-\mathbf{l}\downarrow} c_{\mathbf{l}\uparrow}$ (in usual notations) and applied the Bogoliubov transformation to diagonalize it: $H_M \equiv H_{BCS} - \mu N = \sum_{\vec{k}} (\xi_{\mathbf{k}} - \epsilon_{\mathbf{k}} + \Delta_{\mathbf{k}} b_{\mathbf{k}}^{*}) + \sum_{\vec{k}} \epsilon_{\mathbf{k}} (\gamma_{\mathbf{k}0}^{+} \gamma_{\mathbf{k}0} + \gamma_{\mathbf{k}1}^{+} \gamma_{\mathbf{k}1})$. In the expression of H_M, $\gamma_{\mathbf{k}0} = u_{\mathbf{k}} c_{\mathbf{k}\uparrow} - v_{\mathbf{k}} c_{-\mathbf{k}\downarrow}$ and $\gamma_{\mathbf{k}1}^{+} = v_{\mathbf{k}} c_{\mathbf{k}\uparrow} + u_{\mathbf{k}}^{*} c_{-\mathbf{k}\downarrow}$ are quasiparticle operators, $v_{\mathbf{k}}^2 = 1 - u_{\mathbf{k}}^2 = \frac{1}{2}\left(1 - \frac{\xi_{\mathbf{k}}}{\epsilon_{\mathbf{k}}}\right)$ are coefficients obtained in the diagonalization procedure, $\xi_{\mathbf{k}} \equiv \epsilon_{\mathbf{k}}^{(0)} - \mu$, $\epsilon_{\mathbf{k}} = \sqrt{\xi_{\mathbf{k}}^2 + \Delta_{\mathbf{k}}^2}$, and $\Delta_{\mathbf{k}} = -\sum_{\mathbf{l}} V_{\mathbf{kl}} \langle c_{-\mathbf{l}\downarrow} c_{\mathbf{l}\uparrow} \rangle = -\sum_{\mathbf{l}} \frac{V_{\mathbf{kl}} \Delta_{\mathbf{l}}}{\epsilon_{\mathbf{l}}} \langle 1 - \gamma_{\mathbf{k}0}^{+} \gamma_{\mathbf{k}0} - \gamma_{\mathbf{k}1}^{+} \gamma_{\mathbf{k}1} \rangle$ (if $V_{\mathbf{kl}} \equiv V$ in the attraction band, then $\Delta_{\mathbf{k}} \equiv \Delta$). Taking into consideration the variation of all the parameters with the number of quasiparticles we maximize the partition function in the grandcanonical ensemble. *The essential point* is that we consider μ as the middle of the attraction band, which may differ from the chemical potential (imposed by the reservoir), which is denoted by μ_R. In this way we obtain the quasiparticle populations $n_{ki} = \frac{1}{e^{\beta(\epsilon_k - \tilde{\mu})} + 1}$, where $\tilde{\mu} = \frac{\mu_R - \mu}{\epsilon_k} \left[\xi_k - \left(\sum_{\vec{k}} (1 - n_{\vec{k}0} - n_{\vec{k}1}) \frac{\xi}{\epsilon_{\vec{k}}^3} \right) \Big/ \left(\sum_{\vec{k}} \frac{1 - n_{\vec{k}0} - n_{\vec{k}1}}{\epsilon_{\vec{k}}^3} \right) \right]$. The self-consistent set of equations for Δ gives two solutions even when $\mu \to \mu_R$ (the textbook case), as seen in Fig. 1.

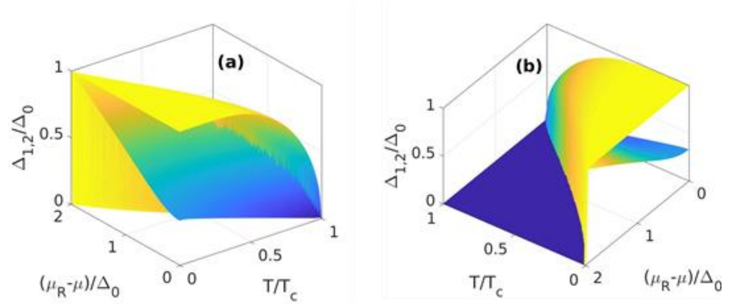

Fig. 1: *The two solutions for the energy gap, when the chemical potential μ_R is different from the middle of the attraction band μ. The same functions are plotted in both pictures; Δ_0 is the standard (textbook) energy gap at zero temperature.*

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Device Physics of Josephson Junctions and Their Fundamental Technologies I-II-III-IV

09.05.2023 TUESDAY

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SERIAL BIASING TECHNIQUE FOR RSFQ CIRCUITS DESIGNED FOR MIT-LL SFQ5EE FABRICATION NODE

Timur V. Filippov[1], Dmitri E. Kirichenko[1], Ashish Shukla[2], Anubhav Sahu[1], M. Eren Çelik[1], Sukanya S. Meher[1], A. Erik Lehmann[3], Mingoo Seok[2], Deepnarayan Gupta[3]

[1]Hypres, 10523, Elmsford, USA
[2]Department of Electrical Engineering, Columbia University, 10027, New York, USA
[3]Formerly with Hypres, 10523, Elmsford, USA
E-mail: tfilippov@hypres.com

Serial biasing (SB) is a known technique to reduce the total current, required to bias Rapid Single Flux Quantum (RSFQ) circuits. In contrast to the traditional parallel biasing, SB assumes sequential biasing of identical digital blocks placed on islands with electrically isolated ground planes. The recent progress in SB is achieved mostly by implementation of on-chip current management technique, called the grapevine (GV) approach, which permits to control the return current density over isolated islands. The GV approach, together with reoptimized design of a driver-receiver pair (DRP) used to transfer pulses between islands, allowed us to demonstrate 50 GHz operation of RSFQ circuits at the BER level of 10^{-12}. In this paper we review the recent experimental results for RSQF circuits fabricated at MIT Lincoln Laboratory using SFQ5ee fabrication node. We compare implementations of SB technique for two cell libraries, designed using two different sets of rules. We discuss fab-related limitations and possible solutions. We provide a list of test structures and discuss experiments required to push the serial biasing technique toward its maturity.

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HIGH EFFICIENCY JOSEPHSON RATCHETS BASED ON YBCO JOSEPHSON JUNCTIONS FABRICATED WITH A FOCUSED He-ION BEAM

E. Goldobin, A. Jozani, C. Schmid, R. Kleiner, D. Koelle

Universität Tübingen, Physikalisches Institut, Center for Quantum Science (CQ) and LISA⁺, 72076, Tübingen, GERMANY

E-mail: gold@uni-tuebingen.de

We report on the fabrication of Josephson ratchets with very strong asymmetry by using Josephson junctions (JJ) of inline-like geometry. The JJs are fabricated from YBCO films by means of irradiation with a focused He-ion beam (He-FIB) [1].

He-FIB irradiation of different doses allows us to "write" both Josephson barriers as well as resistive walls (circuit boundaries) on a sub-micron scale [1]. In this way we have fabricated sub-μm JJs of inline-like geometry that have rather skewed $I_c(H)$ dependences. At the optimal value of the applied magnetic field H, the asymmetry (the ratio of positive and negative critical current I_c) reaches ~10. The high asymmetry is a key for achieving good figures of merit, e.g. a wide rectification window, large stopping force and high rectification efficiency [2].

Further, the rectification of an ac current $I_{ac}\cdot\sin(\omega t)$ into an average dc voltage $\langle V\rangle$ was investigated experimentally by measuring a rectification curve $\langle V\rangle(I_{ac})$ at T=4.2 K (when thermal noise is relatively low). Average dc voltages as high as 120 μV were achieved for the optimum value of the driving amplitude I_{ac}. Further, we have investigated the strength of the ratchet effect, namely, against which dc countercurrent the ratchet can still rectify. The operation of the ratchet in this loaded regime allows us measuring the input and the output power and, therefore, lets us calculate the efficiency of our rectifier. In some regimes the efficiency reaches 80%.

The choice of YBCO allows us to operate our rectifier also in the high-T (high noise) regime, where the thermal energy becomes comparable with the Josephson energy $E_J = \Phi_0 I_c/2\pi$ and the current-voltage characteristic is very smeared near the origin. Practically, the critical current of our JJs vanishes at about 40 K, so that we could apply up to 10 times stronger noise than at 4.2 K. We demonstrate that in this high noise regime one can detect a small finite dc voltage even at zero applied dc current, i.e., the dc I--V characteristic does not cross the origin.

Experimental data are complemented with simulations based on experimentally measured current voltage characteristic.

All together, we demonstrate a Josephson rectifier with the record parameters, which works in both deterministic and high noise regimes.

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Abstract ID: 360

SWITCHABLE VORTEX-BASED SUPERCONDUCTING DIODES

T. Golod, V.M. Krasnov

Department of Physics, Stockholm University, AlbaNova University Center SE-10691 Stockholm, SWEDEN
E-mail: vladimir.krasnov@fysik.su.se

Diode is one of the primary electronic components. It has a nonreciprocal current–voltage (I–V) characteristics. This allows rectification of alternating currents, which is necessary for signal processing and ac–dc conversion. Diodes can be also used as building blocks for Boolean logics in digital computation. Superconducting diodes should have strongly asymmetric critical currents, $|I_c^+| \neq |I_c^-|$. It is well known that nonreciprocity may appear in spatially asymmetric superconducting devices [1,2]. Superconducting diodes, based on spatially nonuniform Josephson junctions, were demonstrated long time ago [1]. Also superconducting ratchets, rectifying motion of either Josephson or Abrikosov vortices, were intensively studied [3]. However, such spatially asymmetric devices operate only at finite magnetic fields, while computer components should work at zero field. Nonreciprocity at $H = 0$ is prohibited by the time-reversal symmetry, which requires invariance of electromagnetic characteristics upon simultaneous flipping of current and magnetic field [2]. Therefore, zero-field superconducting diode requires breaking of both space and time-reversal symmetry.

In this talk, we present our recent results on development of a simple and efficient superconducting diode, with large and switchable nonreciprocity at zero magnetic field [4]. The diodes are made of a conventional Nb superconductor and contain cross-like planar Josephson junctions with additional electrodes and an artificial vortex trap. Nonreciprocity is induced by a combination of self-field effect from asymmetric bias and stray fields from a trapped Abrikosov vortex. The vortex is manipulated (introduced or removed) by short current pulses [5]. We demonstrate that the nonreciprocity of critical currents of such diodes can reach an order of magnitude and rectification efficiency can exceed 70%. Furthermore, we can switch nonreciprocity on and off, as well as change diode polarity in one and the same device. This is achieved by trapping/removing either a vortex, or an antivortex, and/or by changing the bias configuration. This facilitates memory functionality. We argue that such a diode-with-memory can be used for a new generation of superconducting in-memory computers.

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COMPREHENSIVE PERFORMANCE EVALUATION AND OPTIMIZATION OF JOSEPHSON COMPARATOR

Jie Ren[1,2,3], Yang Gao[1,2]

[1]*Shanghai Institute of Microsystem and Information Technology (SIMIT), Chinese Academy of Sciences (CAS), Shanghai 200050, CHINA*
[2]*University of Chinese Academy of Sciences (UCAS), Beijing 100049, CHINA*
[3]*Shanghai University, Shanghai 200444, CHINA*
E-mail: jieren@mail.sim.ac.cn

The Josephson comparator, composed of two Josephson junctions in series, is the decision-making element of the SFQ circuit and the sampling element of the superconducting ADC. Its resolution and speed determine the up-limit performance of the SFQ circuit and the superconducting ADC. We report the progress of our study on the optimization of a comparator.

Firstly, we develop the process for simulating the comparator using a resistive-capacitive-inductive shunted junction (RCLSJ) model for the Josephson junction to establish an increased correlation between simulation and measurement. We propose a method for extracting parameters for the RCLSJ model by regular process control monitor (PCM) measurement. Josephson comparator is then designed with our developed RCLSJ model, and measurement results show that our method ensures 2 to 3 times higher simulation accuracy at frequencies above 60 GHz than the traditional method.

Secondly, we propose a parameter named NSAR (Normalized Speed Resolution Ratio) for evaluating the performance of a comparator. The NSAR can be used to compare the comprehensive performance of the Josephson comparator under different fabrication processes and designs. We explain how to optimize a comparator using the NSAR by numerical simulation and demonstrate the efficacy of our method with measurement results. A method for estimating the reference value of NSAR is developed by co-fitting the experimental data in other reports, which can then be used to evaluate the comprehensive performance of the comparator under different processes.

Abstract ID: 255

STRONGLY COUPLED RF SQUID METAMATERIALS WITH NOVEL COLLECTIVE PROPERTIES

Jingnan Cai[1], Ethan Zack[1], Nikos Lazarides[2], Johanne Hizanidis[3], Steven M. Anlage[1]

[1]*Quantum Materials Center, Physics Department, University of Maryland, College Park, MD 20742-4111, USA*
[2]*Khalifa University of Science and Technology, Abu Dhabi, UNITED ARAB EMIRATES*
[3]*Department of Physics, University of Crete, Herakleio, GREECE*
E-mail: anlage@umd.edu

The self-resonant radio frequency Superconducting Quantum Interference Device (rf SQUID) has been established as a unique building block for microwave frequency metamaterials [1-4]. We consider two-dimensional arrays of rf SQUIDs constructed in a way to create strong inductive, as well as capacitive, coupling between the meta-atoms. New collective properties of the materials arise from these strong interactions, allowing for new applications, such as travelling-wave parametric amplification [5]. The nonlinearity and nonlocal coupling of rf SQUID metamaterials endow them with interesting dynamical properties, such as chaos and chimera states, both of which have been studied extensively by theorists in the context of rf SQUID metamaterials [6-9]. Laser scanning microscopy [10] with single SQUID resolution is employed to study collective states of the nonlinear metamaterial with strong inductive coupling. To quantitatively characterize the nonlinearity, intermodulation (IM) measurements of rf SQUID metamaterials are carried out as a function of dc and rf magnetic flux, as well as frequency [11]. These measurements reveal different dynamics, including dc flux tunability of deep gaps in IM production, and enhanced IM response near the geometric resonance of the rf SQUID. These features observed experimentally are understood and analyzed theoretically through a combination of a steady-state analytical modeling and a full numerical treatment of the rf SQUID dynamics.

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Abstract ID: 242

EFFECTIVE MODELS FOR SINGLE AND DOUBLE QUANTUM DOTS COUPLED TO SUPERCONDUCTING LEADS

M. Žonda[1], P. Zalom[2], T. Novotný[1], V. Pokorný[2]

[1]*Department of Condensed Matter Physics, Faculty of Mathematics and Physics, Charles University, Ke Karlovu 5, CZ-12116 Praha 2, CZECH REPUBLIC*
[2]*Institute of Physics, Czech Academy of Sciences, Na Slovance 2, CZ-18221 Praha 8, CZECH REPUBLIC*
E-mail: martin.zonda@karlov.mff.cuni.cz

We will present an exactly solvable effective model of single quantum dot coupled to superconducting leads and its generalization to the double dot system. Both versions are in principle modifications of the well-known superconducting atomic limit approximation of the paradigmatic superconducting impurity Anderson model (SCIAM). However, in contrast to the standard atomic limit, they give quantitatively correct predictions for the quantum phase transition boundaries, subgap bound states as well as Josephson supercurrent in a broad range of parameters including experimentally relevant regimes. We will show that to reach such a good agreement of the atomic limit model with the precise numerical solutions of the full SCIAM, the parameters of the standard atomic limit have to be rescaled. The origin of the well motivated scaling factors will be discussed in detail.

The advantage of the resulting effective models is that they allow for fast and reliable parameter scans otherwise inaccessible by more precise but computational heavy methods such as quantum Monte Carlo or the numerical renormalization group. This can be important for preparation and analysis of experiments and, as we will demonstrate, in the theoretical search for new regimes and properties of the system.

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Abstract ID: 393

INFLUENCE OF ANHARMONIC AND FRUSTRATION EFFECTS ON CRITICAL CURRENT OF DC SQUID

I.N.Askerzade[1,2]

[1] *Department of Computer Engineering and Center of Excellence of Superconductivity Research, Ankara University, TR06100, TURKEY*
[2] *Institute of Physics Azerbaijan National Academy of Sciences 33, H.Cavid 33.Baku, AZ1143, AZERBAIJAN*
E-mail: imaskerzade@gmail.com

It is well known that, dc SQUID consists of two Josephson junction in parallel, including to superconducting loop. Detail description of dc SQUID on conventional superconductor based Josephson junctions were presented in Ref. [1,2]. In the investigations of the dynamics of dc SQUID, the conventional current-phase relation of Josephson junctions [1,2] $I = I_{c0} Sin\phi$ were used. This relationship $I = I_{c0} Sin\phi$ is fulfilled with a high accuracy for Josephson junctions on low temperature superconductors [3]. In the case of Josephson junctions on high temperature superconductors, the current-phase relation becomes anharmonic [3]

This study devoted to investigation critical current of dc SQUID taking into account anharmonic current-phase relation. Changing of critical current of dc SQUID based on single-band/multiband-band Josephson junctions [4] is analyzed also. It was shown that the presence of anharmonic and frustration effects in junction leads to changing critical current in the different inductance of superconducting ring and as result to different characteristics.

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Abstract ID: 526

REVIEW OF SYNOPSYS TOOLS DEVELOPED UNDER IARPA SUPERTOOLS PROGRAM FROM A CIRCUIT DESIGNER'S PERSPECTIVE

M. Eren Çelik[1], Sukanya S. Meher[1], Jushya Ravi[2], Ashish Shukla[2], Amol Inamdar[2], Timur Filippov[1], Deepnarayan Gupta[2]

[1]Hypres, Inc., 10523, Elmsford, NY, USA
[2]Formerly with Hypres, Inc., 10523, Elmsford, NY, USA
E-mail: mecelik@hypres.com

Synopsys has developed a suite of circuit design tools under the IARPA SuperTools contract, a five-year program to provide open/interoperable Cell Library standards for superconducting electronics (SCE), a toolchain for electronic design and automation (EDA), and tools for technology computer aided design (TCAD) [1]. Synopsys in collaboration with Hypres, Yokohama National University, and University of Rochester, has created a set of tools for superconducting circuit designers ranging from building fundamental circuit schematics and layouts, verification tools for design rule checks (DRC) and layout vs. schematic comparisons (LVS), circuit parameter extraction tools (StarRC), RTL-to-GDS flow circuit synthesis and placement and routing tools (P&R flow). In this work, we will provide a summary of the Synopsys tool capabilities that a circuit designer might utilize to create fabrication-ready circuits using Hypres cell libraries as an example.

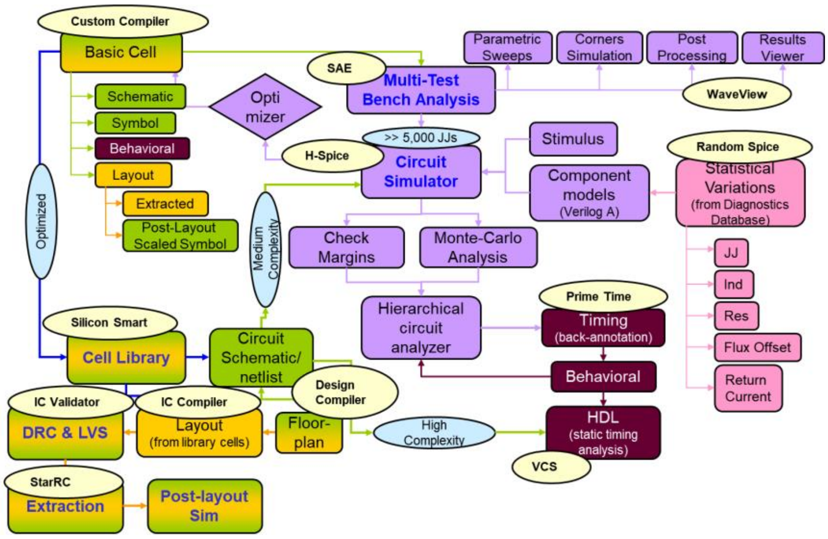

Fig. 1: *Superconductor advanced design flow [2].*

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Abstract ID: 80

QUANTUM INTERFERENCE IN HIGH-TEMPERATURE CUPRATE SUPERCONDUCTOR WITH NOVEL WEAK LINKS BASED ON ARTIFICIAL BOTTOM-UP ENGINEERING

Jianxin Lin[1,2] , Han Zhou[1], Huachuan Wang[1]

[1]Qingdao Innovation and Development Center of Harbin Engineering University, Qingdao, 266404, CHINA
[2]College of Intelligent Systems Science and Engineering, Harbin Engineering University, Harbin 150001, CHINA
E-mail: linjianxin@hrbeu.edu.cn

Significant progress has been made in superconducting quantum devices. However, in contrast to semiconductor p-n junctions, which have affected our lives in such a powerful way, Josephson junctions, the key element of superconducting quantum circuits, is much less mature especially for the high-transition temperature (high-T_c) cuprate superconductors [1-2]. Here, we report on the realization of quantum interference in high-T_c cuprate superconductor with novel weak links based on artificial bottom-up technology. We demonstrate the ability to manipulate the current-voltage characteristics (IVC) of Josephson junctions continuously from superconducting current dominated to almost the resistively and capacitively shunted junction (RCSJ) model by changing the irradiation parameters on STO substrate with Ga+ ion beam. By applying a modulation current through the constriction, the periodic critical current depends on the magnetic flux coupled into the superconducting quantum interference device (SQUID) ring was observed, which exactly reflects the effect of flux quantization. This technique shows the potential to provide a cost-effective and reliable pathway for scaling up quantum-mechanical superconducting devices operating at the liquid-nitrogen temperature as well as an inspiration for the novel fabrication process.

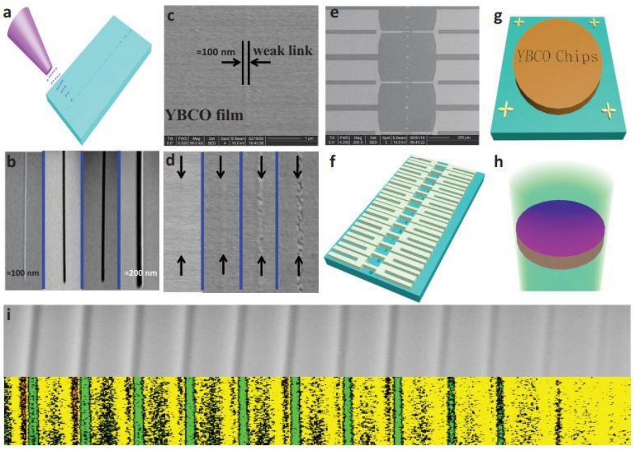

Fig. 1: *Fabracation process of novel week links based on artificial bottom-up engineering.*

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Abstract ID: 341

UNIVERSAL MODELING OF ELECTROSTATIC SEMICONDUCTOR QUANTUM GATES OF ANY TOPOLOGY INTERFACED TO JOSEPHSON JUNCTION QUANTUM CIRCUIT

Krzysztof Pomorski[1,2]

[1] *Cracow University of Technology, Faculty of Electrical and Computer Engineering*
[2] *Quantum Hardware Systems, Lodz*
(www.quantumhardwaresystems.com)
E-mail: kdvpomorski@gmail.com

Single electron devices implemented in the chain of coupled quantum dots become quite promising ways of implementation of qubits [1], quantum logical gates and quantum communication systems due to usage of well-developed CMOS technology that guarantees very high integration. On another hand the superconducting circuits achieved limited level of scalability and are the less noisy integrated systems at low temperatures, so they account for scalable superconducting qubits. High level of CMOS scalability and low noise level in case of Josephson junction makes it necessary to consider the hybrid superconducting-semiconductor quantum devices and interfaces between them as given by [2-3]. The concept of programmable quantum matter and thus quantum circuits can be modeled by usage of quasi one-dimensional models of semiconductor (superconducting) nanowires in Schrodinger (Bogoliubov-de Gennes) or tight-binding formalisms. In such a case, open loop nanowires of arbitrary topology can be approximated by quasi one-dimensional description. The presented scheme can be easily generalized to N interacting electrons placed at N different semiconductor nanowires, whose functionality can be regulated with proper external biasing electric and electromagnetic fields. The interaction of Josephson junction with semiconductor quantum dots is described both by capacitive or inductive channels. In such a way, quantum information processing can be studied in dependence on different topologies of semiconductor nanowires in various electromagnetic conditions.

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Abstract ID: 543

DISCRETE SINE-GORDON EQUATION ON METRIC GRAPHS: A SIMPLE MODEL FOR JOSEPHSON JUNCTION NETWORKS

M.E. Akramov[1], J.R. Yusupov[2], I.N. Askerzade[3], D.U. Matrasulov[4]

[1]*National University of Uzbekistan, 4 University Str., 100174, Tashkent, UZBEKISTAN*
[2]*Kimyo International University in Tashkent, 156 Usman Nasyr Str., 100121, Tashkent, UZBEKISTAN*
[3]*Department of Computer Engineering, Ankara University, 06100, Ankara, TURKEY*
[4]*Turin Polytechnic University in Tashkent, 17 Niyazov Str., 100095, Tashkent, UZBEKISTAN*
E-mail: mashrabresearcher@gmail.com

Sine-Gordon solitons attracted much attention in different contexts, from solid state mechanics to quantum field theory and Josephson junctions (see, Refs. [1–3]). We consider the model, which is directly related to the problem of soliton dynamics in Josephson junction networks. Namely, we consider the sine-Gordon equation on a discrete branched lattice. An effective way for modelling of solitons in networks can be based on the solution of different nonlinear evolution equations (approving soliton solutions) on metric graphs (see Ref. [4]).

The DSG equation is written on each bond of the star graph as follows

$$\frac{d^2u_{j,n}}{dt^2} - a_j\left(u_{j,n+1} - 2u_{j,n} + u_{j,n-1}\right) + \beta_j \sin u_{j,n} = 0, \tag{1}$$

where $j = 1,2,3$ is bond index, n is the site number, a_j, β_j are constants. Using the time derivatives of the conservation laws we derive the "quasi" vertex boundary conditions. We assume that α_j and β_j fulfill the certain relation called sum rule.

In Fig. 1 spatiotemporal evolution of the sine-Gordon soliton obtained in two cases: the sum rule is fulfilled and broken. The problem of discrete sine-Gordon equation on a branched lattice is studied by addressing the problem of integrability and soliton solutions. It is shown that the problem approves exact soliton solutions, provided the nonlinearity coupling constant (penetration depth in case of Josephson junction) assigned to each bond of the graph fulfill certain sum rule. Such case associated also with the reflectionless transmission of sine-Gordon solitons through the branching point. For the cases, when the sum rule is not fulfilled the problem solved numerically. It is shown for the latter case that reflection of soliton at the vertex can be observed.

Fig. 1: *Contour plots of the numerical solutions of DSG equation on the star graph when the sum rule (2) is fulfilled (left) and broken (right) cases.*

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Abstract ID: 583

ELECTRICALLY SMALL SUPERCONDUCTING ANTENNAS FOR TELECOMMUNICATION APPLICATIONS

N.V. Kolotinskiy, V.K. Kornev

Lomonosv Moscow State University, Faculty of Physics, 119991, Moscow, RUSSIA

E-mail: nkolotinsky@gmail.com

Further progress in communication and information technologies that we need now with increase in the number and variety of the involved information data [1,2] cannot be provided by the only semiconductor-based technologies. Therefore, development of the fundamentally new technologies including the ones based on quantum physics laws and effects ought to be put on the agenda. At present, using the macroscopic quantum effects in superconductors has been yielded in outstanding progress of both the analog and digital superconductor devises. Among them, the high-sensitive broadband analog-to-digital converters (ADC) capable of providing outstanding linearity and dynamic range jointly allowing SFDR of up to 90 to 100 dB [3-5] are of great practical importance. Actually, this allows designing superconductor broadband receivers with direct signal digitization by a single superconductor ADC and following digital extraction of sub-bands with programmable band location and bandwidth.

In the receiving systems, however, the inferior linearity and dynamic range of a conventional antenna and a low noise amplifier as compared to those of the ADC can essentially constrain the overall system performance. The problem solution allowing overcoming this limitation can be found with designing the proper antenna and feeder system using also the superconductor-based technology.

In the presentation, we report and discuss our achievements in development of both the physical and design grounds of creating the superconducting active electrically small antennas (ESA) capable of providing high sensitivity and high dynamic range in the wide frequency band ranged from several hertz to tens of gigahertz.

This work is supported by Russian Foundation for Basic Research Grant 19-72-10016.

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Fe-Based Superconductors: Growth and Properties Relevant to Applications I-II-III-IV

09.05.2023 TUESDAY

Abstract ID: 181

PROMINENT PERFORMANCE OF $FeSe_{0.5}Te_{0.5}$ THIN FILMS PRODUCED BY LOW-ENERGY ION IRRADIATION

T. Ozaki[1], S. Yamashita[1], T. Yoshida[1], H. Okazaki[2], S. Yamamoto[2], H. Koshikawa[2], T. Yamaki[2], Q. Li[3]

[1] *Kwansei Gakuin University, 669-1330, Sanda, Hyogo, JAPAN*
[2] *Takasaki Advanced Radiation Research Institute, National Institutes for Quantum and Radiological Science and Technology (QST), 370-1292, Takasaki, Gunma JAPAN*
[3] *Brookhaven National Laboratory, Condensed Matter Physics and Materials Science Department, 11973, Upton, NY, USA*

E-mail: tozaki@kwansei.ac.jp

Iron-based superconductors discovered in 2008 have attracted a great deal of interests in both fundamental physics and potential applications. Iron-chalcogenide superconductors have the simplest structure among iron-based superconductors, which is composed of FeCh layers. Although their superconducting transition temperatures are typically lower than those of iron pnictides, iron chalcogenides exhibit remarkable properties including small anisotoropy, high upper critical fields H_{c2}, which makes iron-chalcogenide superconductor an excellent candidate for high-magnetic-field and energy applications. We have grown epitaxial ion-chalcogenide $FeSe_{0.5}Te_{0.5}$ thin films with CeO_2 buffer layer using pulsed laser deposition. These films exhibit enhanced T_c (T_c^{zero} ~ 18 K), which is about 30% higher than that found in the bulk materials and high in-field J_c performance over the low temperature superconductors.[1,2] The higher in-field J_c performance could be obtained by the introduction of nano-sized precipitates and defects, which can pin the vortices. The desirable pinning structures could be afforded by ion irradiation, which enable the creation of various defects, such as points, clusters and tracks, by opting appropriate ion species and energy.

We were successful in further enhancement of J_c without T_c degradation by proton irradiation.[3,4] Extensive TEM studies of the irradiated FST films have been performed, which revealed an intriguing defect morphology provided by the irradiation. In this talk, we will present the effect of proton fluence on the superconducting properties and flux pinning. Also, we will discuss the superconducting properties on FST films irradiated with different energies and different ion species.

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Abstract ID: 260

HEAVILY ELECTRON DOPING NdFeAsO WITH HIGH J_c AND LOW ANISOTROPY

K. Iida[1,7], J. Hänisch[2], M. Chen[3], K. Kondo[3], T. Hatano[3,7], C. Wang[4], H. Saito[5,7], S. Hata[4,6,7], H. Ikuta[3]

[1] *College of Industrial Technology, Nihon University: Narashino, Chiba 275-8575 JAPAN*
[2] *Karlsruhe Institute of Technology: Hermann-von-Helmholtz-Platz-1, Eggenstein-Leopoldshafen 76344 GERMANY*
[3] *Nagoya University: Chikusa-ku, Nagoya 464-8603 JAPAN*
[4] *The Ultramicroscopy Research Center, Kyushu University: Nishi-ku, Fukuoka 819-0395 JAPAN*
[5] *Institute for Materials Chemistry and Engineering, Kyushu University: Kasuga, Fukuoka 816-8580 JAPAN*
[6] *Interdisciplinary Graduate School of Engineering Sciences, Kyushu University: Kasuga, Fukuoka 816-8580 JAPAN*
[7] *JST CREST: Kawaguchi, Saitama 332-0012 JAPAN*
E-mail: iida.kazumasa@nihon-u.ac.jp

One of the most important quantities for superconducting power applications is the critical current, the maximum electrical current without facing any resistance. Obviously, the larger critical current density J_c, the more favorable for applications. Recently, J_c of the cuprate $REBa_2Cu_3O_{7-\delta}$ (RE: rare earth elements, REBCO) was increased to more than triple the value of an optimally doped REBCO by over-doping [1-2]. Over-doping triggered decrease of both the penetration depth and the coherence length, leading to an increase of the condensation energy.

With this in mind, we have explored for another superconductor to apply this J_c-improvement strategy. Our choice of material is electron doped NdFeAsO, since NdFeAsO exhibits a constant high superconducting transition temperature T_c of around 50 K over a wide range of doping. Electron doping can be realized by a partial substitution of oxygen by fluorine or hydrogen (LnFeAsO$_{1-x}$(F or H)$_x$, Ln: lanthanide element). The respective solubility limit for F and H are $x \leqq 0.2$ and $x \leqq 0.8$. We fabricated NdFeAs(O,H) thin films by a topotactic chemical reaction [3]. NdFeAs(O,H) showed a very high J_c of over 17 MA/cm^2 at 4.2 K, which is almost more than twice as large as our best performed NdFeAs(O,F) [4]. Additionally, the electromagnetic anisotropy of NdFeAs(O,H) was much lower than that of NdFeAs(O,F) [5]. Heavily electron doping benefits the superconducting properties of NdFeAs(O,H) with respect to the critical current and its anisotropy.

This work was supported by JST CREST Grant Number JPMJCR18J4 as well as JSPS Grant-in-Aid for Scientific Research (B) Grant Number 20H02681. A part of work was also supported by Advanced Characterization Platform of the Nanotechnology Platform Japan sponsored by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan.

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Abstract ID: 427

MAGNETIC GRANULARITY IN IRON-BASED SUPERCONDUCTING FILMS ON RABITS TEMPLATES

S. Holleis[1], F. Semper[1], A.A. Thomas[2], I.A. Shipulin[2], A. Steiger-Thirsfeld[3], J. Bernardi[3], A.R. Hühne[2], M. Eisterer[1]

[1]*Atominstitut, TU Wien, 1020 Vienna, AUSTRIA*
[2] *Institute for Metallic Materials, Leibniz-IFW Dresden, 01069 Dresden, GERMANY*
[3] *USTEM, TU Wien, 1040 Vienna, AUSTRIA*
E-mail: michael.eisterer@tuwien.ac.at

Iron-based superconductors are a popular candidate in the search for affordable superconductors for high-field applications. In particular, the relaxed texture requirements resulting from a less severe reduction of the currents across grain boundaries fuel hope that films deposited on RABiTS with simple buffer layer architectures could enable cheap coated conductors. We investigated the local current flow of iron-based superconductors deposited by PLD on RABiTS templates by means of scanning Hall probe microscopy. Local current densities exceeding 1 MA cm^{-2} were observed, however, granularity still seems to be an issue.

Transmission electron microscopy images and analysis by transmission Kikuchi diffraction show that the out-of-plane orientation of underlying Ni-W grains in the substrate has a severe impact on the growth of the films.

We assessed the granularity by deriving the distribution density of the local current densities in order to compare it quantitatively to the granularity of YBCO based coated conductors.

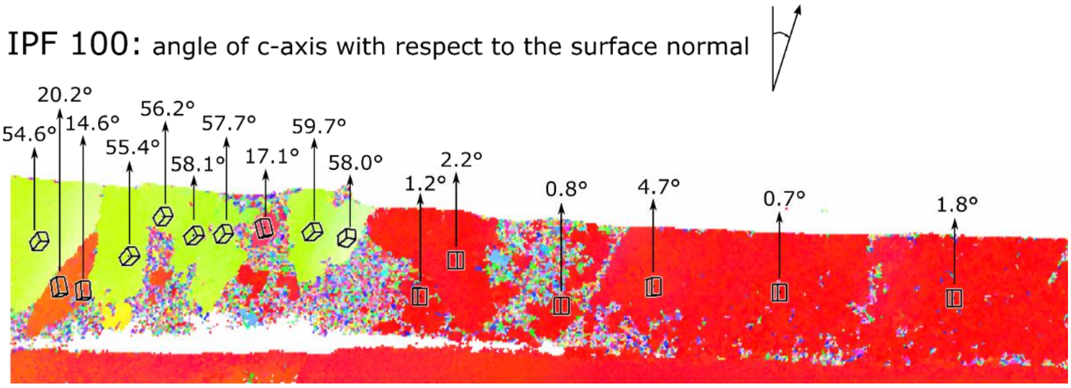

Fig. 1: *Local misorientation of the film assessed by transmission Kikuchi Diffraction (TKD)* [1].

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Abstract ID: 153

NODAL MULTIGAP SUPERCONDUCTIVITY IN THE ANISOTROPIC IRON-BASED COMPOUND $RbCa_2Fe_4As_4F_2$

D. Daghero[1], D. Torsello[1,2], E. Piatti[1], G.A. Ummarino[1], X. Yi[3], X. Xing[3], Z. Shi[3], G. Ghigo[1,2]

[1]*Department of Applied Science and Technology, Politecnico di Torino, I-10129 Torino, ITALY*
[2]*Istituto Nazionale di Fisica Nucleare, Sezione di Torino, I-10125 Torino, ITALY*
[3]*School of Physics, Southeast University, 211189 Nanjing, CHINA*
E-mail: dario.daghero@polito.it

The $RbCa_2Fe_4As_4F_2$ compound, like all the members of the recently discovered family of 12442 iron-based superconductors, is characterized by a crystal structure that originates from the intergrowth of 122-type and 1111-type unit cells. It is a stoichiometric superconductor (i.e. it does not require any substitution to display superconductivity) because of an intrinsic doping of 0.25 holes/Fe atom, and its critical temperature is $T_c \cong 30$ K [1].

Unlike all other Fe-based compounds, 12442 compounds feature double Fe_2As_2 layers (with alkali atoms sandwiched) separated by insulating Ca_2F_2 layers, which makes them similar to double-layer cuprates. Indeed, the *c*-axis coherence length is smaller than the distance between adjacent bilayers, that are therefore almost decoupled [2] – suggesting a quasi-two-dimensional superconductivity – and the anisotropy is much larger than that of other Fe-based compounds [3].

The similarity with cuprates seems to be even deeper, according to various experimental evidences of nodal gap – although there is no consensus yet on the number of gaps and on their symmetry. In order to give a contribution to solve this issue, we carried out directional point-contact Andreev-reflection spectroscopy (PCARS) measurements, combined with coplanar waveguide resonator (CPWR) measurements, in $RbCa_2Fe_4As_4F_2$ single crystals [4]. PCARS allows a direct determination of the number, amplitude and symmetry of the gaps, while CPWR provides the temperature dependence of the London penetration depth and of the superfluid density, whose fit gives an estimation of the gap amplitudes and information on their symmetry.

The two complementary techniques concur to indicate that $RbCa_2Fe_4As_4F_2$ presents *two gaps*, with clear signatures of *d*-wave-like nodal structures (i.e. with the order parameter changing sign on the same Fermi surface). Owing to the tetragonal symmetry of the compound, the most likely conclusion is that *both* the gaps are nodal. The PCARS spectra and the superfluid density were indeed very well fitted by a two-band $d - d$ model.

The evidence of nodal gaps persists even upon 5% Ni doping, that reduces the critical temperature from 30 K to about 20 K. This suggests that nodes are more likely to be symmetry-protected rather than accidental, and supports the two-band $d - d$ picture. Further indications in favor of this picture come from the large anisotropy of the London penetration depth, which is weakly dependent on temperature and fully compatible with the $d - d$ model.

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Abstract ID: 161

MAJOR CAUSES DEGRADING THE GRAIN BOUNDARY CONNECTIVITY IN K-DOPED Ba122 Fe-BASED SUPERCONDUCTORS

F. Kametani[1,2], S. A. Limon[1], S. Mao[1,3], Y. Oz[1], C. Tarantini[1], E. Hellstrom[1,2]

[1]*Applied Superconductivity Center, National High Field Magnet Field Laboratory, Florida State University, 32310, Tallahassee, USA*
[2]*Mechanical Engineering, FAMU-FSU College of Engineering, Florida State University, 32310, Tallahassee, USA*
[3]*Industrial & Manufacturing Engineering, FAMU-FSU College of Engineering, Florida State University, 32310, Tallahassee, USA*

E-mail: kametani@asc.magnet.fsu.edu

The Fe-based superconductor (FBS) K-doped Ba122 (K-122) has the potential to transform into a cost-effective high field superconductor. However, despite of its high T_c, H_{c2} and intragrain J_c, unpredictable superconducting connectivity at grain boundaries (GBs) is still the critical problem that limits the long-range J_c of polycrystalline K-122 bulks, wires and tapes. Indeed, one of the important challenges for making high-J_c 122 wires and tapes is to understand how the GB nanostructures affects the GB connectivity and establish the effective processing to control them. Currently the GB connectivity is not fully under control even in our best bulks, nor in other groups' best wires and tapes. There are different kinds of extrinsic current blockers at GBs including FeAs, Ba oxide, and/or nanocracks. Although we have reduced some of these by employing the cleaner synthesis protocol, it is still largely unknown what synthesis parameter plays a role to effectively remove each of them. Reduction of impurity phases at the GBs also depends on how to control the intragrain composition of K-122. The polycrystalline bulk is the simple platform to investigate the correlation of synthesis parameters on the intra-/intergrain properties of K-Ba122. We performed compositional analysis using TEM on individual K-122 grains in various K-122 bulks and found that the average intragrain composition became off-stoichiometry relative to the starting composition as the 2nd heat treatment (HT) temperature increases, resulting in significant reduction of J_c (4.2 K, 0.5 T) from 1.85×10^5 to 6.0×10^4 A/cm^2. The Ba/K ratio stays close to the optimum (Ba : K = 6 : 4) despite very minor K loss. However, the intragrain composition obviously became Fe-rich and/or As-rich, potentially degrading the intragrain superconducting properties in addition to losing intergrain connectivity. Our recent studies of varying the 1st milling and HT temperature showed that despite of the fixed 2nd milling and HT parameters, the large milling energy in the 1st milling increases the diamagnetic signal per volume, but reduces the intergrain J_c, implying that the multi-scale current loops might appear depending on the synthesis conditions. Our results of polycrystalline samples demonstrate the need to deconvolute the effects that these entangled synthesis parameters have on J_c by employing the very clean synthesis protocols.

Abstract ID: 169

VORTEX MOTION IN FeSeTe THIN FILMS AT MICROWAVE FREQUENCIES: ANISOTROPY, FLUX-FLOW, PINNING AND EFFECT OF IRRADIATION

E. Silva[1,2], A. Alimenti[1], V. Braccini[3], G. Ghigo[4,5], M. Iebole[6], M. Meinero[6], S. Okayasu[7], N. Pompeo[1,2], T. Tamegai[8], K. Torokhtii[1], D. Torsello[4,5], P. Vidal García[1,2]

[1]*Dept. of Industrial, Electronic and Mechanical Engineering, University Roma Tre, 00146 Roma, ITALY*
[2]*INFN Sezione Roma Tre, 00146, Roma, ITALY*
[3]*CNR-SPIN, Genova, ITALY*
[4]*Dept. of Applied Science and Technology, Politecnico di Torino, 10129 Torino, ITALY*
[5]*INFN Sezione di Torino, Torino, ITALY*
[6]*Dept. of Physics, University of Genova, Genova, ITALY*
[7]*ASRC, Japan Atomic Energy Agency, Ibaraki 319-1195, JAPAN*
[8]*Department of Applied Physics, The University of Tokyo, Tokyo 113-8656, JAPAN*
E-mail: enrico.silva@uniroma3.it

Applications of Fe-based superconductors (IBS) are mostly affected by anisotropy, pinning strength, flux creep, and changes of those factors with defects introduced in the superconducting matrix. All those properties are affected by the multigap nature of IBS. To shed light on those aspects we perform microwave measurements of the field (H) and angle (θ) dependent surface impedance $Z(H,\theta)$ with a two-frequency (16/27 GHz) dielectric resonator. We explore fields up to 12 T (1.3 T in the variable orientation setup). We investigate the behavior of $FeSe_xTe_{1-x}$ films (240 nm thick, T_c~18 K) grown by Pulsed Laser Deposition from $FeSe_{0.5}Te_{0.5}$ targets on CaF_2 substrates [1]. Heavy ion irradiation (320 MeV Au-ion, fluence 10^{11} cm^{-2}) is employed to introduce correlated defects. Multifrequency complex Z measurements can disentangle the flux-flow resistivity ρ_{ff}, the pinning constant – Labusch parameter k_p, and the flux-creep normalized dimensionless parameter χ [2], and give access to the intrinsic and pinning anisotropies, separately [3].

We find that the angular dependence of ρ_{ff} closely follow the single- band BGL scaling theory [4], whence the intrinsic material anisotropy $\gamma \approx 2$, almost constant in the obtained temperature range 8-14 K. Neither ρ_{ff} nor γ are significantly affected by irradiation, within our experimental uncertainty. In pristine samples, the low field angular dependence of k_p is characteristic of pinning as dominated by point pins. The high field dependence of k_p (H // c-axis) shows signatures of collective pinning regime behavior above 3 T, consistently with the single-to-collective crossover observed through d.c. magnetoresistance measurements performed on similar samples [5]. With irradiation, signs of the effect of correlated disorder appear. The temperature dependence of the creep factor χ shows that thermally activated jumps involve small vortex portions, with sizes on the scale of ξ^3.

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Abstract ID: 454

PHASE DIAGRAM OF $Fe_ySe_xTe_{1-x}$ SUPERCONDUCTING FILMS

Jia-Ying Zhang, Ya-Xun He, Tian He, Jing-Yu He, Qi-Ling Xiao, Jun-Yi Ge

Shanghai University, Materials Genome Institute, 200444, Shanghai, PEOPLE'S REPUBLIC OF CHINA
E-mail: junyi_ge@t.shu.edu.cn

Because of the simple crystal structure and rich phase diagrams, FeSeTe is considered as an ideal candidate to study the superconducting mechanism of iron-based superconductors, and even high-temperature superconductors. In addition, FeSeTe superconducting film shows great potential in the high-field applications due to its high critical temperature and ultra-high upper critical magnetic field. The superconductivity of FeSeTe film is sensitive to its compositional variation. Several Se content-dependent electronic and magnetic phase diagrams for FeSeTe superconductors have been established [1-3], but the Fe content-dependent phase diagram is still absent. Here, we investigated a series of $Fe_ySe_xTe_{1-x}$ films and developed a more complete phase diagram for $Fe_ySe_xTe_{1-x}$ superconducting films with wider range of Fe content.

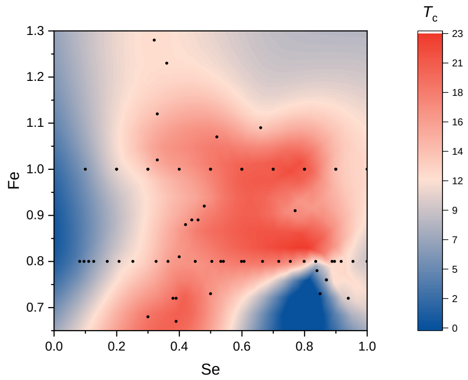

Fig. 1: *Phase diagram of $Fe_ySe_xTe_{1-x}$ superconducting films.*

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Abstract ID: 190

HIGHLY HYDROGEN-SUBSTITUTED 1111-TYPE SmFeAsO EPITAXIAL FILMS: FABRICATION AND SUPERCONDUCTING PROPERTIES

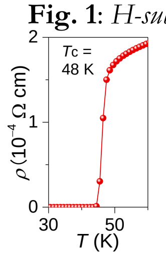
Kota Hanzawa[1], Hidenori Hiramatsu[1,2], Hideo Hosono[2,3]

[1] *Laboratory for Materials and Structures, Tokyo Institute of Technology, JAPAN*
[2]*MDX Research Center for Element Strategy, Tokyo Institute of Technology, JAPAN*
[3]*National Institute for Materials Science, JAPAN*
E-mail: K-hanzawa@mces.titech.ac.jp

1111-type *Re*FeAsO (*Re* = rare earth) is the highest critical temperature (T_c) family among iron-based superconductors, and its T_c reaches 55 K when *Re* = Sm. The superconductivity is usually induced by electron doping through O-site substitution with F. The solubility limit of F is as low as ~20 %. In 2011, another donor, H, was proposed for *Re*FeAsO. The H-substitution expanded the solubility limit up to ~80 % and led to discovery of e.g., a unique electronic phase diagram. Even though single crystals or epitaxial thin films are essential to examine detailed superconducting properties and mechanism, the growth was very challenging particularly for H-substituted *Re*FeAsO. In 2017, SmFeAs(O,H) single crystals were successfully grown by high pressure method, whereas their sizes were too small and the H density was too low [1]. This situation had restricted basic researches on the critical current (J_c), upper critical field (μ_0H_{c2}), and its anisotropies ($\gamma = \mu_0H_{c2}||ab$ / $\mu_0H_{c2}||c$) for SmFeAs(O,H). Recently, we first developed an effective H-substitution process for SmFeAsO epitaxial thin films and evaluated their superconduting properties.

Fig. 1 schematically depicts the H-substitution process: the post-deposition thermal anneaing using topochemical reaction between CaH_2 powder and undoped SmFeAsO epitaxial film [2]. The SmFeAs(O,H) film contains high-density H (~35%), i.e., $SmFeAsO_{0.65}H_{0.35}$, resulting in emergence of high-T_c superconductivity at 48 K (**Fig. 2**) [2]. The J_c was ~1 MA/cm² under a self-field and ~0.5 MA/cm² under μ_0H = 9 T at 2 K [3], which are comparable with those of 122-type $BaFe_2As_2$. Furthermore, the μ_0H_{c2} was examined with pulsed high-field magnets generating up to 130 T (**Fig. 3**) [4]. Consequently, it was clarified that $SmFeAsO_{0.65}H_{0.35}$ posseses high μ_0H_{c2} of 120 T under $\mu_0H||ab$ at 2 K, which is the first experimental determination of μ_0H_{c2} at low-temperature limit in SmFeAsO. The γ was estimated to be ~2 around T_c. This value is about half of SmFeAs(O,F), suggesting that high-density H efficiently enhances three dimensionality. These results imply that SmFeAs(O,H) is a promising candidate for a next generation superconducting applications such as cables and high-field electromagnets.

Fig. 1: *H-substitution process.*



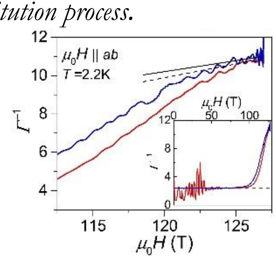


Fig. 2 (left): *Temperature dependence of resistivity (ρ).*
Fig. 3 (right): *Impedance measuremet under high magnetic field of 130 T.*

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Abstract ID: 510

DATA DRIVEN PROCESSING AND RECORD TRAPPED FIELD PROPERTIES OF IRON-BASED BULK SUPERCONDUCTORS

Akiyasu Yamamoto1,4, Shota Ishiwata1, Shinjiro Kikuchi1, Yuta Hasegawa1, Shinnosuke Tokuta1, Yusuke Shimada2,4, Akimitsu Ishii3,4, Akinori Yamanaka1,4

[1] *Tokyo University of Agriculture and Technology, Tokyo 184-8588, JAPAN*
[2] *Tohoku University, Ibaraki 311-1313, JAPAN*
[3] *NIMS, Tsukuba 305-0047, JAPAN*
[4] *JST-CREST, Kawaguchi 332-0012, JAPAN*
E-mail: akiyasu@cc.tuat.ac.jp

122 phase iron-based superconductors show high upper critical field (H_{c2} > 50 T) with small electromagnetic anisotropy (γ ~ 1-2) [1] and large critical grain boundary angle (θ_c ~9°) [2], and therefore is a promising material for applications in polycrystalline form. Foreseeing bulk magnet applications, Weiss et al. have reported demonstration of trapped field of 1 T for K-doped $BaFe_2As_2$ (Ba122) polycrystalline bulks synthesized by hot isostatic pressing [3]. In this study, we synthesized K-doped Ba122 bulks in a highly pure Ar glove box from mechanically alloyed precursor powder which was prepared by high-energy ball-milling of elemental metals with the molar ratios of Ba:K:Fe:As = 0.6:0.4:2:2 [4,5]. The mechanically alloyed precursor powder was then spark plasma sintered. Processing conditions were optimized based on the knowledge of nanostructural analysis and multi-scale observations [6,7], and by the process machine learning [8]. Bayesian optimization was applied to find the best input parameters that maximize the target output property, critical current density (J_c), on the experimentally available range of processing conditions. High J_c value exceeding 10^5 A/cm^2 was developed by both experiments guided by researchers and such an adaptive experimental optimization process. High trapped field exceeding the previous record by Weiss et al. [3] was measured. Trapped field properties of Ba122 bulk magnets and the key microstructural features associated with J_c will be discussed.

Acknowledgement

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Abstract ID: 567

HIGH-PRESSURE GROWTH AND PHYSICAL PROPERTIES OF IRON-BASED SUPERCONDUCTORS: 1111 AND 1144

Shiv J. Singh

Institute of High-Pressure Physics (IHPP), Polish Academy of Sciences, Sokolowska 29/37,Warsaw, POLAND
E-mail: shivjees@gmail.com

Iron-based superconductors (FBS) present an ideal material platform for studying fundamentaland applied research [1]. More than 100 compounds have been reported for this high-T_c superconductor that can be categorized into 5–6 families [2–4]. The 1111 (*RE*FeAsO, *RE* = rareearth) and 1144 (*AE*AFe4As4, *AE* = Ca, Eu; *A* = K, Rb) families are the two most important families of FBS, which offer high T_c of 58 and 36 K with and without doping, respectively. Furthermore, sample growth of these families is not an easy process, and a lot of research efforts have been reported in this direction. However, the preparation of high-quality and suitable-sized samples is still challenging. In this presentation, we review the superconductingproperties of 1111 and 1144 families as well as their growth processes, such as polycrystals and single crystals. A brief comparison is made between the reported papers to better understand the developmental issues [4], implying that high-pressure techniques may be a viable option for resolving the sample issues of these families. In this regard, we are currentlyusing Hot-Isostatic Pressing (HIP) technique to optimize the growth parameters and the appliedgas pressure to grow high-quality single crystals and polycrystals of 1111 and 1144 families. Our HIP technique can generate an inert gas pressure of up to 1.5 GPa in a cylinder chamber fitted with a three-zone furnace capable of reaching 1700°C. All prepared samples arecharacterized by various measurements to reach the final conclusions. We present our brief findings in this presentation, which is our new research project funded by the Polish government.

Acknowledgments

The work was supported by SONATA-BIS 11 project (Registration number: 2021/42/E/ST5/00262) funded by National Science Centre (NCN), Poland. SJS acknowledges the financial support from National Science Centre (NCN), Poland through Project number 2021/42/E/ST5/00262.

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Abstract ID: 128

ANOMALOUS PEAK EFFECTS IN IRON-BASED SUPERCONDUCTORS WITH COLUMNAR DEFECTS

T. Tamegai[1], A. Takahashi[1], Y. Kobayashi[1], J. Wang[1], K. Kato[1], Y. Hirota[1], S. Pyon[1], R. Sakagami[1], T. Kambara[2], A. Yoshida[2], S. Okayasu[3], A. Ichinose[4]

[1]*Department of Applied Physics, The University of Tokyo, Tokyo 113-8656, JAPAN*
[2]*Nishina Center, RIKEN, Saitama 351-0198, JAPAN*
[3]*Advanced Science Research Center, Japan Atomic Energy Agency, Ibaraki 319-1195, JAPAN*
[4]*Central Research Institute of Electric Power Industry, Electric Power Engineering Research Laboratory, Kanagawa 240-0196, JAPAN*

E-mail: tamegai@ap.t.u-tokyo.ac.jp

Columnar defects (CD) in superconductors introduced by heavy-ion irradiation are known to be excellent pinning centers for vortices, leading to strong enhancement of critical current density (J_c) [1]. Further enhancement of J_c by splaying the direction of CDs has been predicted theoretically [2] and demonstrated experimentally in $YBa_2Cu_3O_{7-d}$ [3]. In addition, introduction of CDs can cause an anomalous enhancement of J_c, known as peak effect, at a field that is ~1/3 of matching field (B_F) defining the density of CDs [1,4]. The peak effect in superconductors with CDs, which we call anomalous peak effect (APE), has been identified in $(Ba,K)Fe_2As_2$ when two kinds of CDs are introduced symmetrically with respect to the *c*-axis [4]. APE becomes weaker when asymmetry is introduced in the configuration or density of two species of CDs and the magnetic field is applied away from the symmetric direction [5]. On the other hand, introduction of splayed CDs inevitably introduces two kinds of J_c in the superconducting plane; one parallel to the splay plane and another perpendicular to it. We explore such in-plane anisotropy of J_c by magneto-optical imaging and magnetization measurements [6]. Recently, a similar APE has been observed in a conventional layered superconductor $NbSe_2$ when CDs was introduced at an angle from the *c*-axis. We also confirmed the presence of APE in iron-based superconductors (IBSs) with tilted CDs. In this talk, we summarize the present status of APE in IBS with CDs and compare it with similar phenomena in other superconductors.

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Abstract ID: 305

SYNTHESIS AND CHARACTERIZATION OF Cs-BASED Eu/Sr-1144 SUPERCONDUCTORS

A. Yu. Degtyarenko[1], V.A. Vlasenko[1], S. Yu. Gavrilkin[1], A. Yu. Tsvetkov[1], S.A. Kuzmichev[1,2], T.E. Kuzmicheva[1], A.V. Ovcharov[3], K.S. Pervakov[1]

[1] *V.L. Ginzburg Centre for High-Temperature Superconductivity and Quantum Materials P.N. Lebedev Physical Institute of the Russian Academy of Sciences (LPI RAS), 53, Leninsky Ave., 119991 Moscow, RUSSIA*
[2]*Faculty of Physics, Moscow State University, 1, Leninskiye Gory 119234, Moscow RUSSIA*
[3]*National Research Centre "Kurchatov Institute", 1, Kurchatov Sq, Moscow 123182, RUSSIA*
E-mail: degtyarenkoayu@lebedev.ru

Discovered in 2016 new system of the iron-based superconductors named 1144 family [1] are actively investigated by scientific groups around the world. First of all, interest is caused by a stoichiometric composition and high critical temperatures, second point of interest is a unique coexistence of magnetic ordering at $T_m \approx 15$ K and superconducting transition at $T_c \approx 36$ K in europium containing 1144 compounds. Here we report the successful growth of the single crystals of magnetic $EuCsFe_4As_4$ and nonmagnetic $SrCsFe_4As_4$ iron-based superconductors of 1144 family. High-purity materials Eu (99.9%), Cs (99.99%), Sr (99.9%), Fe (99.98%) and As (6N) were used as initial components for precursors. Previously obtained precursors were placed in corundum crucibles in stoichiometric ratio and welded in tantalum containers, after which a long-term multistage heat treatment was carried out. Varying the growth temperature regimes and flux amount of CsAs, we obtained single crystals of the $EuCsFe_4As_4$ and $SrCsFe_4As_4$ with trace inclusions of related 122 phase. The $\chi(T)$, M(H) and R(T) measurements show bulk superconductivity, and rather sharp superconducting transition for examined single crystals. Using Andreev spectroscopy, we directly showed a multiple-gap superconductivity with at least two nodeless superconducting gaps, and a homogeneity of the superconducting properties at nanometer scale [2]. Following microstructure investigations of the 1144 superconductors show that crystals have planar defects [3, 4, 5]. This confirms the assumption that the 1144 phase competes with the related 122 phase during crystal growth. In our 1144 samples we observed the inclusions of related 122 phases: $SrFe_2As_2$, $EuFe_2As_2$, $CsFe_2As_2$. It also confirmed by XRD results.

The work was performed using equipment of the Lebedev Physical Institute's Shared Facility Center. This research was funded by the RUSSIAN SCIENCE FOUNDATION, project number 22-22-00776.

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Abstract ID: 432

SUPERCONDUCTIVITY AND THERMAL STABILITY OF $Ba_{1-x}K_xFe_2As_2$ COMPOSITE WIRES AND TAPES

Chiheng Dong[1,2], Caida Fu[1,2], Meng Han[1], Yanwei Ma[1,2]

[1] *Institute of Electrical Engineering, Chinese Academy of Sciences, Beijing 100190, PEOPLE'S REPUBLIC OF CHINA*
[2] *University of Chinese Academy of Sciences, Beijing 100049, PEOPLE'S REPUBLIC OF CHINA*
E-mail: dongch@mail.iee.ac.cn

Iron-based superconductors are potential candidates for high-field applications not only because of their high upper critical field and low anisotropy but also due to the cost-effective powder-in-tube fabrication technique. Benefiting from the designing flexibility of conductor architectures, different metals and alloys other than expensive silver can be applied as sheath materials. Here, we combined traditional mechanical deformation methods and non-silver sheath materials to fabricate composite $Ba_{1-x}K_xFe_2As_2$ superconducting wires and tapes. The silver sheath is considerably diminished and only acts as a barrier layer, resulting in a large reduction in material cost. Based on the finite element simulation and microscopic analysis, we conclude that flat/groove rolling applies a large deformation stress on the superconducting filaments which realigns and considerably densifies the crushed superconducting grains. Without the aid of high-pressure sintering, we obtained highly compacted superconducting cores with a large critical current density that can compete with that of the hot-isostatic-pressing wires and hot-pressed tapes. Moreover, we found that the thermal conductivity is dominated by the sheath materials. It can be varied from 1 to 1000 W/m K by optimizing the conductor architectures. By using the equivalent heat current circuit model, we reveal the mechanism of element diffusion between sheath materials. Our studies highlight the importance of the conductor design and the deformation process for low-cost, high-performance iron-based superconducting wires and tapes.

Kitaev Model and Materials

09.05.2023 TUESDAY

Abstract ID: 134

KITAEV MODEL IN THE EASY-PLANE LIMIT: QUANTUM EFFECTS AND EXOTIC STATES

Pavel Maksimov

Joint Institute for Nuclear Research, Jolio-Curie st., 20, BLTP Dubna, RUSSIA
E-mail: pmaksimo@uci.edu

Kitaev spin liquid is a quantum paramagnetic state of a honeycomb magnet which is able to host Majorana excitations necessary for topological quantum computation. Anisotropic bond-dependent interactions of the Kitaev honeycomb model were proposed to be realized in d5 Ru and Ir, as well as d7 Co compounds. However, it turned out that in reality additional bond-dependent interaction, allowed by symmetry of edge-sharing octahedra, are present in these materials, which often correspond to the easy-plane exchange interactions. Moreover, probably more importantly, third-neighbor interactions are comparable to nearest-neighbor exchange. We will discuss two cases of easy-plane anisotropic-exchange models. First, we will discuss quantum corrections to the spin-wave spectrum of zigzag and polarized states of the easy-plane anisotropic-exchange model and its connections to a-$RuCl_3$. Second, we present ab initio calculations for exchange parameters of $BaCo_2(AsO_4)_2$, a Kitaev candidate which is essentially an easy-plane J1-J3 magnet but nonetheless hosts a unique double-zigzag state stabilized by non-negligible third-neighbor anisotropic interactions.

Abstract ID: 557

JANH-TELLER POLARON IN A SPIN-ORBIT MULTIPOLAR MAGNETIC OXIDE

Cesare Franchini[1,2]

[1]*University of Vienna AUSTRIA*
[2]*University of Bologna ITALY*
E-mail: cesare.franchini@univie.ac.at

Polarons and spin-orbit coupling are distinct fundamental quantum effects that play a crucial role in charge transport and spin-orbitronics. Polaron quasiparticles originate from electron-phonon interaction and are ubiquitous in polarizable materials featuring electron localization, particularly in 3d transition metal oxides. The relativistic coupling between the spin and angular orbital momentum is notable in lattices with heavy atoms and develops in 5d transition metal oxides, where electrons are more spatially delocalized than their 3d counterparts. In this talk, we show that these two different properties can be integrated and connected in the multipolar magnet $Ba_2(Na,Ca)OsO_6$.

By combining density functional theory and dynamical mean field theory calculations with nuclear magnetic resonance and muon spin rotation measurements, we prove the formation of a relativistic polaron, i.e. a polaron with an intrinsic spin-orbit coupled nature. Its formation, enabled by the cooperative action of phonon flexibility provided by the Jahn-Teller activity and the unusually strong electron-electron correlation, converts the 5d1 J_{eff}=3/2 ground state levels via LS coupling into a 5d2 J_{eff}=2 manifold. Polaron charge trapping ultimately leads to the coexistence of different J-effective states in a single-phase material.

Low Dimensional Frustrated Magnetism

09.05.2023 TUESDAY

Abstract ID: 622

LOW DIMENSIONAL TRANSITION METAL NITRATES

O. Volkova[1,2]

[1]M.V. Lomonosov Moscow State University, 119991, Moscow, RUSSIA
[2] National University of Science and Technology "MISiS", 119049, Moscow, RUSSIA
E-mail: os.volkova@yahoo.com

Anhydrous transition metal nitrates stand out by peculiar properties stemming from the frustration of leading exchange interactions. The investigation of physical properties of these systems has been focused on $M(NO_3)_2$ (M = Co, Ni), $Rb_3Ni_2(NO_3)_7$ and $(NO)M(NO_3)_3$ (M = Co, Ni, Cu) [1-5]. This work represents properties of highly disordered nitrosonium manganese nitrate $(NO)Mn_6(NO_3)_{13}$. It demonstrates the correlated disorder in magnetic and anionic subsystems at temperatures exceeding 12.8 K and 192 K, correspondingly. Its crystal structure was established in a broad temperature range at T ≥ 55 K. It is described by space group P63/m with unit cell parameters a = 10.630(2) Å, c = 15.150(8) Å, V = 194.3(0) Å^3 at T = 300 K. It contains quantum tubes of corner shared MnO_6 octahedra strengthened with nitrate groups NO_3^- inside and outside. The space between the tubes is occupied with intermediate NO^+ groups. One of nitrate groups outside the tubes may occupy two positions and orders at 190 K. The antiferromagnetic ordering of the magnetic subsystem occurs after antiferromagnetic low-dimensional correlations with characteristic temperature T_{max} = 25 K in two steps at T_{N1} = 12.8 K and T_{N2} = 8.3 K. The structural and magnetic phase transitions are confirmed by the anomalies in specific heat, magnetic susceptibility shown in Fig. 1, dielectric constant and ESR data.

The work is supported by the megagrant project 075-15-2021-604.

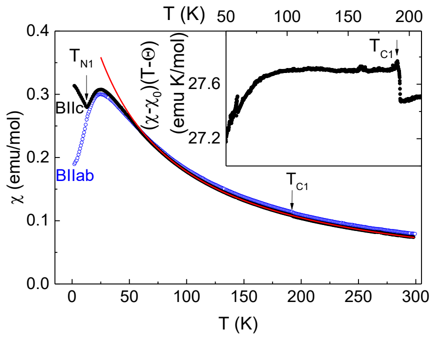

Fig. 1*: Temperature dependences of magnetic susceptibility χ of $(NO)Mn_6(NO_3)_{13}$ obtained in field – cooled regime at B = 0.1 T applied along c – axis (closed circles) and in the ab – plane (open circles). Solid line is a fit with Curie – Weiss law. The inset represents the field cooled curve in a special scale $(\chi\text{-}\chi_0)(T\text{-}\Theta)$ vs. T. Arrows indicate structural and magnetic phase transitions.*

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Abstract ID: 623

SQUARE KAGOME LATTICES

A.N. Vasiliev1,[2]

[1]*Functional Quantum Materials Laboratory, National University of Science and Technology "MISiS", Moscow, RUSSIA*
[2]*Low Temperature Physics and Superconductivity Department, Moscow State University, Moscow, RUSSIA*
E-mail: vasil@lt.phys.msu.ru

A quantum antiferromagnet with a square kagomé lattice (SKL) represents the rare case when it is possible to establish precisely the origin of a new physical concept. In 2001, Siddharthan and Georges introduced a two-dimensional network of corner-sharing triangles with square lattice symmetry [1]. In variance with kagomé lattice, which is a two-dimensional network of corner-sharing triangles with hexagonal voids, SKL is a two-dimensional network of corner-sharing triangles with alternative square and octagonal voids. There are two non-equivalent positions for the magnetic ions, α and β, being in ratio one to two. The shape of the unit cell resembles shuriken, a Ninja concealed weapon of ancient time. It has been shown numerically that the properties of a square kagomé antiferromagnet should be similar to those on a kagomé lattice. For the spin-1/2 Heisenberg quantum antiferromagnet, a resonating valence bond ground state has been predicted with a triplet gap filled by a continuum of low-lying singlet states.

In the large-N limit, N being the number of lattice sites, a finite temperature phase transition into a phase with ordered resonance loops and broken translational symmetry has been predicted. This exotic transition is not forbidden by the Mermin-Wagner theorem since it stems from the breaking of a translational symmetry. Recently, it has been shown that the model of geometrically frustrated SKL possesses just single thermodynamically stable solution for arbitrary values of model parameters. The very existence of this unique solution means that the model cannot exhibit either first order or second order phase transitions, at least, at non-zero temperatures. The temperature dependence of the specific heat of spin-1/2 Heisenberg SKL antiferromagnet has been analyzed by Tomczak and Richter who predicted the broad peak located at $T \sim 0.85J$ which is a correlation one typical for any low-dimensional magnetic systems, and the second one, at $T \sim 0.10J$, which indicates an additional energy scale relevant to SKL being ascribed to the energy of the lowest spin triplet excitation.

For a long time, the studies of the thermodynamic properties of compounds with SKL or its derivatives were carried out exclusively by theoretical methods, albeit the nature provided such patterns in some rare minerals. Among these minerals are nabokoite $KCu_7(SO_4)_5(TeO_3)OCl$, atlasovite $KCu_6FeBiO_4(SO_4)_5Cl$, elasmochloite $Na_3Cu_6BiO_4(SO_4)_5$ and favreauite $PbCu_6BiO_4(SeO_3)_4(OH)H_2O$. The intrinsic properties of SKL in nabokoite and atlasovite are masked by the presence of magnetic ions extraneous to this network. Recently, the iron-free sibling of atlasovite, $KCu_6AlBiO_4(SO_4)_5Cl$, has been synthesized and thoroughly investigated in measurements of thermodynamics, muon spin relaxation and neutron scattering. It has been established that down to 58 mK this compound persists in a gapless quantum spin liquid state. Additionally, a novel sodium bismuth oxo-cuprate phosphate chloride, $Na_6Cu_7BiO_4(PO_4)_4Cl_3$, containing both square kagomé layers and interlayer Cu^{2+} ions has been synthesized by hydrothermal technique. This material shows no magnetic ordering down to 50 mK forming quantum spin liquid state similar to $KCu_6AlBiO_4(SO_4)_5Cl$. Here, we present the results of various measurements on synthetic $KCu_6AlBiO_4(SO_4)_5Cl$, $Na_6Cu_7BiO_4(PO_4)_4Cl_3$ and $KCu_7(SO_4)_5(TeO_3)OCl$. This work has been supported by the Megagrant program of the Government of Russian Federation through the project 075-15-2021-604.

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Abstract ID: 638

CLASSICAL AND QUANTUM DYNAMICS OF RELATIVISTIC TWO-DIMENSIONAL ATOM IN GRAPHENE INTERACTING WITH CONSTANT UNIFORM MAGNETIC FIELD

J. Matrasulov[1], J. Yuspov[2]

[1]*National University of Uzbekistan, 4 University Str., 100174, Tashkent, UZBEKISTAN*
[2]*Kimyo International University in Tashkent, 156 Usman Nasyr Str., 100121 Tashkent, UZBEKISTAN*
E-mail: jasur1362@gmail.com

We consider the problem of 2D relativistic hydrogen-like atom in a uniform magnetic field. We study both classical and quantum chaos by using this model, by solving Hamilton-Jacobi equation and eigenvalue problem for Dirac equation we observed transition from regular to chaotic dynamics. Experimental realization of the model is discussed.

Nonrelativistic hydrogen atom in a uniform magnetic field well known paradigm for study of the chaos and its quantum manifestation and was extensively studied in eighties of 20th century (see, e.g., Refs. [1-3], for review).

In this work we'll study relativistic extension of this problem considering 2D relativistic hydrogen like atom in a constant uniform magnetic field. Unlike its nonrelativistic counterpart, such system was not studied yet, in the context of classical and quantum chaos theories.

Recent discovery of graphene makes possible experimental realization of relativistic planar atom and its interaction with different external fields.

One of the methods observing planar atom is doping of graphene by charged impurities. In this case by capturing a free electron, becomes relativistic planar atom. In this theoretical study, we found that planar atom in external constant magnetic field is integrable, while its quantum counterpart manifests quantum chaos behavior.

This work is supported by the Research Excellence Program of the Ministry of Innovative Development of Republic of Uzbekistan (Ref. Nr. REP-05032022/235).

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Low Dimensional Frustrated Magnetism and Spin-Orbital Materials

09.05.2023 TUESDAY

Abstract ID: 235

FRUSTRATED MAGNETISM AND DECONFINEMENT IN DOPED AND UNDOPED MOTT INSULATORS

V. Yu. Irkhin

M. N. Mikheev Institute of Metal Physics, 620108 Ekaterinburg, RUSSIA
E-mail: virkhin@gmail.com

The Mott (metal-insulator) transition occurs in *d*-metal compounds owing to strong Coulomb interaction (electron correlations). More often, this transition occurs in antiferromagnetic phase (so-called Slater scenario), but the situation changes for magnetically frustrated systems: only paramagnetic metallic and insulator states are involved, a spin liquid being formed. The transition into such insulator state is related to correlation-induced Hubbard splitting (the Mott scenario). New theoretical developments provided a topological point of view for the Mott transition, since spin liquid possesses topological order. Phase transitions in frustrated systems can be treated in terms of topological excitations (e.g., vortices and monopoles) which play a crucial role for confinement.

In the Mott state the gap in the spectrum is essentially the charge gap determined by boson excitation branch. Therefore the electrons become fractionalized: the spin degrees of freedoms are determined by neutral fermions (spinons), and charge ones by bosons. In fact, bosons and fermions are coupled by a gauge field, so that the problem of confinement occurs. The transition into the metallic confinement state is described as a Bose condensation, the electron Green's function acquiring finite residue. On the other hand, in the deconfinement insulator state the bosons have a gap, so that the spectrum is incoherent (the full electron Green's function is a convolution of boson and fermion ones) and includes Hubbard's bands. In the doped system, a partial Mott transition occurs.

To describe the Mott insulator state and the process of its doping we use the Kotliar-Ruckenstein slave-boson representation which provides explicitly the spectrum of both Hubbard bands. In the absence of considerable quasimomentum dependence of spinon distribution function (a localized spin phase without fermion hopping), the corresponding self-energy tends to zero. However, for a spin liquid we have a sharp Fermi surface. Thus for the Mott insulators the spinon Fermi surface is expected to be preserved even in the insulating phase, so that the Luttinger theorem (conservation of the volume under the Fermi surface) remains valid. However, this Fermi surface is strongly temperature dependent since a characteristic scale of spinon energies is small in comparison with that of electron ones. Therefore the spectrum picture in the insulating state is considerably influenced by the spinon spin-liquid spectrum and hidden Fermi surface.

An exotic fractionalized Fermi-liquid FL* theory of metallic systems, which combines resonant-valence-bond (RVB) state and the band of current carriers, is treated. An application of this theory to spin-liquid, antiferromagnetic and nearly antiferromagnetic systems is proposed with the use of various bosonic and fermionic representations, a comparison with perturbation theory in the *s-d(f)* exchange model being performed. The topological aspects including formation of the small Fermi surface are considered. Examples of Kondo lattices, doped pyrochlores, and metallic manganese systems are discussed, analogies with copper-oxide systems being treated.

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Abstract ID: 342

ROLLER-COASTER IN A FLATLAND: MAGNETISM OF EU-INTERCALATED GRAPHITE

A.L. Chernyshev[1], O.A. Starykh[2]

[1]*Department of Physics and Astronomy, University of California, Irvine, 92697, USA*
[2] *Department of Physics and Astronomy, University of Utah, Salt Lake City, Utah 84112, USA*
E-mail: sasha@uci.edu

Novel phenomena in magnetically-intercalated graphite has been a subject of much research in the 1980s, with the most enigmatic findings of that era being a dramatic, roller-coaster-like behavior of the magnetoresistivity in EuC_6 compound, which remained unexplained until now. In our recent study [1], we have provided a long-awaited *microscopic* explanation of this behavior, demonstrating that the resistivity of EuC_6, in which magnetic Eu^{2+} ions form a triangular lattice that is commensurate with the graphite honeycomb planes, is dominated by spin excitations in Eu-planes and their highly nontrivial evolution with the magnetic field. Together with our theoretical analysis, this study showcases the power of the synthetic 2D materials as a potential source of significant novel insights into the nature of exotic spin excitations such as fractionalized spinons in a quantum spin liquid.

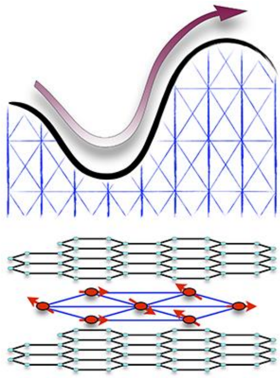

Fig. 1: *Schematics of the rollercoaster and EuC_6 layered structure.*

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Abstract ID: 563

ARE COBALTITES KITAEV MATERIALS?

S. Streltsov

RUSSIA
E-mail: streltsov@imp.uran.ru

In the last decade, one of the hottest topic in condensed matter physics has been the study of Kitaev magnetic systems, in which the exchange interaction turns out to be strongly anisotropic and direction of anisotropy is different for different bonds in the lattice [1]. The presence of anisotropy is due to the special lattice geometry and strong spin-orbit interaction. Initially, the main interest was concentrated on oxides of 4d – 5d transition metals, but later in [2,3] it was shown that in some compounds of 3d elements, for example, cobaltites (based on Co^{2+}), similar effects are possible. We will present the results of theoretical and experimental studies of such compounds as $BaCo_2(AsO_4)_2$ [4], $Na_3Co_2SbO_6$ [5], $SrCoGe_2O_6$ [6], and some other systems.

The work is supported by the grant RSF 23-42-00069.

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Low Dimensional Magnetism of Dichalcogenides

09.05.2023 TUESDAY

Abstract ID: 230

NONCENTROSYMMETRIC MAGNETIC STRUCTURES BASED ON GROUP IV TRANSITION METAL DICHALCOGENIDE INTERCALATES

A.N Titov, A.S. Shkvarin, A.I. Merentsov, E.G. Shkvarina, M.S. Postnikov

M.N. Mikheev Institute of Metal Physics of Ural Branch of Russian Academy of Sciences, 620108, Yekaterinburg, RUSSIA

E-mail: antitov@mail.ru

Layered dichalcogenides of group IV transition metals are formed by layers X-T-X, T = Ti, Zr, Hf; X = S, Se, Te, separated by a gap approximately equal to the width of the X-T-X layer. The atoms of alkali, noble, transition and rare earth metals can be embedded in the interlayer space. Positions with octahedral and tetrahedral coordination by chalcogen are available for filling them. Octahedral coordinated positions, shown in Fig. 1 as octa-positions, are located in the center of the unit cell, while tetrahedrally coordinated positions form two planes shifted relative to the middle of the interlayer space. They are marked in Fig.1 as alpha- and beta- tetra sites. Intercalate materials with tetrahedral coordination of the intercalant tend to form a structure with only one plane filled. This leads to the formation of non-centrosymmetric structures. An analysis of the crystal and electronic structure of materials with an octa-tetra-coordinated intercalant led us to the conclusion that the parameter determining the coordination is the ionization potential of the metal T of the host lattice. Ways of influencing the metal ionization potential T by intercalation with donor objects, formation of Janus layers, and substitution in sublattice T of the metal are proposed. It is shown that by this way it is possible to create materials with a non-centrosymmetric distribution of the magnetic intercalant. This leads to a high polarizability of the lattice and, in some cases, stabilizes the superconducting state.

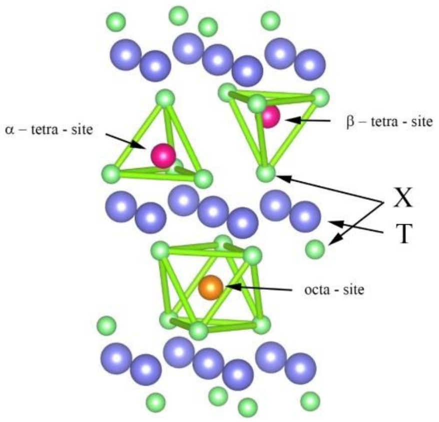

Fig. 1: *Crystal structure of layered dichalcogenides with the general formula TX_2. Shown are octa- and tetra-coordinated positions available for filling with intercalant.*

The work was supported by a grant from the Russian Science Foundation 22-13-00361

Abstract ID: 233

TRANSITION METAL-BASED LAYERED VAN DER WAALS CHALCOGENIDES: EXPLORING MAGNETISM IN TWO DIMENSIONS

V.Y. Verchenko[1], A.V. Kanibolotskiy[1], A.V. Stepanova[1], I.V. Chernoukhov[1], A.V. Bogach[2], A.V. Mironov[1], K.A. Cherednichenko[3], A.V. Shevelkov[1]

[1]Lomonosov Moscow State University, Dept. of Chemistry, 119991, Moscow, RUSSIA
[2]Prokhorov General Physics Institute of the Russian Academy of Sciences, 119991 Moscow, RUSSIA
[3]Gubkin University, Dept. of Physical and Colloid Chemistry, 119991, Moscow, RUSSIA
E-mail: valeriy.verchenko@gmail.com

Transition metal-based layered compounds with van der Waals (vdW) gaps between the structural layers are a rich source of magnetic materials for spintronic applications. Bulk crystals can be cleaved, providing high-quality two-dimensional nanomaterials, which are promising for the manipulation of spins in spintronic devices and low power quantum logic interfaces. In this contribution, Fe- and Mn-based Fe_5AsTe_2 [1], $NbFe_{1.3}Te_3$ [2], $FeAl_2S_4$ [3], $FeAl_2Se_4$ [4], $MnAl_2S_4$ [3], and $MnAl_2Se_4$ layered vdW materials will be presented. Crystal structures are probed by single-crystal and powder X-ray diffraction, and high-resolution transmission electron microscopy. The listed compounds are built by atomically thin layers with the embedded transition metal atoms, which are terminated by vdW gaps. Crystal growth employing chemical vapor transport reactions yields bulk crystals (Fig. 1), which can be cleaved providing high-quality two-dimensional nanomaterials. Magnetization measurements reveal rich magnetic properties of the title chalcogenides, including bulk ferromagnetism, quasi-one-dimensional antiferromagnetism, spin-flop transitions, and low-temperature spin-glass behavior. This rich variety opens new ways of controlling spins in the cutting-edge spintronic technologies.

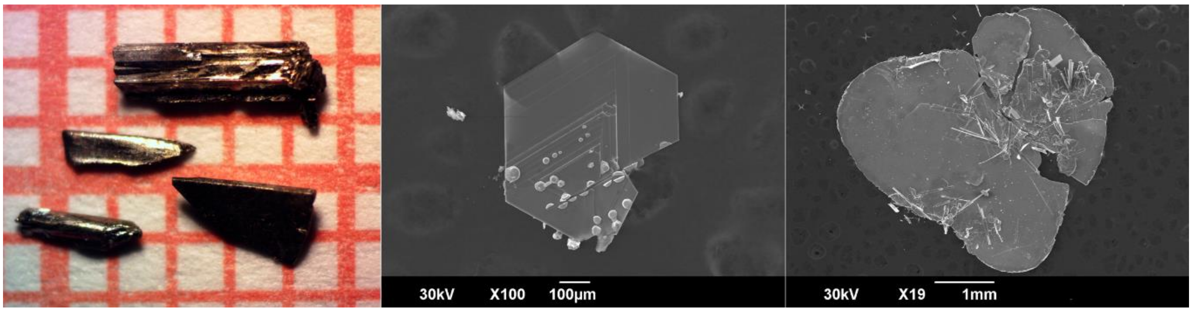

Fig. 1: *Bulk crystals of the $NbFe_{1.3}Te_3$ (left), $FeAl_2S_4$ (middle), and $FeAl_2Se_4$ (right) layered van der Waals chalcogenides.*

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Abstract ID: 457

COMPLEXITIES OF 2H-NbS_2 INTERCALATIONS

Petar Popčević[1], Y. Utsumi[1], W. Tabis[2,3], J.J. Kolodziej[4,5], H. Berger[6], N.S. Dhami[1], B. Gudac[7], I. Batistić[7], L. Forró[8], N. Barišić[2,7], E. Tutiš[1]

[1]*Institute of Physics, Zagreb, CROATIA*
[2]*Institute of Solid State Physics, TU Wien, Vienna, AUSTRIA*
[3]*Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Krakow, POLAND*
[4]*Solaris National synchrotron Radiation Centre, Krakow, POLAND*
[5]*Institute of Physics, Jagiellonian University, Kraków, POLAND*
[6]*EPFL, Lausanne, SWITZERLAND*
[7]*Department of Physics, University of Zagreb, Zagreb, CROATIA*
[8]*Department of Physics, University of Notre Dame, Indiana, US*
**e-mail: ppopcevic@ifs.hr*
E-mail: ppopcevic@ifs.hr

2H-NbS_2 is superconducting, quasi 2D system, which can host different ions and molecules in van der Waals gaps between metallic layers. When intercalated with transition metal (TM) ions system becomes magnetic. The coexistence of metallic and magnetic degrees of freedom coupled with reduced dimensionality and anticipated frustration renders these compounds battlefield of different interactions resulting in different magnetically ordered ground states.

We have studied Ni and Co [1,2,3] intercalations. The degree of crystal order plays a vital role in obtaining correct conclusions. Thus, we started with synthesis and detailed characterization and managed to correlate physical properties with structural complexities. Finally, using angle-resolved photoelectron spectroscopy (ARPES), we identified limitations of the DFT calculations casting new light on these compounds.

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Magnetism, Lattice Dynamics and Superconductivity

09.05.2023 TUESDAY

Abstract ID: 97

MAGNETISM AND LATTICE DYNAMICS

S.M. Dubiel

AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, al. A. Mickiewicza 30, 30-059 Krakow, POLAND

E-mail: dubiel@novell.ftj.agh.edu.pl

Following the standard theory (ST) of the electron-phonon interaction (EPI) the effect of magnetism is negligibly small, because the so-called small adiabatic parameter equal to the ratio between the Debye and the Fermi energy is of the order of 10^{-2} [1 and references therein]. However, Kim showed that the impact of the EPI on the spin susceptibility of metals can be enhanced by two orders of magnitude in systems with itinerant magnetism [1]. In other words, the effect of the EPI on magnetic properties of metallic systems, and *vice versa*, is much more significant than commonly believed. Based either on calculations and/or on measurements some authors recently reported results that do not agree with the ST-predictions. .In particular, M. S. Lucas et al. wrote [2]: "*The phonon densities of states of bcc Fe-V alloys across the full composition range were studied by inelastic neutron scattering, nuclear resonant inelastic x-ray scattering, and ab initio calculations. Changes in the PDOS were revealed at crossing the Curie temperature*", B. Alling et al. based on disordered local moments molecular dynamics calculations concluded that [3]: "*Lattice vibrations strongly affect the distribution of local magnetic moment in experimental evidence paramagnetic Fe*", and I. S. Tupitsyn et al. noticed that [4]: "*This theory (ST) neglects the effect of magnetism on lattice dynamics and fails to explain enhancement of the critical temperature in phonon-mediated superconductors.*"

In this talk I present results obtained with ^{57}Fe Mössbauer spectroscopy (MS) on σ-phase Fe-Cr, Fe-V and Fe-Cr-Ni, λ-phase $NbFe_2$ and Fe-As compounds and with ^{119}Sn MS on metallic Cr. The common feature of these systems is delocalized (itinerant) magnetism. The results clearly show that the lattice dynamics in the magnetic state of the investigated samples is significantly different than the one in the paramagnetic state.

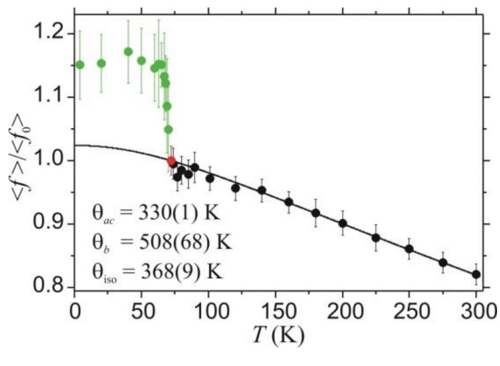

Fig.1: *Temperature dependence of relative recoil-free fraction in FeAs. Debye temperture, θ, values obtained by fitting the data in the paramagnetic phase with different approaches are marked.*

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Abstract ID: 258

MAGNETISM FROM THE POINT OF VIEW OF NUCLEAR RESONANT INELASTIC X-RAY SCATTERING

Michael Y. Hu

Advanced Photon Source, Argonne National Laboratory, USA
E-mail: myhu@anl.gov

In the long history of experimental methods in condensed matter physics, Nuclear Resonant Inelastic X-ray Scattering (NRIXS) is a relative newcomer. Nonetheless, it has established itself as a ubiquitous and routine mode of research at 3rd and 4th generation synchrotron radiation facilities worldwide. NRIXS is a spectroscopy method to study atomic vibrations and dynamics [1-3]. In an NRIXS experiment, one measures the number of nuclear resonant absorption events as a function of energy transfer from an incident x-ray beam to the sample under study. Besides the resonant enhancement so that minute sample can be studied, a unique aspect of using resonant isotopes is its isotopic and elemental selectivity. This means that vibrations can be probed locally in systems that have resonant isotopes at specific locations in the lattice, e.g., of biomolecules, catalysts, thin films, and materials under extremely high pressures. Many atomic dynamics and lattice thermodynamics information can be extracted from NRIXS measurements [4]. Phonon density of states (DOS), which characterizes lattice dynamics of a material, can be derived under quasi-harmonic approximation [2,5]. Furthermore, the anharmonic terms in the lattice potential can be measured [4]. This opens up venues in studying phonon interactions. A few examples of NRIXS studies of magnetic systems are discussed to illustrate its application in the magnetism research, particularly relating to lattice dynamics.

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Abstract ID: 389

INTERPLAY BETWEEN SUPERCONDUCTIVITY AND MAGNETISM: A GUIDE FOR SEARCHING HIGH T_c SUPERCONDUCTORS

Israel Felner

Racah Institute of Physics, The Hebrew University, Jerusalem, 91904, ISRAEL

E-mail: israel.felner@mail.huji.ac.il

The ongoing scientific endeavor to have superconducting materials at room temperature we adopted the interplay between SC and magnetism as a guide line for searching new SC materials. It is well accepted that in most of the cuprates-based high T_c systems, superconductivity (SC) and long-range anti-ferromagnetic (AFM) order are closely related, they compete with each other and rarely coexist. Moreover, their phase diagrams indicate, that the SC state emerges only when the AFM state is suppressed.

(i) In the past, we have found that in all systems, the highest T_N obtained in the AFM regime, is directly proportional to the highest T_c deduced in the SC state. This observation suggests a new guideline in searching new high T_c SC materials. Several AFM Cu-based layered compounds with high T_N values have been synthesize, but no SC was detected.

(ii) (ii) Following the similar phase diagram in the of iron-based AFe_2As_2 (A=Ba, Sr) in which superconductivity (SC) emerges from magnetic states, we proposed the RFe_2X_2 (R=La, Y and Lu, X=Si or Ge), systems as a potential candidate for a new high T_c SC family. In RFe_2X_2 the non-magnetic Fe-X layers replace the Fe-As, and our ^{57}Fe Mössbauer studies confirmed the absence of long-range magnetic ordering of Fe down to 5 K. Dozens of various $RFe_{2-x}M_xX_2$ (M=Ni, Mn and Cu) materials have been prepared. Unfortunately, no SC traces have been observed down to 1.8 K. On the other hand, in all materials studied, pronounced short-range magnetic peaks appear at various temperatures up to 232 K for YFe_2Si_2. The origin on these peaks will be discussed.

(iii) Accidently**,** traces for two SC phases (at T_c= 32 and 66 K) have been observed in inhomogeneous commercial and fabricated amorphous carbon doped with sulfur. That reminiscences the recent discovery of SC at T_c>200 K in sulfur hydride (H_3S) under high pressure of p=155 GPa.

MgB2 – Materials and Applications I-II-III-IV

09.05.2023 TUESDAY

Abstract ID: 237

CRITICAL CURRENT DENSITY IN MgB_2 WIRES WITH NANO-AMORPHOUS ISOTOPIC BORON (^{11}B) MADE BY CTFF METHOD

D. Gajda[1], M. Babij[1], A.J. Zaleski[1], L.M. Tran[1], A.J. Morawski[2], D. Szymański[1], M.A. Rindfleische[3], M.S.A. Hossain[4]

[1] *Institute of Low Temperature and Structure Research, Polish Academy of Sciences, 50-422, Wrocław, POLAND*
[2] *Institute of High Pressure Physics, Polish Academy of Sciences,, 01-142, Warsaw, POLAND*
[3]*Hyper Tech Research, Inc., Ohio 43228 Columbus, , USA*
[4] *School of Mechanical and Mining Engineering, The University of Queensland, QLD 4072, Brisbane, AUSTRALIA*
E-mail: d.gajda@intibs.pl

The MgB_2 wires produced by the continuous tube forming and filling (CTFF) method have many advantages e.g.: allows to obtain very long superconducting MgB_2 wires, high critical temperature (T_c), low anisotropy, high upper critical field (B_{c2}), high irreversible magnetic field (B_{irr}), low weight, low cost components. This shows their high application potential, e.g. in superconducting coils.

The boron has two stable isotopes ^{10}B (18.98%) and ^{11}B(81.02%). These two stable isotopes are significantly different: atomic mass, magnetic moment, neutron absorption cross section [1]. Those factors affect at physical and chemical properties, of the compound, such as chemical (reaction speed), mechanical (hardness, stiffness etc) and thermal (temperatures of the phase transitions) [1]. Moreover, $Mg^{11}B_2$ material has features low activation energy, shorter decay time compared with Nb-based superconductors, ^{11}B isotope is stable for neutron irradiation and has higher T_c of 39.2 K. These factors indicate that the $Mg^{11}B_2$ superconductor is better for fusion reactor applications than Nb-based superconductors

However, the $Mg^{11}B_2$ wires have significantly lower critical current density in high magnetic fields (5.5 T–100 A/mm^2) than NbTi wires (9 T–100 A/mm^2) [2]. This limits their use for fusion reactor.

The monofilament isotopic $Mg^{11}B_2$ wires with Nb barrier was produced by Hyper Tech Research Inc. using continuous tube forming and filling (CTFF) method. We investigated samples that were annealed under high (1.1 GPa) and low (0.1 MPa) isostatic pressure. Our results showed that the HIP process allows to obtain the more number of connections between grains, increases the density of high-field pinning centers, accelerates the synthesis reaction, improves the irreversible magnetic field and allows to obtain the high critical current density - 100 A/mm^2 in 8.5 T at 4.2 K.

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Abstract ID: 332

MgB_2 BULK SUPERCONDUCTOR PROCESSED BY SPARK PLASMA SYNTHESIS AND SINTERING

J. Noudem[1], Y. Xing[1], P. Bernstein[1], M. Muralidhar[2]

[1]***Normandie Univ, ENSICAEN, UNICAEN, CNRS, CRISMAT, 14000 Caen, FRANCE***
[2]*Materials for Energy and Environmental Laboratory, Superconducting Materials Group, Graduate School of Science & Engineering, Shibaura Institute of Technology, 3-7-5 Toyosu, Koto-ku, Tokyo 135-8548, JAPAN*
E-mail: jacques.noudem@ensicaen.fr

We report on the spark plasma synthesis, sintering and characterization of bulk MgB_2 superconductors prepared according to three processing routes using non-conventional Spark Plasma Sintering (SPS):

i) Sintering of a commercially available MgB_2 powder
ii) In-situ synthesis followed by sintering of a mixture of magnesium and carbon-encapsulated nano-boron powder (Mg+2B).
iii) Synthesis and sintering of a mixture of Mg and MgB_4 powder.

The density of the obtained bulks was up to 98 % of the theoretical density of the material. The highest critical current densities, J_c, at 20K in self-field, 1, 2 and 4 T were equal to 700 kA/cm², 570 kA/cm², 270 kA/cm² and 30 kA/cm² respectively, and were obtained with the MgB_2 sample processed according to the Mg+2B route. Moreover, the effect of Mg addition on J_c of dense MgB_2 bulk was also investigated and will be discussed.

The structural characterization and chemical analysis were carried out as well as the superconducting properties. In addition, we investigated the magnetic levitation force and the magnetic flux mapping for the homogeneous current distribution in the whole sample.

Abstract ID: 620

BULK MgB_2 AND RARE EARTH IRON GARNETS PROCESSED BY SPARK PLASMA SINTERING

P. Badica

National Institute of Materials Physics, Atomistilor street 405A, 077125 Magurele, ROMANIA
E-mail: badica2003@yahoo.com

The work presents the progress in processing and characterization of (001) textured bulk MgB_2 superconductor. Materials were obtained by combining slip casting under elevated magnetic fields (12 T) and *ex situ* spark plasma sintering. Spark plasma sintering was also applied for processing of rare earth garnet bulks of $Gd_3Fe_5O_{12}$.

Peculiar profiles in the shape of the pinning force curves with magnetic field and difficulties in fitting these curves with the universal scaling procedure point on necessity of new approaches. We show that most these features involving dissipation generated by e.g. the presence of slightly non-stoichiometric phases, defects, homogeneity, anisotropy, and others comply with the Dew-Hughes scaling law predictions within the grain boundary pinning mechanism if a connecting factor related to the superconducting connection of the grains is used. The connecting factor in the proposed model is expressed through a connecting function that takes the form of a single or double peaked function, Gaussian or LogNormal.

Spark plasma sintering of the garnet, depending on the precursor powder, is a reliable method to obtain single phase material with close to ideal stoichiometry and a low level of cation inversions.

Authors acknowledge project PN-III-P2-2.1-PED-2021-2007 (contract no. 676PED/2022) funded by the Romanian Ministry of Research, Innovation, and Digitalization through UEFSCDI

Abstract ID: 403

EFFECT OF BALL MILLING ON MICROSTRUCTURES AND SUPERCONDUCTING PROPERTIES OF *EX-SITU* MgB_2 BULK SAMPLES

Z.L. Gao[1], S. Santra[2], C.R.M. Grovenor[1], S.C. Speller[1]

[1]*Department of Materials, University of Oxford, Parks Rd, Oxford OX1 3PH, UK*
[2]*Department of Material Science and Engineering, Indian Institute of Technology Delhi, Delhi 110016, INDIA*
E-mail: zilin.gao@materials.ox.ac.uk

Magnetised bulk superconductors with high trapped fields are promising as quasi-permanent magnets in portable systems for medical applications [1]. In comparison to high temperature superconducting cuprates, grain boundaries in MgB_2 are not weak-links, enabling bulk samples to be manufactured by simpler and more scalable powder processing methods. Together with the low cost of the precursor materials, this makes MgB_2 an attractive alternative for moderate field applications. However, improvements are still required to optimize the macroscopic critical current density values to maximise the flux trapping performance in the bulks. In this study, ball milling has been used to modify MgB_2 powders prior to consolidation using Field Assisted Sintering, and the effect of milling time on microstructure and phase evolution in both precursors and bulks is systematically investigated. A dramatic decrease in particle size is seen within the initial 10 min of milling, followed by a relatively steady drop until 12 h of milling when the refinement reaches saturation in pure MgB_2 powders. Ball-milled powders also show a bimodal distribution in particle size and are free of large MgB_4 phases, and therefore have different sintering behaviour compared with unmilled powders, resulting in different microstructures in the final bulk samples. Moreover, it is found that ball milling for longer than 6 h degrades T_c by around 1 K but improves the J_c performance of bulk samples at low fields because of the removal of regions rich in insulating phases, impurity barriers.

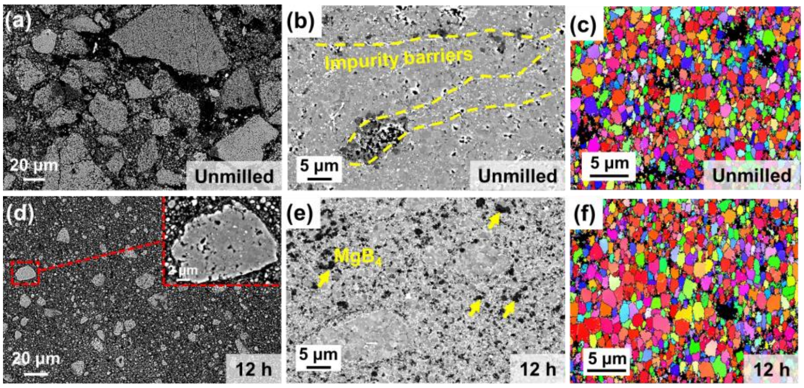

Fig. 1: *(a)(d) BSE images of unmilled and 12h-milled powders, (b)(e) BSE images of corresponding MgB_2 bulk samples, and (c)(f) EBSD results of bulk samples showing grain orientation and grain size.*

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Abstract ID: 463

3D MICROSTRUCTURAL OBSERVATION IN MgB_2 POLYCRYSTALLINE MATERIALS

Y. Shimada[1], S. Hata[2], A. Yamamoto[3], Y. Hishinuma[4], A. Matsumoto[5], H. Kumakura[5]

[1] *Institute for Mater. Res., Tohoku University, Oarai, Ibaraki 311-1313, JAPAN*
[2] *Dept. of Adv. Mater. Sci., Kyushu University, Kasuga, Fukuoka 816-8580, JAPAN*
[3] *Tokyo University of Agriculture and Technology, Koganei, Tokyo 184-8588, JAPAN*
[4] *National Institute for Fusion. Sci., Toki, Gifu 509-5292, JAPAN*
[5] *National Institute for Mater. Sci., Tsukuba, Ibaraki 305-0047, JAPAN*
E-mail: yusuke.shimada.e1@tohoku.ac.jp

Polycrystalline superconducting materials are expected to be used as circular cross-section wires and small strong bulk magnets due to their simplicity of fabrication and shape selectivity, including large-size applications. On the other hand, the problems such as the reduction of transport current properties due to imperfections in the internal microstructure have motivated various process development studies for practical use [1]. Here, it is known that intergranular connectivity is one of the major microstructural factors in the transport current properties of polycrystalline superconductors [2]. For the evaluation of intergranular connectivity, two-dimensional macroscopic observation by optical microscopy and scanning electron microscopy (SEM) is generally employed. However, when bulk/wire materials are assumed, the three-dimensional (3D) connectivity affects the transport current [3, 4]. This study shows the results of our group's macroscale 3D microstructural observations of MgB_2 and other polycrystalline superconductors.

The macroscale 3D characterization was employed by X-ray computed tomography (XCT) and serial sectioning method by SEM-equipped focus ion beam (FIB). The phases were identified using transmission electron microscopy (TEM).

As an example of the results, Figure 1 shows the XCT reconstruction images of MgB_2 wires fabricated at 800°C by the internal Mg diffusion (IMD) method [5]. The wire had almost zero J_c, which is suggested to be significantly affected by the three-dimensional connection of cracks as indicated by the arrow in the figure. TEM observation suggests that Mg_2Si crystals are formed in the cracks and that the grain growth of Mg_2Si crystals due to high-temperature sintering is a factor in the expansion of the cracks.

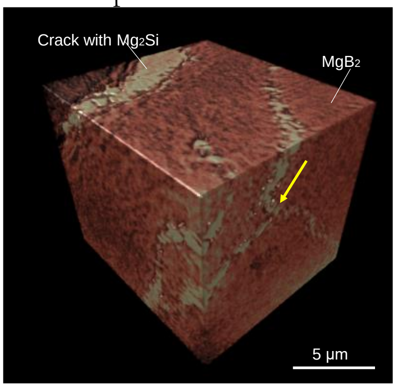

Fig. 1: *XCT reconstruction image of IMD MgB_2 wire sintered 800°C.*

Acknowledgment

This work was supported by JST CREST (JPMJCR18J4), JSPS KAKENHI (20K03899), and under the auspices of the NIFS Collaboration Research Program (NIFS22KIEF019).

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Abstract ID: 541

DISORDER ANISOTROPY OF STRUCTURES IN HIGH-PERFORMANCE MgB_2 MATERIALS

Minoru Maeda[1,3], Jung Ho Kim[2], Seyong Choi[1,3]

[1] *Kangwon National University, Department of Electrical Engineering and Research Institute for Energy, 25913, Gangwon, REPUBLIC OF KOREA*
[2] *University of Wollongong, Institute for Superconducting and Electronic Materials, Australian Institute for Innovative Materials, 2500, New South Wales, AUSTRALIA*
[3] *Kangwon National University, Kangwon High Magnetic Field Center, Institute of Quantum Convergence Technology, 24341, Gangwon, REPUBLIC OF KOREA*
E-mail: mmaeda@kangwon.ac.kr

Polycrystalline MgB_2 materials (e.g., wires and tapes) are widely studied and developed for innovative applications (e.g., power grids across Europe and hybrid energy storage systems combined with hydrogen technologies). The material performance (e.g., the transport critical current density (J_c)) has been so far improved thanks to many past studies for powder-in-tube (PIT) processes, which are used in many companies to produce kilometer-long MgB_2 wires. The currently attainable performance at 7 T and 4.2 K for the *in situ* PIT processed wires is approximately 1.0 × 10^5 A/cm^2 (or 2.0 × 10^5 A/cm^2) [1]. Such a performance level is rarely achieved by utilizing at least either mechanical milling (MM), mechanical alloying (MA), tape deformation, ultrafine B powders with sizes of 10–100 nm, cold high pressure densification (CHPD), or hot isostatic pressing (HIP). Here, a key question naturally arises: what is the next approach to further enhancement beyond the currently attainable performance? To address this issue, we focus on “disorder anisotropy”, which is not well understood in the case of MgB_2 materials. In this presentation, we therefore introduce and discuss the disorder anisotropy of structures in high-performance MgB_2 wires (Fig. 1) with experimental results [1]. We also argue the relation to the in-field critical current performance to provide clues towards further appropriate modification of MgB_2 materials.

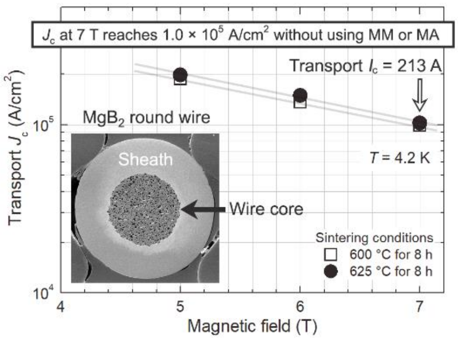

Fig. 1: *Magnetic field dependence of the transport J_c at 4.2 K for the round MgB_2 wires fabricated through an in situ PIT process, which is used in many companies to produce kilometer-long wires for superconducting applications. The transport J_c at 7 T reaches more than 1.0 × 10^5 A/cm^2. The high transport performance (in the case of the PIT process) was achieved without using MM, MA, tape deformation, ultrafine B powders with sizes of 10–100 nm, CHPD, or HIP.*

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Abstract ID: 152

RESEARCH ON THE IMPACTS OF SiC REINFORCEMENT ON THE DENSIFICATION, MICROSTRUCTURE, ELECTRICAL AND MAGNETIC PROPERTIES OF MgB_2 BULK SUPERCONDUCTORS PRODUCED BY IN-SITU SPARK PLASMA SINTERING TECHNIQUE

H. Ağıl[1], A.A. Agil[2], S.B. Güner[3], E. Ayas[2]

[1]*Department of Material Science and Engineering, Faculty of Engineering, Hakkari University, 30000, Hakkari, TURKEY*
[2]*Department of Materials Science and Engineering, Eskişehir Technical University, Eskişehir, 26555, TURKEY*
[3]*Department of Physics, Faculty of Arts and Sciences, Recep Tayyip Erdogan University, 53100 Rize, TURKEY*
E-mail: hasanagil@hakkari.edu.tr

We investigated the synthesis of MgB_2 bulk superconductor produced by in-situ spark plasma technique of different contents of nano SiC reinforcement and the effects of this addition on the critical parameters of the superconductor. The microstructure of a material includes the compositional, morphological, and crystallographic properties of its phases. Studying the microstructure can help us understand the chemical, thermal, electrical, and mechanical properties of a material. The analytical techniques used to analyze the microstructure in this study are X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM). The effects of SiC addition on the consolidation of the MgB_2 bulk superconductor were determined by Archimedes' principle. The transition temperatures of bulk superconductors from the normal state to the superconducting state were determined from resistivity measurements. Materials processed by in situ spark plasma sintering were found to carry critical current densities comparable to those produced by solid-state sintering. Also, the levitation force behavior of SiC addition under zero field-cooled (ZFC) and field-cooled (FC) regimes was analyzed by measuring it at different temperatures.

Acknowledgment

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Abstract ID: 509

STRONG INFLUENCE OF BORON PRECURSOR POWDER ON THE MAGNETIC LEVITATION FORCE OF BULK MgB_2

Burcu Savaşkan[1], Sait Barış Güner[2], Petre Badica[3], Alina Ionescu[3], Şükrü Çelik[4], Kemal Öztürk[5]

[1]*Energy Systems Engineering, Faculty of Technology, Karadeniz Technical University, Trabzon, TURKEY*
[2]*Department of Physics, Faculty of Arts and Sciences, Recep Tayyip Erdogan University, Rize, TURKEY*
[3]*National Institute of Materials Physics, Atomistilor street 405A, 077125 Magurele, ROMANIA*
[4]*Energy Systems Engineering, Faculty of Technology, Sinop University, Sinop, TURKEY*
[5]*Department of Physics, Faculty of Science, Karadeniz Technical University, 61080 Trabzon, TURKEY*
E-mail: bsavaskan75@gmail.com

MgB_2 bulks were prepared by an *in-situ* solid synthesis route from mixtures of Mg and B powders. The B powders were produced by two methods: the first is a self-propagating high temperature magnesiothermic synthesis (SHS) process followed by acid and fluorine cleaning and a heat treatment in inert atmosphere and the second is a diborane pyrolysis process. In the SHS process produced boron powders with purities between 86 and 97 %, where the main impurity was Mg. Amorphous lower purity boron (86-97 %) obtained by the first processing route was found to promote the largest levitation forces of the MgB_2 bulks and, among the samples, the best levitation results were recorded when using boron with a purity of 95-97%. Slightly lower values, but significantly higher force values when compared with samples fabricated from the amorphous boron with high purity of 99% or crystalline boron with purity 95-97% were measured for samples obtained from amorphous boron with low purity of 86-93 %. Results show that cheap boron, i.e. boron with a low purity, can be used to fabricate MgB_2 bulk magnets for levitation devices, promoting large scale industrial production and new applications.

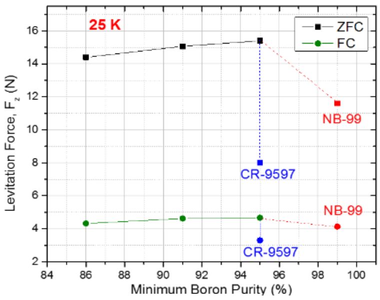

Fig. 1: *The maximum values of vertical levitation force in the ZFC and the FC regimes at 25 K depending on the minimum purity of boron precursor powder.*

Acknowledgments

This work was supported by the Scientific Research Projects Coordination Unit of Karadeniz Technical University with project No. FBA-2021-9738 and the Energy, Nuclear and Mineral Research Council of Turkey (TENMAK), with project no. 2020–31-07-20E-002.

Abstract ID: 548

OUR CONTINUOUS EFFORTS TO ENHANCE MgB_2 SUPERCONDUCTOR AND ITS APPLICATION

J.H. Kim

University of Wollongong, Wollongong, NSW2500, AUSTRALIA
E-mail: jhk@uow.edu.au

In the past 20 years, the University of Wollongong and our colleagues have made significant contributions to the development of magnesium diboride (MgB_2), a superconductor suitable for use in cryogenic-free magnets at temperature range between 10 K and 20 K. Intensive research effort has resulted in noticeable progress with high-field properties comparable to Nb-Ti due to carbon doping and low-field properties comparable to those of YBCO due to core densification. Additionally, several crucial studies have been conducted on magnet applications. In this talk, I would like to provide more valuable insights into MgB_2 wire conductor and magnet applications.

Abstract ID: 227

THE ROLE OF SURFACE BARRIERS IN THE MAGNETIC LEVITATION OF SUPERCONDUCTORS

Pierre Bernstein, Yteng Xing, Jacques Noudem

Crismat-Ensicaen, Normandy University, CNRS, Caen, FRANCE
E-mail: pierre.bernstein@ensicaen.fr

Magnetic levitation results from the interaction of a field cooled superconductor and a field source, such as a bulk magnet, generating a non-uniform magnetic field. It is characterized by two forces: the repulsive force between the magnet and the superconductor, which is the levitation force and the restoring force stabilizing the system. Different models have been proposed for the calculation of the levitation and restoring forces. Most of them consist in numerical simulations based on the differential Maxwell equations and different versions of a power law between the current density and the electric field [(see [1] and the references herein)]. Taking another point of view, the group at Normandy University has proposed a mean field model permitting one to reproduce the forces applied to cylindrical YBCO and MgB_2 bulks when interacting with a magnet [2]. However, the model was verified with small diameter bulks generating a moderate levitating force only. Additional measurements with larger bulks were achieved in the LIMSA laboratory of the University of Bologna. This laboratory has available a system permitting one to measure levitation forces in excess of 1000N. The measurements have shown that for superconductors presenting a large critical current density, above a threshold B_{ZL} in the field generated by the magnet, there is a strong increase of the levitation force, which is not accounted for by the mean field model. This failure of the model has been attributed to the entry and exit of vortices across the surface barriers of the superconductors at fields $B \geq B_{ZL}$. A modified model taking into account these effects has permitted to reproduce the measurements as well below as above B_{ZL}. This model and the corresponding results will be presented in this talk.

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Abstract ID: 386

SMALL JOINT DESIGN FOR SUPERCONDUCTING MgB_2 WIRE

Doğan Avcı[1], Hakan Yetiş[1], Daniel Gajda[2], Michal Babij[2], Lan Maria Tran[2], Fırat Karaboğa[3], Canan Aksoy[4], Andrzej Zaleski[2], İbrahim Belenli[1]

[1] Bolu Abant İzzet Baysal University, Department of Physics, 14030 Bolu, TURKEY
[2] Institute of Low Temperature and Structure Research PAS, Okólna 2, 50–422 Wroclaw, POLAND
[3] Bolu Abant İzzet Baysal University, Mehmet Tanrikulu Vocat. Sch. Hlth. Serv., 14030 Bolu, TURKEY
[4] Karadeniz Technical University, Electronics and Communication Engineering, Trabzon, TURKEY
E-mail: davci.0209@gmail.com

A semi-cylindrical core structure such that magnesium and boron powders are filled side by side along the Cu/Nb composite tube is designed for joining of mono-core unreacted Fe/MgB_2 wires. The small-sized joint enabled the formation of a high-density superconducting core in the wire-core-wire contact region by the external magnesium diffusion process. The size of the joint is one of the critical parameters for large magnet applications. It has been observed that the joint, which has a distinctive core structure, provided very low joint resistance as well as advantages such as easy construction, fast cooling, and uniform superconducting core formation. The transport measurements under the external magnetic field and field decay measurement of the joint were carried out at 20 K. The MgB_2 structure formed within the joint and in the contact region of wire ends is examined using the scanning electron microscopy (SEM).

Quantum Functional Materials and Quantum Technology I-II

09.05.2023 TUESDAY

Abstract ID: 498

ANYONIC PHYSICS IN THE FRACTIONAL QUANTUM HALL EFFECT STUDIED WITH THE HONG-OU-MANDEL DIP FOR FRACTIONAL EXCITATIONS

T. Jonckheere, J. Rech, B. Grémaud, T. Martin

Centre de Physique Théorique, CNRS – Aix Marseille Université 13009 Marseille FRANCE
E-mail: jonckhee@cpt.univ-mrs.fr

The fractional quantum Hall effect (FQHE) is known to host anyons, quasiparticles whose statistics is intermediate between bosonic and fermionic. Thanks to their exceptional properties, these anyonic excitations might offer new opportunities for quantum computation schemes. With the goal of getting a better undesrtanding of anyonic statistics in the FQHE, we show here that Hong-Ou-Mandel (HOM) interferences between excitations created by narrow voltage pulses on the edge states of a FQHE system at low temperature show a direct signature of anyonic statistics. The width of the HOM dip is universally fixed by the thermal time scale, independently of the intrinsic width of the excited fractional wavepackets. This universal width can be related to the anyonic braiding of the incoming excitations with thermal fluctuations created at the quantum point contact. We show that this effect could be realistically observed with periodic trains of narrow voltage pulses using current experimental techniques.

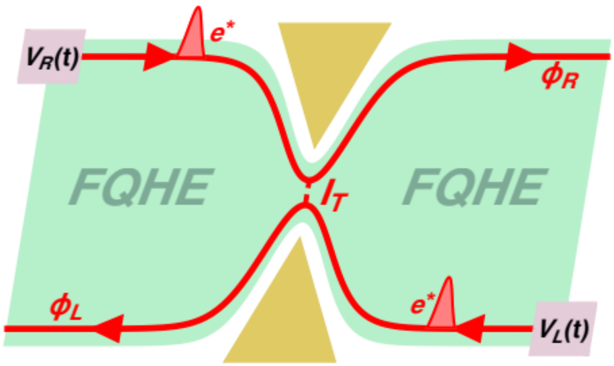

Fig. 1: *Setup used to study the anyonic statistics of excitations in the Fractional Quantum Hall effect. Voltage pulses excite fractional charge excitations on the edge states of the FQHE, which meet at a QPC. Current correlations are measured at the output of the QPC.*

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Abstract ID: 613

MACHINE LEARNING ASSISTED CONTINUOUS TIME QUANTUM MONTE CARLO

Taegeun Song

Kongju National University, Dept. of Data Information and Physics, 32588, Gongju, KOREA
E-mail: tsong@kongju.ac.kr

In this talk, I will discuss the integration of machine learning (ML) with Continuous-time quantum Monte Carlo (CTQMC) method to enhance the computational speed and accuracy of the method in studying strongly correlated systems. The latest advances in ML have shown tremendous potential in accelerating calculations in various fields, including quantum physics. Our proposed method, previously reported [1], eliminates the computational cost of inverting matrices and measuring m-point correlators in the CTQMC fast update, which can be time-consuming. By combining the CTQMC method with machine learning, we can eliminate the operations for computing two-point impurity Green's functions and four-point vertices. This approach significantly reduces the computational time and accurately predicts physical properties at low temperatures. Furthermore, it decreases the computational time required for nonlocal extensions of the DMFT approximation. Our findings suggest that the integration of CTQMC with machine learning techniques can improve the efficiency and accuracy of the method in studying strongly correlated systems [2]. Overall, this research demonstrates the potential of combining quantum physics and machine learning to overcome complex computational problems in the field.

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Abstract ID: 614

TUNABLE TRANSPORT OF QUASIPARTICLES IN LOW-DIMENSIONAL SUPERCONDUCTING NETWORKS QUANTUM GRAPHS BASED APPROACH

D.U. Matrasulov[1], M.E. Akramov[2], I.N. Askerzade[3]

[1]*Turin Polytechnic University in Tashkent, 17 Niyazov Str., 100095, Tashkent, UZBEKISTAN*
[2]*National University of Uzbekistan, 4 University Str., 100174, Tashkent, UZBEKISTAN*
[3]*Department of Computer Engineering, Ankara University, 06100, Ankara, TURKEY*
E-mail: dmatrasulov@gmail.com

Superconducting networks appear in many branches modern science and technology. The main problem arising in designing and utilization of such systems in the device structure is tuning their electronic properties. The latter is directly related to the problem of controlling quasiparticle dynamics in a superconducting network, i.e. achieving needed regime of charge carrier transport minimizing of back scattering effects, enhancing ballistic regime, etc. In this study, we propose a model, which is based on the use of Landau-Ginzburg equation on graphs for describing quasiparticle dynamics in superconducting networks. Using the earlier developed approach for solving of nonlinear evolution equations on networks [1-3], we show the integrability of the problem under certain conditions and obtain exact solutions of the problem. Using such solution we show that integrability of the problem causes absence of the quasiparticle back scattering at the network nodes. Breaking of the integrability condition leads to appearing of quasiparticle reflection at the nodes. Achieving the regime with the absence of back scattering allows to avoid energy, signal and spin losses in using superconducting network as a device structure.

This work is supported by the joint grant of the Ministry of Innovative Development of Uzbekistan (Ref. Nr.MRT-2130213155) and TUBITAK (Ref. Nr. 221N123).

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Abstract ID: 399

NONLOCAL PROBLEMS FOR IMPULSIVE HYPERBOLIC EQUATION WITH DISCRETE MEMORY

A. Assanova[1], A. Imanchiyev[2], Zh. Kadirbayeva[1,3]

[1]*Institute of Mathematics and Mathematical Modeling, 050010, Almaty, KAZAKHSTAN*
[2]*K.Zhubanov Aktobe Regional University, 030000, Aktobe, KAZAKHSTAN*
[3]*International University of Information Technology, 050008, Almaty, KAZAKHSTAN*
E-mail: anartasan@gmail.com

In this communication we consider the following nonlocal problem for impulsive hyperbolic equations with discrete memory:

$$\frac{\partial^2 v}{\partial t \partial x} = A(t,x)\frac{\partial v}{\partial x} + B(t,x)\frac{\partial v}{\partial t} + C(t,x)v +$$

$$+ A_0(t,x)\frac{\partial v(\gamma(t),x)}{\partial x} + B_0(t,x)\frac{\partial v(t,x)}{\partial t}\Big|_{t=\gamma(t)} + C_0(t,x)v(\gamma(t),x) + f(t,x), \quad t \neq \theta_j, \quad j = \overline{1,m-1}, \quad (1)$$

$$P(x)v(0,x) + S(x)v(T,x) = \varphi(x), \qquad x \in [0,\omega], \quad (2)$$

$$\lim_{t\to\theta_j+0} v(t,x) - \lim_{t\to\theta_j-0} v(t,x) = \varphi_j(x), \qquad x \in [0,\omega], \quad j = \overline{1,m}, \quad (3)$$

$$v(t,0) = \psi(t), \qquad t \in [0,T], \quad (4)$$

where the $v(t,x) = (v_1(t,x), v_2(t,x), \dots, v_n(t,x))$ is unknown vector function, the $(n\times n)$ matrices $A(t,x)$, $B(t,x)$, $C(t,x)$, $A_0(t,x)$, $B_0(t,x)$, $C_0(t,x)$ and the n vector function $f(t,x)$ are continuous on $\Omega = [0,T]\times[0,\omega]$, the $(n\times n)$ matrices $P(x)$, $S(x)$ and the n vector function $\varphi(x)$ are continuously differentiable on $[0,\omega]$, $\gamma(t) = \xi_r$, $t \in [\theta_{r-1},\theta_r)$, $\theta_{r-1} \le \xi_r < \theta_r$, $r = \overline{1,m}$, $0 = \theta_0 < \theta_1 < \dots < \theta_m = T$, the n vector function are continuously differentiable on $[0,\omega]$, $j = \overline{1,m}$, the n vector function $\psi(t)$ is continuously differentiable on $[0,T]$.

The impulsive hyperbolic equations with discrete memory have intensively studied in recent decades [1-4]. We study a question for a uniqueness and existence of solution to problem (1)-(4). A constructive approach to solve the problem (1)-(4) is proposed by using methods and results in [5,6].

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WEIGHTED LIMIT SOLUTION OF A NONLINEAR DIFFERENTIAL EQUATION

R. Uteshova

Institute of Mathematics and Mathematical Modeling, 050010, Almaty, KAZAKHSTAN
E-mail: ruteshova1@gmail.com

On a finite interval $(0, T)$, we consider the differential equation

$$\frac{dx}{dt} = f(t, x), \quad x \in R^n, \tag{1}$$

where $f(t, x): (0, T) \times R^n \to R^n$ is a continuous function with singularities at the endpoints of the interval. In order to study the behavior of solutions of equation (1) at singular points, one can use so-called "limit solutions". In [1], for a nonlinear differential equation considered on the whole real axis, the concept of a "limit solution as $t \to \infty$" was introduced. It was proved that, under certain assumptions on the right-hand part of the equation, the limit solution $x_0(t)$ possesses an attracting property; i.e. there exists a functional ball centered at $x_0(t)$ where the differential equation has at least one solution, and all solutions from this ball coincide with $x_0(t)$. This property made it possible to solve the problem of approximation of a solution bounded on the whole real axis. The attracting property of the limit solution was established under assumption that the differential equation linearized along the limit solution

$$\frac{dy}{dt} = f_x{}'(t, x_0(t))y,$$

admits an exponential dichotomy on R. However, if the differential equation has certain singularities in the domain, this assumption may be violated. In the present paper, we extend the concept of a limit solution to the case of the differential equation with singularities at the endpoints of the domain interval. The limit solution is introduced with a weight which is chosen taking into account the singularities. We establish conditions under which the weighted limit solution possesses the attracting property. We then construct approximating regular two-point boundary value problems that allow us to find approximate solutions of the singular boundary value problem with any specified accuracy.

Acknowledgements

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Abstract ID: 419

COULOMB IMPURITIES IN GRAPHENE: SUPERCRITICAL STATES OF 1D ARTIFICIAL RELATIVISTIC ATOM

S. Rakhmanov[1], D. Matrasulov[2]

[1]*Chirchik State Pedagogical University, Chirchik, UZBEKISTAN*
[2]*Turin Polytechnic University in Tashkent, Tashkent, UZBEKISTAN*
E-mail: saparboy92@gmail.com

We study supercritical states in artificial relativistic 1D atom, created by charged impurities in graphene nanoribbon. Experimental realization of the interaction of high-Z atoms and ions with strong electromagnetic fields is not a trivial task and requires using the expansive facilities with the high-power lasers or expansive accelerators of highly charged ions. Using graphene for such studies provides their realization at the low-cost, table top level. Especially, this concerns the supercritical phenomena such as particle-antiparticle pair creation and vacuum polarization, whose experimental study requires using of LHC (CERN), FAIR (GSI), RHIC (BNL) and other facilities providing possibility for stripping and acceleration of high-Z atoms and highly charged ions. By solving stationary 1D Dirac equation with Coulomb potential both for subcritical and supercritical (near the Dirac sea), we obtain estimates for the values of the critical charge needed for embedding of the atomic ground state energy into the Dirac sea. Besides the bulk atom created in long graphene nanoribbon, we consider also atom confined in 1D graphene nanoribbon quantum dot. For this case, we study the role of the confinement in spearing of supercritical states. In addition, we consider the case of 1D artificial atom driven by external optical field. We derive exact analytical expressions for the probabilities of excitation, ionization and electron-hole pair creation in such system.

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Abstract ID: 559

PROSPECTS FOR QUANTUM MEDICINE

V.M. Vinokur, E.N. Sobol

Terra Quantum AG, CH-9000, St. Gallen, SWITZERLAND
E-mail: vmvinokour@gmail.com

We discuss the healthcare progress based on the applications of modern lasers combined with the diagnostic techniques based on the extensive use of quantum algorithms and quantum computers. The use of lasers in the healthcare counts about 50 years and has been mostly a replacement of a standard surgical scalpel for tissue ablation or the use of lasers as an optical tool for diagnostics. We put forth an approach utilizing lasers for treatment of widespread intractable diseases via non-destructive tissue modification. The approach builds on the successful experience on restoration of degenerated or damaged spinal discs via promoting the porosity of the disc cartilage by the gentle laser irradiation. The increasing porosity stimulates the flow of the organism liquid delivering nutrients that launch the regeneration processes. Building on this success, we have developed new methods for curing osteoarthritis of the knee, hip, and elbow joints, long-term normalization of intraocular pressure in glaucoma, and treatment of atherosclerotic arteries damaged by formation of calcium plaques via the recovery of the vessel elasticity. The curing methods utilize the novel diagnostic and imaging methods extensively using the novel quantum and hybrid algorithms for superpower computing that provide the real-time feedback control necessary for the successful treatment.

Strongly Correlated Electrons and Systems I-II-III-IV

09.05.2023 TUESDAY

Abstract ID: 101

PRESSURE-INDUCED PARTIAL DISORDER AND MAGNETISM IN Li_2MnO_3

T. Takami[1], A. Abulikemu[1], S. Gao[2], T. Matsunaga[1], C. Tassel[2], H. Kageyama[2], T. Saito[3], T. Watanabe[1], T. Uchiyama[1], K. Yamamoto[1], Y. Uchimoto[1]

[1]Graduate School of Human and Environmental Studies, Kyoto University, Sakyo-ku, Kyoto 606-8501, JAPAN
[2]Department of Energy and Hydrocarbon Chemistry, Graduate School of Engineering, Kyoto University, Nishikyo-ku, Kyoto 615-8510, JAPAN
[3]Institute of Materials Structure Science, High Energy Accelerator Research Organization, 203-1 Shirakata, Tokai, Ibaraki 319-1106, JAPAN
E-mail: takami.tsuyoshi.2m@kyoto-u.ac.jp

Materials with honeycomb lattices have been vigorously studied from both experimental and theoretical aspects due to the variety of magnetic properties resulting from frustration. Pressure is an important parameter that affects magnetism through changes in the bond length of magnetic ions. In this study, Li_2MnO_3, which is also known as a cathode material for lithium-ion batteries, was synthesized under high pressure to form a new magnetic structure.

Synchrotron X-ray diffraction measurements showed that, at 1 GPa, a system in which Mn and Li are disordered in the $Mn_{2/3}Li_{1/3}O_2$ plane was synthesized. The resulting lattice mimics a honeycomb lattice and a triangular lattice in the plane. It was also confirmed that the application of high pressure was effective in suppressing stacking faults. Thus, so-called partial disorder, in which Mn and Li are disordered only on the $Mn_{2/3}Li_{1/3}O_2$ plane while maintaining order in the Li layer, was achieved. Magnetization and specific heat measurements showed long-range ordering below 35 K associated with an antiferromagnetic transition. Neutron diffraction measurements were performed at different temperatures from room temperature to 26 K, as shown in Fig. 1. Magnetic structure analysis showed that the coexistence of antiferromagnetism and a partial magnetic disorder explained these peaks consistently. Thus, the magnetic structure is different from the Néel-type antiferromagnetism reported for conventional Li_2MnO_3 prepared at ambient pressure.

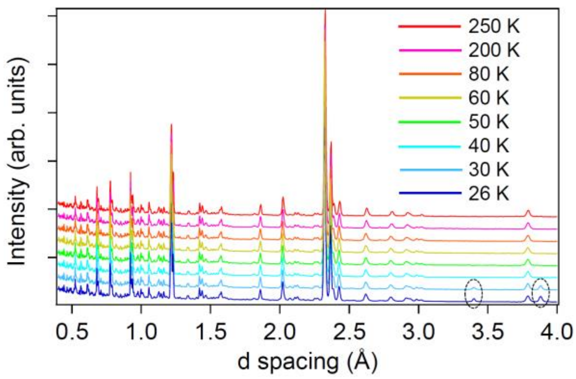

Fig. 1: *Neutron powder diffraction patterns of Li_2MnO_3 from 250 to 26 K. Dashed circles denote the magnetic Bragg peaks.*

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Abstract ID: 174

FERROMAGNETIC CLUSTER-GLASS BEHAVIOR IN KONDO LATTICE SYSTEM

Obinna Uzoh, Suyoung Kim, Eundeok Mun

Simon Fraser University, Dept. of Physics, Burnaby, BC, V5A 1S6 CANADA
E-mail: emun@sfu.ca

We have studied thermodynamic and transport properties of $Yb_{1-x}Y_xCuAs_2$ ($0.0 \leq x \leq 1.0$) single crystals. For $x = 0$, magnetic susceptibility measurement shows an antiferromagnetic (AFM) ordering below 3.7 K and electrical resistivity measurement reveals a typical Kondo lattice behavior. A small Y substitution for Yb in $YbCuAs_2$ lowers the AFM ordering temperature. Interestingly, a ferromagnetic (FM) state is induced between $x = 0.2$ and 0.7. The ac-susceptibility as a function of magnetic field and temperature suggests a FM-cluster formation. At further elevated Y concentrations ($0.8 \leq x \leq 1.0$) a paramagnetic state is realized. We will discuss the evolution of the magnetic ground state under various Y concentrations. We suggest that the transition from AFM to FM state arises from the formation of a ferromagnetic cluster in conjunction with crystallographic disorder accompanied by Y substitution.

Abstract ID: 202

STRUCTURES AND TRANSPORT PROPERTIES OF HIGH-Z METALS UNDER HIGH PRESSURE OF HYDROGEN

Jiafeng Yan[1], Zhongyan Wu[1], Bin Li[1], Soonbeom Seo[2], Youngjay Ruy[3], Dongzhou Zhang[3], Tuson Park[2,], Jaeyong Kim[1]

[1]*Department of Physics, Institute for High Pressure, Hanyang University, Seoul, 04763, REPUBLIC OF KOREA*
[2] *Department of Physics, Center for Quantum Materials and Superconductivity (CQMS) and Sungkyunkwan University, Suwon, 16419, REPUBLIC OF KOREA*
[3]*Advanced Photon Source, Argonne National Laboratory, IL, 60439, USA*
E-mail: kimjy@hanyang.ac.kr

Recent experimental results revealed that the synthesis of metal hydrides is a possible route to form high-transition temperature superconductors (SCs) by enhancing the electron-phonon coupling. DFT calculations suggest that alkali metals, where electrons can play either donor or acceptor, are good impurity elements combining hydrogen for evaluating the high-Tc SCs.

Stable polyhydrides of alkali metals have been predicted by theoretical analysis of MHn (M= Li, Na, K, Rb, Cs) compounds with variable hydrogen composition. Potassium (K), for example, has been proposed as a promising candidate for pressure-induced SC (~60 K at 166 GPa), but no experimental report on the structure and transport properties have been reported. This may be due to the experimental difficulties handling the sample at high temperatures and pressure without exposing it to air.

We reacted various metals, including potassium, serum, tellurium under high pressure of hydrogen, and effects of hydrogen on the structure, electronic resistance, and the critical magnetic field for superconductivity will be presented. We will also present the enhanced Tc of TiZr alloys induced by pressure, not by hydrogen, which demonstrates the contribution of hydrogen for increasing Tc in transition metals is different from the ones observed in polyhydrides.

Abstract ID: 77

METALLIC SPIN LIQUID AS A FRACTIONALIZED HEAVY FERMION LIQUID ON FRUSTRATED KONDO LATTICE

Yi-feng Yang

Institute of Physics, Chinese Academy of Sciences, 100190, Beijing, CHINA
E-mail: yifeng@iphy.ac.cn

Metallic spin liquid has been reported in several correlated metals including the frustrated Kondo lattice CePdAl [1], but a satisfactory theoretical description is not yet available. Here we propose a potential route to realize the metallic spin liquid [2] and construct an effective Z_2 gauge theory with charged fractionalized excitations on the triangular Kondo lattice [3]. This leads to a Z_2 metallic spin liquid featured with long-lived, heavy holon excitations of spin 0 and charge $+e$ and a partially enlarged electron Fermi surface. It differs from the weak-coupling FL* state proposed earlier and may be viewed as a ***fractionalized heavy fermion liquid***. Our theory provides a general framework to describe the metallic spin liquid in frustrated Kondo lattice systems.

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Abstract ID: 164

CHARGE DELOCALIZATION IN THE QUANTUM CRITICAL SUPERCONDUCTOR $CeRhIn_5$

Honghong Wang[1,2], Tae Beom Park[1,2,3], Jihyun Kim[1,2], Harim Jang[1,2], Eric D. Bauer[4], Joe D. Thompson[4], Tuson Park[1,2]

[1]*Center for Quantum Materials and Superconductivity (CQMS), Sungkyunkwan University, Suwon 16419, SOUTH KOREA*
[2]*Department of Physics, Sungkyunkwan University, Suwon 16419, SOUTH KOREA*
[3]*Institute of Basic Science, Sungkyunkwan University, Suwon 16419, SOUTH KOREA*
[4]*Los Alamos National Laboratory, Los Alamos, NM 87545, USA*
E-mail: tp8701@skku.edu

The nature of charge degrees-of-freedom distinguishes scenarios for interpreting the character of a second order magnetic transition at zero temperature, that is, a magnetic quantum critical point (QCP). Heavy-fermion systems are prototypes of this paradigm, and in those, the relevant question is where, relative to a magnetic QCP, does the Kondo effect delocalize their *f*-electron degrees-of-freedom. In this presentation, we report the discovery of an energy scale E_{loc} that signals a local-to-itinerant crossover of 4*f* degrees-of-freedom at an antiferromagnetic quantum-critical point (AFM QCP), a fundamental hallmark of Kondo-breakdown quantum criticality. In $CeRhIn_5$, Hall measurements reveal that $E_{loc}(P)$ extrapolates smoothly to zero temperature at the pressure-induced QCP in which earlier quantum oscillation measurements have provided direct evidence for Fermi surface reconstruction. Replacing 4.4% of the In atoms by Sn in $CeRhIn_5$, however, shifts $E_{loc}(P)$ such that it extrapolates inside the magnetically ordered phase, decoupling it from the pressure-induced magnetic quantum-critical point that becomes a 'conventional' spin-density-wave (SDW) QCP involving only quantum-critical magnetic fluctuations. The qualitative change from Kondo-breakdown criticality in pure $CeRhIn_5$ to SDW criticality with slight Sn doping signals an essential difference in the nature of fluctuations leading to Cooper pairing, i.e., from quantum-critical fluctuations of only a magnetic order parameter in the Sn-doped case to quantum-critical magnetic and charge fluctuations in pure $CeRhIn_5$.

Abstract ID: 513

MAPPING OF MAGNETIC ANISOTROPY FOR VAN DER WAALS MAGNETS

Joonyoung Choi[1], Do Hoon Kiem[2], Je-Geun Park[3], Myung Joon Han[2], Younjung Jo[1]

[1]*Kyungpook National University, Dept. of Physics, 41566, Daegu, REPUBLIC OF KOREA*
[2]*Korea Advanced Institute of Science and Technology, 34141, Daejeon, REPUBLIC OF KOREA*
[3]*Seoul National University, Dept. of Physics, 08826, Seoul, REPUBLIC OF KOREA*
E-mail: jophy@knu.ac.kr

The microscopic interpretation of magnetism is complex because spin, orbit, and crystal structures are intertwined. Two-dimensional layered materials exhibit distinctly different physical and magnetic behaviors compared to conventional three-dimensional materials. In this presentation we address the challenge of understanding magnetism and related phenomena in condensed matter physics.

This presentation focuses on the magnetic interaction and anisotropy of $M\mathrm{PS}_3$ materials, including the discovery of new in-plane magnetic anisotropy in FePS_3, which is consistent with a magnetostatic model. This presentation also highlights the identification of non-linear off-diagonal components of magnetic susceptibility in FePS_3, which are closely associated with crystals having rotational symmetry without mirror planes. In addition, the general configuration of microscopic spin Hamiltonian for NiPS_3 using first-principle calculations will be shown. The analysis of experimental torque magnetometer data confirms the magnetic dipole-dipole interaction as a major contributor to the magnetic anisotropy of NiPS_3.

Abstract ID: 79

ORIGIN OF RESIDUAL FERROMAGNETIC STATE IN FeRh FILM BELOW THE TRANSITION TEMPERATURE

Sehwan Song[1], Jiwoong Kim[1], Jisung Lee[2], Hyegyeong Kim[1,3], Noboru Miyata[4], Neeraj Kumar[5], Y. Soh[5], Jae Hyuck Jang[2], Chanyong Hwang[6], Brian J. Kirby[7], Sungkyun Park[1]

[1]*Department of Physics, Pusan National University, Busan 46241, KOREA*
[2]*Korea Basic Science Institute, Daejeon 34133, KOREA*
[3]*Core Research Facilities, Pusan National University, Busan 46241, KOREA*
[4]*Neutron Science and Technology Center, Compressive Research Organization for Science and Society, 162-1 Shirakata, Tokai, Naka, Ibaraki 319-1106, JAPAN*
[5]*Paul Scherrer Institute, 5232 Villigen, SWITZERLAND*
[6]*Quantum Spin Team, Korea Research Institute of Standards & Science, Daejeon 34113, KOREA*
[7]*NIST Center for Neutron Research, National Institute Standard & Technology, Gaithersburg, MD 20878, USA*
E-mail: psk@pusan.ac.kr

FeRh exhibits antiferromagnetic (AFM) to ferromagnetic (FM) transition above room temperature (i.e., T_C ~ 340 K) along with volume expansion. Therefore, FeRh is a valuable material in modern AFM-based spintronic applications if it can be controlled the phase transition characteristics with a clean interface. However, it was found that the thin film FeRh reveals unusual FM characteristics even below the transition temperature (i.e., AFM region).

In this presentation, we examined the detailed temperature-dependent physical property measurements to understand the origin of the residual FM in the AFM region. As a result, we found the coexistence of antiferromagnetic and residual FM states induces thermomagnetic irreversibility (e.g., spin-glass-like behavior) and negative magnetoresistance. Furthermore, temperature-dependent polarized neutron reflectometry profiles and room temperature structural and spectroscopic analyses confirmed that the bottom FM region is correlated with structural distortion. In contrast, the top FM region is temperature-dependent and originates from non-stoichiometry.

This study was supported in part by NRF-2020K1A3A7A09077715, NRF-2021M3H4A6A02045432, NRF-2021M3I3A1084719, and grant No. 2021R1A6C101A429.

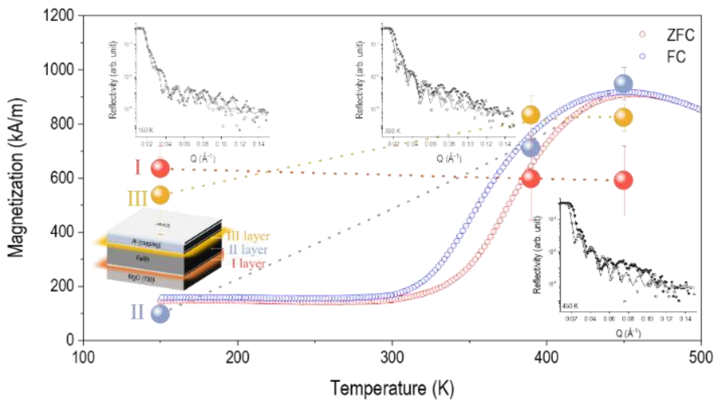

Fig. 2. *Temperature- and depth-dependent magnetic characteristics of FeRh film*

Abstract ID: 111

EFFECT OF EXTERNAL PRESSURE ON THE METAL-INSULATOR TRANSITION OF THE ORGANIC QUASI-TWO-DIMENSIONAL METALS κ-$(ET)_2Hg(SCN)_2X$ (X=Cl, Br)

S.I. Pesotskii[1], R.B. Lyubovskii[1], G.V. Shilov[1], V.N. Zverev[2], S.A. Torunova[1], E.I. Zhilyaeva[1], E. Canadell[3]

[1] *Institute of Problems of Chemical Physics and Medicinal Chemistry, RAS, Chernogolovka, Moscow region, RUSSIA*
[2] *Institute of Solid State Physics, RAS, Chernogolovka, Moscow region, RUSSIA*
[3] *Institut de Ciència de Materials de Barcelona, ICMAB-CSIC, Barcelona, Bellaterra, SPAIN*
E-mail: zverev@issp.ac.ru

The organic quasi-two-dimensional metals are strongly correlated systems in which electron correlations often lead to the Mott metal-insulator (MI) transition. Due to their high sensitivity to external pressure one can easily suppress the MI-transition and recover the metallic state. Here we study the influence of external pressure on MI transition in two organic quasi-two-dimensional metals κ-$(ET)_2Hg(SCN)_2X$, where ET=bis(ethylenedithio)tetrathiafulvalene, X=Cl, Br, (hereafter κ-Hg-Cl and κ-Hg-Br). The crystals are isostructural, i.e. have the same monoclinic structure at T=300 K and both of them have metallic-like temperature dependence, but at $T_{MI} \approx 30$ K for k-Hg-Cl and at $T_{MI} \approx 90$ K for κ-Hg-Br the MI transition takes place. The application of comparatively small external pressure suppresses the Mott transition for both crystals. We have found that despite the similarity of the structure and transport properties above T_{MI} the transition scenario for these crystals is strictly different. Unlike to the crystal κ-Hg-Cl, where we have Mott-type transition in electronic system, the transition in κ-Hg-Br takes place with hysteresis, which indicates on the first order type of the transition. The observed Shubnikov-de Haas (SdH) quantum oscillations of the magnetoresistance in κ-Hg-Cl look typical for the κ-salts and correspond to the well known Fermi surface with α and β electron orbits. Whereas in κ-Hg-Br the oscillations have only one frequency, which value is far from the reasonable one for the traditional Fermi surface of κ-salts. Our low temperature X-ray studies have shown that in this crystal the structure changes during the transition from monoclinic above T_{MI} to triclinic below T_{MI}. A theoretical study suggests that this phase transition should be of the metal-to-metal type and brings about a substantial change of the Fermi surface. Apparently, the electronic system in the triclinic phase is unstable toward a Mott insulating state leading to the growth of the resistance when the temperature drops below $T_{MI} \approx 90$ K. The observed quantum oscillations of the magnetoresistance are in good agreement with the calculated Fermi surface for the triclinic phase, thus providing a plausible explanation for the puzzling behavior of κ-Hg-Br as a function of temperature and pressure around 100 K, and for the difference in the SdH oscillations. The present study points out interesting differences in the structural and physical behavior of the two room temperature isostructural salts κ-$(ET)_2Hg(SCN)_2X$ with X=Cl, Br.

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Abstract ID: 372

SPIN ORBIT COUPLING DRIVEN NOVEL QUANTUM MAGNETISM IN IRIDATE DOUBLE PEROVSKITES

Roumita Roy, Sudipta Kanungo

School of Physical Science, Indian Institute of Technology Goa, Goa, INDIA
E-mail: sudipta@iitgoa.ac.in

3d-5d based Double Perovskites are an ideal platform to understand the interplay of spin orbit coupling (SOC), electronic correlation and the crystal field splitting. The said interplay of different energy scales leads to counter-intuitive behaviour of the underlying magnetic phases, which has been discussed in the present investigations[1,2] in the case of Ca doped Sr_2FeIrO_6. In the first principles electronic structure calculation we found that the variation of the spin and orbital magnetic moment with the Ca doping is completely non-monotonic in nature, which is more prominent in the case of Ir. We showed that the effect of SOC is very different across the Ca doped series and the ground state magnetic ordering exclusively depends on the strength of the SOC in these cases.

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Abstract ID: 132

PHASE SEPARATION IN DOUBLE PEROVSKITE OXIDES

D.V. Popov[1], I.V. Yatsyk[1], R.G. Batullin[2], M.A. Cherosov[2], T.I. Chupakhina[3], Yu.A. Deeva[3], T. Maiti[4], R.M. Eremina[1]

[1] *Zavoisky Physical-Technical Institute, 420029 Kazan, RUSSIA*
[2] *Kazan (Volga Region) Federal University, 420008 Kazan, RUSSIA*
[3] *Institute of Solid State Chemistry of the RAS (UB), 620990, Ekaterinburg, RUSSIA*
[4] *Department of Materials Science and Engineering Indian Institute of Technology Kanpur Kanpur 208016, UP, INDIA*
E-mail: reremina@yandex.ru

The general formula of a double perovskite is $A_2B'B''O_6$, where A is a divalent alkaline earth metal, B' and B" are occupied by transition metals. Double perovskites remained a fascinating topic of research during the last few decades due to their unique magnetic, electrical, and dielectric properties, as well as extremely high magnetoresistance [1-3]. In addition, insulator-metal and even semimetal-metal transitions were observed in these materials [4,5].

Although some reports are available on magnetic behavior in double perovskite oxides, the detailed understanding of magnetic ordering in this double perovskite is yet to be fully understood. Electron paramagnetic resonance (EPR) or electron spin resonance (ESR) measurement is a great tool to unravel the nature of magnetism in a compound. To the best of our knowledge, no reports are found in the literature on the ESR measurement of STM. In the current work, we have analyzed the magnetic data of STM synthesized by solution chemistry in correlation with ESR measurement and detailed structural and microstructural investigation.

Apart from ESR line with $g{\sim}2$ in $Sr_2TiMnO_{5.87}$ compoundwe observed ESR line on at $B_{res} = 19.3$ mT in both X- and Q- bands measurements in the temperature range 37.5-42.5K which are connected with complex skyrmion buildup. The peaks obtained in real and imaginary parts of AC magnetization measurements confirm phase separation at the same temperatures. The antiferromagnetic ordering was found out below the temperature $T_N \approx 12$ K. The fitting Debye and Einstein temperatures, obtained from the specific heat measurements, are equal to $\theta_D = 217$ K, $\theta_{E1} = 275$ K, $\theta_{E2} = 615$ K, and $\theta_{E3} = 2000$ K.

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Abstract ID: 138

EVOLUTION OF CHARGE CARRIERS NEAR THE MOTT TRANSITION: THEORY VS. EXPERIMENT IN κ-(BEDT-TTF)2X

S. Oberbauer[1,2], S. Erkenov[1,2], W. Biberacher[1], N. Kushch[1,3], R. Gross[1,2], M. Kartsovnik[1]

[1]*Walther-Meißner-Institut, 85748 Garching, GERMANY,*
[2]*Technische Universität München, 85748 Garching, GERMANY*
[3]*Federal Research Center of Problems of Chemical Physics and Medicinal Chemistry, 1424332 Chernogolovka, RUSSIA*
E-mail: Mark.Kartsovnik@wmi.badw.de

Despite the great amount of work devoted to the Mott metal-insulator transition (MIT), some key theoretical predictions in this field are still awaiting experimental verification. This is related, for example, to the quasiparticle coherence and the exact behaviour of the effective mass renormalized by many-body interactions in close proximity to the bandwidth-controlled first-order MIT. To fill this gap of knowledge, we employed the layered organic conductors κ-(BEDT-TTF)$_2$X as exemplary quasi-2D Mott systems, gaining direct access to fundamental properties of their metallic ground state via magnetic quantum oscillations (MQO) of magnetoresistance. By applying physical or "chemical" pressure, we finely tune the location of the materials on the phase diagram.

We have been able to trace the evolution of the MQO in immediate proximity to the MIT including the homogeneous metallic region and the transitional region where the metallic and insulating phases coexist, separated in space. Our data provide a direct evidence of coherent Landau quasiparticle with a large Fermi surface persisting in the coexistence region even on the very border to the purely insulating state.

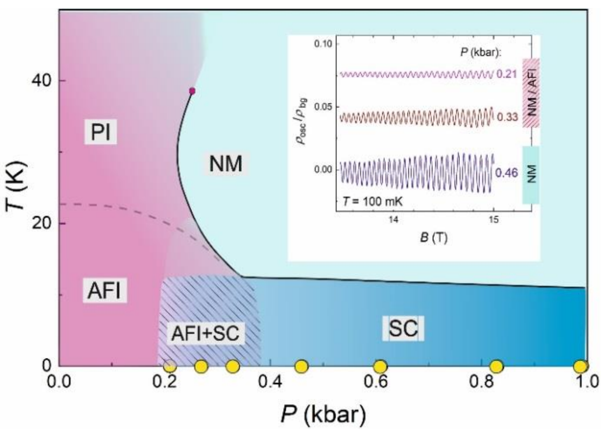

Fig. 1: *Pressure-temperature phase diagram of κ-(BEDT-TTF)$_2$Cu[N(CN)$_2$]Cl. Yellow circles indicate the pressures at which the measurements were done. Inset: Examples of MQO in the purely metallic state and deep in the phase-coexistence region [1].*

For the archetypal pressure-tuned antiferromagnetic Mott insulator, the salt with X = Cu[N(CN)$_2$]Cl, the oscillations reveal a simple inverse-linear pressure dependence of the effective mass, $m^* \propto (P - P_0)^{-1}$ [1]. This looks very consistent with theoretical predictions for the mass renormalization caused by electron correlations near the MIT. However, the slope of this dependence turns out to be strikingly, almost an order of magnitude, steeper than expected. Moreover, it further accelerates upon entering the phase-coexistence region. A comparison with some other, organic and inorganic Mott materials suggests a universal character of the detected inconsistency, thus challenging our present understanding of the renormalization effects in close proximity to the Mott transition.

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Abstract ID: 254

THE MICROWAVE ELECTRODYNAMICS OF UTe_2

Arthur Carlton-Jones, Yun-Suk Eo, Ian Hayes, Shanta Saha, Nicholas P. Butch, Johnpierre Paglione, Steven M. Anlage

Quantum Materials Center, Physics Department, University of Maryland, College Park, MD 20742-4111, USA
E-mail: anlage@umd.edu

The complex surface impedance of a superconductor provides many insights into its properties, such as the pairing mechanism, super- and normal-fluid responses, Fermi surface, and possibly it's topological properties. We explore the surface impedance of UTe_2 single crystals as a function of temperature using resonant cavity measurements for a variety of microwave-frequency modes. The UTe_2 crystals studied are from both older, [1] and newer generations, with the latter showing higher transition temperatures. We determine a composite surface impedance for each mode using resonance data combined with the independently measured normal state dc resistivity tensor. We are able to determine the combination of crystallographic directions excited in each mode using the anisotropy of the resistivity. Studying several modes yields the surface impedance corresponding to each axis. We find approximately a T^2 power-law dependence for the magnetic penetration depth at low temperatures in both the a- and c-directions, which is inconsistent with a single pair of point nodes on the Fermi surface. We find the zero-temperature penetration depth to be largest for the c-direction, which is consistent with current understanding of the Fermi surface shape. The surface resistance demonstrates a relatively large residual loss at zero temperature, and the c-direction is the most lossy. We compare to theoretical expectations of the electrodynamic properties of topological superconductors.

This work is supported by NSF DMR-2004386.

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Abstract ID: 531

REAL-SPACE OBSERVATION OF THE DOMAIN WALL STRUCTURE OF SPIN-DENSITY-WAVE STATE

Yining Hu[1], Tong Zhang[1], Donglai Feng[1,2]

[1]*Fudan University, State Key Laboratory of Surface Physics, Dept. of Physics, and Advanced Materials Laboratory, 200438, Shanghai, CHINA*
[2]*University of Science and Technology of China, Hefei National Laboratory for Physical Science at Microscale and Dept. of Physics, 230026, Hefei, CHINA*
E-mail: ynhu19@fudan.edu.cn

Understanding the atomic-scale structure of magnetic domain walls is of fundamental importance for both the basics and applications of magnetism. Although the domain wall structures of local moment magnets are well studied, little is known for that of itinerant magnetism, such as the spin density waves (SDW) state. Here by using scanning tunneling microscopy, we studied the domain wall structure of the SDW in Cr and its coexisting CDW state. On the Cr (001) surface, two single-Q (stripe-like) SDW/CDW domains with their wave vector Q perpendicular to each other are identified. On their domain boundaries, we observed grid-like CDW modulations. Detailed analysis show that such modulations are not from direct adding of two CDW stripes, but are result of coherent superposition of two single-Q SDW. This means a unique double-Q SDW state is formed at the domain wall. Moreover, the observed domain wall has finite wall width, which indicates there is an energy cost of forming double-Q SDW state. Our simulation shows that the single-Q state exponentially decays when entering the double-Q region, which is a characteristic of the itinerant nature of SDW. Our work not only discovered a new type of magnetic domain wall which is completely different from local moment magnetism, but also brings insights on the microscopic mechanisms of SDW state.

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Superconductivity in Lower Dimensions I

09.05.2023 TUESDAY

Abstract ID: 156

CONTROLLING SUPERCURRENT BY HIGH-ENERGY QUASIPARTICLES

I. Golokolenov[1,2,3], A. Guthrie[1], S. Kafanov[1], Yu. A. Pashkin[1], V. Tsepelin[1]

[1]*Dept. of Physics, Lancaster University, Lancaster LA1 4YB, UK*
[2]*P. L. Kapitza Institute for Physical Problems of RAS, Moscow, RUSSIA*
[3]*National Research University Higher School of Economics, Moscow, RUSSIA*
E-mail: y.pashkin@lancaster.ac.uk

In semiconductor electronics, the field effect refers to the control of electrical conductivity in nanoscale devices, which underpins the field effect transistor, one of the cornerstones of present-day semiconductor technology. The effect is enabled by the penetration of the electric field far into a weakly doped semiconductor, whose charge density is not sufficient to screen the field. On the contrary, the charge density in metals and superconductors is so large that the field decays exponentially from the surface and can penetrate only a short distance into the material. Hence, the field effect should not exist in such materials. Therefore, the reports on the field effect in superconductors [1-4] have sparked a lot of discussions in the scientific community. The effect was attributed to the observed suppression of the critical current in superconducting and proximized normal-metal nanowires under intense electric fields. It is well known that the charge density in metals and superconductors is so large that the electric field decays exponentially from the surface and can penetrate only a short distance into the material. On the other hand, a number of papers published later provide a different explanation of the observed effect as being due to the local suppression of superconductivity by energetic quasiparticles injected at high gate voltages [5-7].

We present an experiment in which we studied the properties of thin-film superconducting coplanar quarter-wavelength waveguide resonators [7]. The resonators were formed in a 30 nm thick vanadium film and grounded through a gated nanoscale constriction about 50 nm wide and 50 nm long. We have found that at high enough gate voltage, $|V_g| > 25$ V, the resonance frequency starts to fall, which is accompanied by the decrease of the quality factor and increase of the low-frequency noise. At the same time, the leakage current between the gate and constriction grows rapidly at $|V_g| = 25$ V and perfectly follows the Fowler-Nordheim model of electron field emission from a metal electrode [8]. The effect is bipolar and can be explained by the injection of high-energy quasiparticles resulting in weaker superconductivity and suppression of the critical current of the constriction. This interpretation, also proposed in the publications by other groups [5,6], refutes the existence of the field effect in superconductors [1-4].

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Abstract ID: 196

FLUX COTUNNELING AND COULOMB DRAG FOR QUANTUM PHASE SLIPS

Alex Latyshev[1,2], Andrew G. Semenov[2,3], Andrei D. Zaikin[2,3]

[1]*Departement de Physique Theorique, Universite de Geneve, CH-1211 Geneve, SWITZERLAND*
[2]*National Research University Higher School of Economics, 101000 Moscow, RUSSIA*
[3]*I.E. Tamm Department of Theoretical Physics, P.N. Lebedev Physical Institute, 119991 Moscow, RUSSIA*
E-mail: andrei.zaikin@kit.edu

Employing charge–flux duality for Josephson junctions and superconducting nanowires, we predict a novel effect of fluxon cotunneling in SQUID-like nanorings [1]. This process is strictly dual to that of Cooper pair cotunneling in superconducting transistors formed by a pairs of Josephson tunnel junctions connected in series. Cooper pair cotunneling is known to lift Coulomb blockade in these structures at low temperatures. Likewise, fluxon cotunneling may eliminate the magnetic blockade of superconducting phase fluctuations in SQUID-like nanorings, driving them into an insulating state. Yet another interesting and novel effect – Coulomb drag for quantum phase slips [2] – emerges in a system of two electromagnetically coupled superconducting nanowires. We demonstrate that applying electric current to one of such wires one induces a non-vanishing voltage across another one. We evaluate the cross-resistance for such a system which turns out to exhibit a non-trivial power-law dependence on both temperature and current bias.

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Abstract ID: 462

SPIN-ORBIT ASSISTED SUPERCONDUCTIVITY IN TRANSITION METAL DICHALCOGENIDES

M. Haim[1], D. Möckli[2], M. Khodas[1]

[1]*The Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 91904010, ISRAEL*
[2]*A Instituto de Física, Universidade Federal do Rio Grande do Sul, 91501-970 Porto Alegre, BRAZIL*
E-mail: maxim.khodas@mail.huji.ac.il

Mono- and few-layer transition metal dichalcogenides (TMDs) are two-dimensional superconductors with the transition temperature of a few Kelvins. These superconductors have an extremely anisotropic critical magnetic field with the parallel critical field far above the Pauli limit. The mono-layer TMDs are non-centrosymmetric with strong spin-orbit interaction polarizing spins out-of-plane. The spin-orbit interaction protects the conventional spin-singlet superconductivity against the pair breaking by the magnetic field. We argue that in addition, the spin-orbit interaction mediates the transformation of singlet Cooper pairs into the triplet Cooper pairs by the applied field. These parallel spin triplets are distinct from the anti-parallel spin triplets present at zero magnetic field. Since the parallel spin triplets are field induced, they have a strong effect on the critical field. Besides, these spin triplets are protected against the disorder scattering thanks to their strong coupling with the spin singlets. In recent experiments a two-fold transport anisotropies have been reported inconsistent with the hexagonal symmetry of the underlying lattice. We list possible scenarios of the two-fold symmetry based on pairing of conventional as well as unconventional symmetry. Finally, I discuss the manifestations of the field induced topological phase transition in the 4π periodic current phase relation of the TMD based planar Josephson junctions.

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Bulk Superconductors I-II

10.05.2023 WEDNESDAY

Abstract ID: 213

DYNAMIC CHARGE STRIPES AND ELECTRON DENSITY MODULATION IN THE ANISOTROPIC TWO-GAP SUPERCONDUCTOR ZrB_{12}

N.B. Bolotina[1,2], O.N. Khrykina[1,2], A.N. Azarevich[1], N.Yu. Shitsevalova[3], V.B. Filipov[3], S.Yu. Gavrilkin[4], S. Gabáni[5], K. Flachbart[5], V.V. Voronov[1], N.E. Sluchanko[1]

[1]*Prokhorov General Physics Institute of RAS, 119991Moscow, RUSSIA*
[2]*Shubnikov Institute of Crystallography, Federal Scientific Research Centre 'Crystallography and Photonics' of RAS, 119333 Moscow, RUSSIA*
[3]*Frantsevich Institute for Problems of Materials Science of NASU, 03680 Kyiv, UKRAINE*
[4]*Lebedev Physical Institute of RAS, 119991 Moscow, RUSSIA*
[5]*Institute of Experimental Physics of SAS, 04001 Košice, SLOVAKIA*
E-mail: nes@lt.gpi.ru

Fine details of crystal structure of ZrB_{12} two-gap superconductor [1], [2] are studied at low temperatures by precise x-ray diffraction technique. Small *static* Jahn-Teller distortions of a face centered cubic lattice are observed in the range 30–70 K, leading also to emergence of two types singularities of electron density (ED), - (*i*) *dynamic charge stripes* along selected directions <110> and <112> in the single-domain crystal (see Fig.1) and (*ii*) *triangular lattice of the ED antinodes* located in the interstices of the boron lattice in the {111} planes passing through boron atoms (not shown). The second anomaly was detected for the first time, and it is very pronounced and intensified in ZrB_{12} at low temperatures.

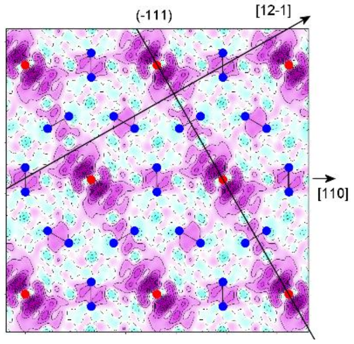

Fig. 1: *Difference Fourier synthesis of the ED distribution in the (-111) plane of the ZrB_{12} lattice at a temperature of 70 K averaged in class -1. The plane is drawn through Zr atoms (red circles); in each B-B pair (blue circles), one is above and the other is below the plane by ~0.7 Å. Areas of positive and negative ED values are highlighted in blue and pink. Contour intervals are 0.1 e Å^{-3}.*

The anisotropy of the two-gap superconductivity in ZrB_{12} is confirmed by measurements of the low temperature heat capacity and magnetization in a magnetic field directed along three principal axes in the crystal, **H** || [100], **H** || [110] and **H** || [111].

We conclude in favor of the magnetic field-induced anisotropy arising from the interaction of vortex lattice in this inhomogeneous superconductor with fluctuating electron density (dynamic charge stripes) of a two-type filamentary structure.

The study was supported by RSF Project No. 22-22-00243.

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Abstract ID: 308

EVALUATION OF CRITICAL CURRENT DENSITY INHOMOGENEITIES IN A LARGE COMMERCIAL REBaCuO BULK

K. Berger[1], Q. Nouailhetas[1], R. Dorget[1,2], Y. Xing[3], J. Noudem[3], J. Plecháček[4], B. Douine[1], J. Lévêque[1]

[1] *Université de Lorraine, GREEN, F-54000 Nancy, FRANCE*
[2] *SAFRAN TECH, Magny-les-Hameaux, FRANCE*
[3] *CRISMAT, ENSICAEN, 14050 Caen Cedex 04, FRANCE*
[4] *Can Superconductors, Kamenice, ČESKÁ REPUBLIKA*
E-mail: kevin.berger@univ-lorraine.fr

Advances in the melt-growth synthesis technique for preparing superconducting REBaCuO bulks allow the production and commercialisation of single crystals with a diameter of about 10 cm. This is in close agreement with the development of new applications such as electric motors where superconducting bulks are used as trapped field magnets or magnetic screens [1], [2]. It is then crucial to determine the superconducting properties such as critical temperature, critical current density and irreversible magnetic field, which is usually done using MPMS-SQUID on a millimetre size sample.

In this study, the characterisation of a 10 cm wide commercial bulk machined for use as a magnetic shield is presented, see Fig. 1. 24 orthorhombic samples were extracted at different positions from the centre of the bulk, prepared and measured on a 14 T MPMS with a VSM head. A comparison of the superconducting properties of each sample will be presented together with the trapped field measurements performed on 10 other wide REBaCuO bulks. This will provide an opportunity to discuss the state of the art of this technology and its possible future development and will highlight the need to measure superconducting properties in different positions.

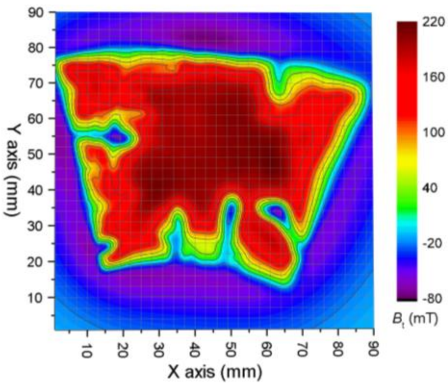

Fig. 1: *Magnetic flux density map measured on the surface of a REBaCuO bulk after magnetisation under 300 mT using a permanent magnet.*

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Abstract ID: 376

MAGNETIC SHIELDS OF VARIOUS SHAPES COMBINING BULK SUPERCONDUCTORS AND TAPES

S. Brialmont[1], J.F. Fagnard[1], J. Dular[1], P. Yang[2], W. Yang[2], A. Patel[3], S. Hahn[4], C. Geuzaine[1], B Vanderheyden[1], P. Vanderbemden[1]

[1] *Department of Electrical Engineering and Computer Science, Montefiore Research Unit, University of Liege, Liege, BELGIUM*
[2] *College of Physics and Information Technology, Shaanxi Normal University, Xi'an, Shaanxi, CHINA*
[3] *Department of Materials Science and Metallurgy, University of Cambridge, Cambridge, U.K.*
[4] *Department of Electrical and Computer Engineering, Seoul National University, Seoul, SOUTH KOREA*
E-mail: Philippe.Vanderbemden@ulg.ac.be

Superconductors can be used to make very efficient low frequency magnetic shields [1]. One of the key advantages of type-II superconducting shields is their ability to operate at much higher fields than conventional ferromagnetic materials, the latter being limited to their saturation magnetization. For superconductors, the maximum magnetic field at which magnetic shielding becomes ineffective depends on both the critical current density J_c and the geometric parameters of the shields, mainly (i) the thickness of the walls and (ii) the size of the superconducting current loops induced by the applied field. Although their geometries differ significantly from each other, bulk superconductors [2-3] and coated conductor tapes [4-5] offer the opportunity to design remarkable magnetic shields or screens: bulk superconductors can be manufactured in the form of plates or cylinders of thick walls and moderate size, while coated conductor tapes involve thin superconducting films over significant lengths. In this contribution, the main design requirements for magnetic shields made of either bulk superconductors or coated conductor tapes will be reviewed, together with their performance levels at low frequency. Then various configurations for which bulks and tapes can be combined efficiently will be investigated. We will consider the situations for which the magnetic shields or screens made of bulk superconductors can benefit from the presence of superconducting tapes and vice-versa. These situations will be illustrated with experimental results at 77 K and finite element modelling of magnetic shields made of bulk large grain (RE)$Ba_2Cu_3O_7$ (RE = Rare Earth), bulk polycrystalline $Bi_2Sr_2Ca_2Cu_3O_{10}$ and 2nd generation (RE)$Ba_2Cu_3O_7$ coated conductor tapes. For the latter we will both consider the case of tapes of nominal width (10-12 mm) and the benefits that can be brought by using much larger (40 mm) tapes.

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Abstract ID: 384

HIGH T_c OF $Tl_2Ba_2CaCu_2O_8$ SUPERCONDUCTOR AT LOW PRESSURE

E. Yusrianto

Universitas Islam Negeri Imam Bonjol Padang, 25153 Padang, West Sumatera, INDONESIA
E-mail: efilyusrianto@uinib.ac.id

The $Tl_2Ba_2CaCu_2O_8$ superconductor was substituted and added with several materials to enhance the $T_{c\text{-}onset}$ [1,2]. But so far the maximum of $T_{c\text{-}onset}$ was around 110K [3,4]. Due to the interesting $T_{c\text{-}onset}$ of $Tl_2Ba_2CaCu_2O_8$ superconductor, several parameter such as paring interaction, lattice dynamics, microwave absorption, electron-density distribution, vortex matter properties, peak anomaly and irreversible magnetization of superconductor has been investigated [5-10]. The T_c of $Tl_2Ba_2CaCu_2O_8$ substitution with Cr was recorded at 157K (Fig.1). The sample still showed Tl-2212 as the major phase and $BaCO_3$, $BaCuO_2$ as the minor phases. This result may be due to the precursor process and heat treatment. According to Kirschner et al. [11], the high Tc superconductivity of Tl-Ba-Ca-Cu-O was depending on the heat treatment. Further studies are needed to evaluate precisely the phase composition of $Tl_2Ba_2CaCu_2O_8$ superconductor to get the correlation with high $T_{c\text{-}onset}$.

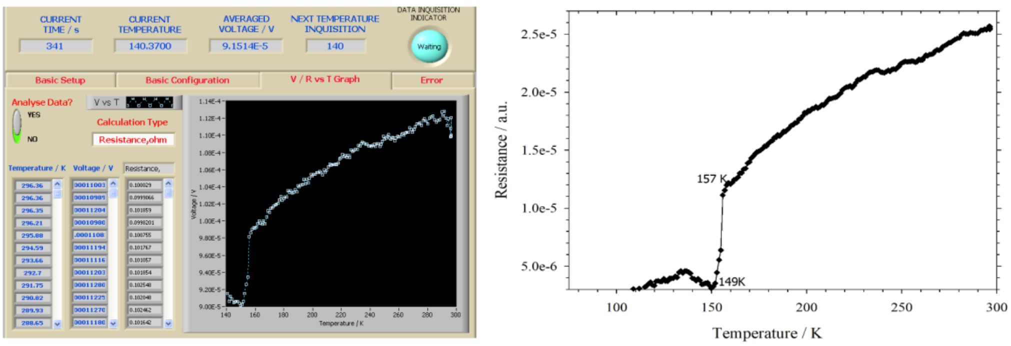

Fig. 1: *Electrical resistance versus temperature curves of $Tl_2Ba_2CaCu_2O_8$ with Cr 0.2 addition.*

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Abstract ID: 429

IMPROVEMENT OF MAGNETIC LEVITATION AND GUIDING FORCE DENSITY OF HTS MAGLEV SYSTEMS USING THINLY SLICED BULK YBCO AND DIFFERENT YBCO-PMG SURFACE INTERACTIONS

U. Kemal Ozturk[1], Murat Abdioglu[1,2], Hakki Mollahasanoglu[1,3,] Sait Baris Guner[3], Ekrem Yanmaz[4]

[1]Electromagnetic Guidance and Acceleration Research Group (EMGA), Department of Physics, Faculty of Science, Karadeniz Technical University, 61080, Trabzon, TURKIYE
[2]Department of Mathematics and Science Education, Faculty of Education, Bayburt University, 69000, Bayburt, TURKIYE
[3]Department of Electrical-Electronics Engineering, Faculty of Engineering and Architecture, Recep Tayyip Erdoğan University, TURKIYE
[3]Department of Electrical-Electronics Engineering Nisantası University, Istanbul, TURKIYE
E-mail: kozturk6167@gmail.com

In superconducting Maglev systems, the vertical and lateral magnetic force efficiency and the total weight of the system are important parameters in terms of energy savings and generated power density. Hence, total bulk YBCO number in the superconducting Maglev system and so total weight of the system have to be decreased while the enhancing magnetic force performance. The studies on superconducting Maglev mostly use the single or three seeded-YBCO samples and their size and masses are about 64mmx33mmx14mm and 172 grams, respectively [1, 2]. Although the superconducting performance of the seeded bulk YBCO sample is great their fabrication is costly and takes a long time. In this study, a standard rectangular bulk three seeded-YBCO superconductor with a certain mass was divided horizontally into three slices and the magnetic force values of these slices for different lying positions on different PMG arrays were experimentally investigated. In the study it was determined that the levitation and guidance force obtained by a special arrangement of the three slices on the different configuration of the magnetic PMG rail, could be greater than 50% and 100%, respectively, than the previous whole superconductor.

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Abstract ID: 487

HOT-PRESSED MgB_2 AND MT-YBCO FOR APPLICATIONS IN LIQUID HYDROGEN

Tetiana Prikhna[1, 3], Michael Eisterer[2], Viktor Moshchil[1], Bernd Büchner[3], Vladimir Sokolovsky[4], Xavier Chaud[5], Dirk Lindackers[3], Dmitriy Efremov[3], Anton Shaternik[1], Volodymyr Sverdun[1], Semyon Ponomarov[6]

[1]V. Bakul Institute for Superhard Materials of the National Academy of Sciences of Ukraine, 2, Avtozavodskaya Str., Kiev 07074, UKRAINE
[2] Institute of Atomic and Subatomic Physics, TU Wien, Stadionallee 2, 1020 Vienna, AUSTRIA
[3]Leibniz-Institut für Festkörper- und Werkstoffforschung Dresden e. V., Helmholtzstraße 20, 01069 Dresden, GERMANY
[4] Ben-Gurion University of the Negev, P.O.B. 653, Beer-Sheva 84105, ISRAEL
[5]Laboratoire National des Champs Magnétiques Intenses (LNCMI/CNRS), 25 Avenue des Martyrs, BP 166, 38042 Grenoble Cedex 9, FRANCE
[6]Institute of Semiconductor Physics of the National Academy of Sciences of Ukraine, 41, Nauky Ave., Kyiv 03028, UKRAINE
E-mail: prikhna@ukr.net

The problems connected with liquid hydrogen transportation result in an increasing interest in the development of pumps working at liquid hydrogen temperature (20 K).The development of hydrogen energy and, in particular, high-performance submersible liquid hydrogen (LH) pumps requires superconducting bearings which can trap magnetic fields up to 1 T at 20 K. MgB_2 is hence a promising candidate for this application. The superconducting properties and microstructure of differently prepared MgB_2 were compared and the ability of different composite materials to trap magnetic fields was studied. Hollow cylinders of the same geometry were manufactured from hot pressed (under 30 MPa) blocks prepared from Mg:2B with Ti, TiC and Ti-O additives as well as from melt-textured YBCO ceramics. The high critical current densities and critical magnetic fields should ensure high trapped fields in all these materials. Indeed all materials demonstrated the required performance; however, flux jumps are a serious issue in MgB_2 even in crack free cylinders and impeded higher trapped fields.

Ferrites and Rare Earth Magnetic Materials

10.05.2023 WEDNESDAY

Abstract ID: 119

CRYSTAL STRUCTURE AND MAGNETIC PROPERTIES OF A-SITE SUBSTITUTED $Nd_{1-x}\boldsymbol{R}_xBaMn_2O_6$ DOUBLE MANGANITES, *R*= Sm, Pr

S.G. Titova, E.V. Sterkhov

Institute of Metallurgy Urals Division of Russian Academy of Sciences, 620016, Ekaterinburg, RUSSIA
E-mail: sgtitova@mail.ru

Double manganites $RBaMn_2O_6$ (R – rare earth) are built as a sequence of $RMnO_3$ and $BaMnO_3$ cubic perovskite cells in *c*-direction. In comparison with disordered manganites $R_{0.5}Ba_{0.5}MnO_3$ the temperatures of magnetic and electric phase transition are much higher; that makes these materials perspective for application as magnetoresistors, magnetocalorics and sensors. Magnetic and electric properties vary significantly when R-element varies; the compound with R=Nd looks like a critical point at the diagram of magnetic and electric states [1]. For the first time we have studied solid solutions of double manganites $Nd_{1-x}R_xBaMn_2O_6$ (R = Sm, Pr) in vicinity of this "critical point" (Fig. 1).

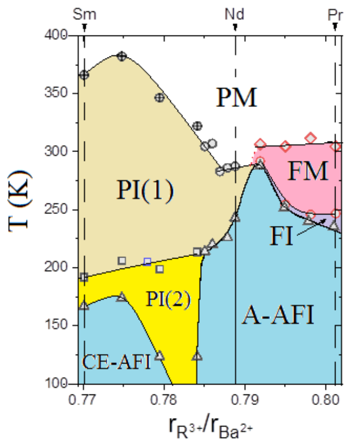

Fig. 1: *Electric and magnetic states for $Nd_{1-x}Sm_xBaMn_2O_6$ and $Nd_{1-x}Pr_xBaMn_2O_6$ solid solutions.*
Notations:
PM – paramagnetic metal;
FM – ferromagnetic metal;
FI – ferromagnetic insulator;
PI(1) – paramagnetic insulator with charge and orbital ordering of the 1-st type;
PI(2) – paramagnetic insulator with charge and orbital ordering of the 2-nd type;
AFI – antiferromagnetic insulator with CE- and A-types of order.

For Sm-doped compounds Néel temperature decreases for Sm content x= 0.2-0.5 due to a competition between A- and CE- types antiferromagnetic ordering in a presence of weak ferromagnetic interactions [2]. An influence of the external pressure up to 5.2 GPa on magnetic and crystal structure of $PrBaMn_2O_6$ is studied using neutron powder diffraction [3], the data are compared with results for disordered manganites.

The work is supported by RFBR, grant No 19-29-12013.

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Abstract ID: 345

EFFECT of La^{3+} ON THE STRUCTURAL AND TRANSPORTATION CHARACTERISTICS OF MANGANESE ZINC FERRITE FOR R-RAM APPLICATIONS

Noshaba Naseer, M. Anis-ur-Rehman

Applied Thermal Physics Laboratory (ATPL), Department of Physics, COMSATS University, Islamabad, PAKISTAN

E-mail: marehman@comsats.edu.pk

Ferrites are ferrimagnetic materials in which metal cations and oxygen anions form geometric patterns in the crystal lattice. Ferrites show two behaviors, they are ferrimagnetic and electrically resistive as well. Due to these properties, they have a wide range of applications. Electric properties of Manganese zinc ferrite are rarely reported. Lanthanum-doped manganese zinc ferrite nanoparticles have a chemical composition of $Mn_{0.2}$ $Zn_{0.8}La_xFe_{2-x}O_4$ where (x=0.03, 0.06, and 0.12) have been synthesized by the Sol-gel method. The dried powder was calcined at 870 ^{0}C for 6 hours. These samples in the form of pellets were sintered at 900^{o}C for 6 hours. X-ray diffraction technique (XRD) was used to study the crystal structure, lattice constant, crystallite size, porosity, and unit cell volume of prepared samples with the help of XRD data. AC electrical properties (conductivity, dielectric constant, loss factor, and impedance) for frequencies (20 Hz-3MHz) at room temperature were investigated and DC electrical properties, like resistivity, and activation energy of our prepared samples, were measured by using two probe methods as a function of temperature. Current-voltage (I-V) measurements were used to study the resistive switching mechanism. The curves displayed a variety of highly non-linear and irreversible electrical characteristics when the electrical bias voltage direction was switched during the measurement of the I-V curve. For concentration at x=0.03 shows the maximum value of resistivity which makes it a potential candidate for high-frequency applications where high resistance and low losses are required. For concentration at x=0.12 shows the maximum hysteresis and could be potential candidate for R-RAM applications.

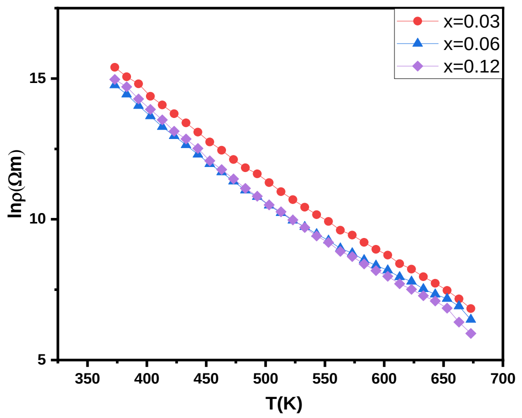

Fig 1: *DC resistivity vs temperature for $Mn_{0.2}Zn_{0.8}La_xFe_{2-x}O_4$(x=0.03, 0.06, 0.12).*

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Abstract ID: 371

AN ELECTRON SPIN RESONANCE STUDY OF MULTIFERROIC PEROVSKITE $BiFe_{0.5}Mn_{0.5}O_3$ DISPLAYING SPONTANEOUS MAGNETIZATION REVERSAL

T.S. Mahule[1], Brain Sibanda[1], Davide Delmonte[2], Edmondo Gilioli[2], V.V. Srinivasu[1]

[1] *Department of Physics, University of South Africa, Johannesburg 1710, SOUTH AFRICA*
[2] *IMEM, CNR, Parma, ITALY*
E-mail: mahults@unisa.ac.za

$BiFe_{0.5}Mn_{0.5}O_3$ was prepared through High Pressure- High Temperature (HP/HT) synthesis[1,2] for Electron Spin Resonance characterization. This system is known to display bulk multiferroism[3] (coexistence of Antiferromagnetism and Ferroelectricity). In particular, the system presents a weak ferromagnetic resultant and a very rare phenomenon: the spontaneous magnetization reversal in low field regimes. This behaviour was explained in terms of a pronounced competition of two magnetic populations (one highly rich in Fe and another one highly rich in Mn), whose presence is determined by the intrinsic inhomogeneity of the sample determined by the exotic synthesis conditions. As this system has in-built magnetic inhomogeneity and frustration, it is interesting to probe this system using ESR technique. Our detailed study shows violent fluctuations of g-factor in the low temperature regime, exactly where appear the thermal crossover marking the appearance of the magnetization reversal. Further, the asymmetry parameter, which represents the magneto-crystalline anisotropy shows a peak around 75K, which falls in the temperature window where a crossover of susceptibility occurs from positive to negative. Thus, a comprehensive analysis of ESR data suggests frustration and competition between Fe and Mn-rich clusters, supporting the earlier interpretation[1] at the origin of the magnetization reversal.

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Abstract ID: 445

CALCINATION TEMPERATURE DEPENDENCE OF TRI-MAGNETIC NANO-FERRITE ($Ni_{1/3}Cu_{1/3}Zn_{1/3}Fe_2O_4$): STRUCTURAL, OPTICAL, AND MAGNETIC PROPERTIES

R.Yassine, M. Farhat, Z. Bitar, R. Awad

Beirut Arab University, Dept. of Physics, Beirut, LEBANON
E-mail: roaaphd@gmail.com

In this study, $Ni_{1/3}Cu_{1/3}Zn_{1/3}Fe_2O_4$ powder was prepared by chemical co-precipitation method and calcined at five different temperatures 500, 550, 600, 650, and 700 °C. The effect of calcination temperature on the structural and magnetic properties of ferrite powders was investigated by X-ray diffraction (XRD), Fourier transform infrared (FTIR), X-ray photoelectron spectroscopy (XPS), energy dispersive X-ray (EDX), transmission electron microscopy (TEM), scanning electron microscopy (SEM), electron paramagnetic resonance (EPR), Raman spectroscopy, and the vibrating sample magnetometer (VSM). The results revealed that increasing calcination temperature led to a change in the crystalline quality of the $Ni_{1/3}Cu_{1/3}Zn_{1/3}Fe_2O_4$ powders. The XRD analysis showed that the crystallite size was affected by the calcination temperature and that the hematite disappeared at 700 °C. The FTIR, XPS, EDX, TEM, and SEM results indicated that the surface morphology of the ferrite powders was influenced by the calcination temperature. The EPR spectroscopy investigated the electron spin resonance intensity with increasing calcination temperature. Finally, the VSM results showed that the magnetic properties of the ferrite powders changed with increasing calcination temperature. These findings provide valuable information for the optimization of the synthesis and processing of $Ni_{1/3}Cu_{1/3}Zn_{1/3}Fe_2O_4$ powders. The $Ni_{1/3}Cu_{1/3}Zn_{1/3}Fe_2O_4$ powders with improved magnetic properties have potential applications in various fields, such as electromagnetic shielding, magnetic data storage, microwave absorbers, and magnetic sensors. The optimization of the synthesis and processing of these ferrite powders through control of the calcination temperature can enhance their performance in these applications, making them more attractive for industrial use.

Micromechanics and Its Application to Energy Storage and Harvesting Application

10.05.2023 WEDNESDAY

Abstract ID: 105

PRINTED ENERGY HARVESTERS AND STORAGE DEVICES FOR SENSORS AND WEARABLES

Sherjeel Khan

Silicon Austria Labs GmbH, 9524, Villach, AUSTRIA
E-mail: sherjeel.khan@silicon-austria.com

Advances in the miniaturization of electronics and manufacturing methods have empowered wearables with high-performance capabilities while reducing their size at the same time. It has led to the widespread adoption of wearables in everyday consumer devices, various industries, and personalized healthcare & remote diagnostics. With the increased processing capacity of modern wearables along with the need to maintain a constant connection with the internet, the energy requirement of the wearables has surged. The physical size of the energy storage elements cannot be increased beyond a certain size to cope with the higher power requirement that is dictated by the intended application. Such portable devices, especially in health care and industrial maintenance, also require structural flexibility and conformability which can be achieved through modern electronic printing methods. Thus, an optimal solution to provide power for modern flexible smart wearables is to i) identify printable novel materials to form higher power density storage devices, ii) use advanced printing methods to increase power density or enable structural flexibility of current energy storage devices, or iii) create high efficiency miniaturized printed energy harvesting devices. Here, we present an insight into the versatility of different printing methods (3D printing, inkjet printing, screen printing, electrohydrodynamic printing,) and novel printable materials for the creation of energy harvesters (triboelectric nanogenerators, solar cells, RF antenna-based, thermoelectric energy generators, and piezoelectric energy harvesters) and energy storage devices (electrochemical batteries, biochemical batteries, and supercapacitors).

Abstract ID: 107

MICROMECHANICS OF ADVANCED ELECTRONICS APPLICATIONS: NUMERICAL AND EXPERIMENTAL PERSPECTIVE

Nadeem Qaiser[1], Maha Nour[2], Vincent Tung[1]

[1]*Material Science Engineering, KAUST Solar center, Physical Science and Engineering Division, King Abdullah University of Science and Technology (KAUST), Thuwal 23955, SAUDI ARABIA*
[2]*Saudi Aramco, Dahran, SAUDI ARABIA*
E-mail: nadeem.qaiser@kaust.edu.sa & vincent.tung@kaust.edu.sa

The mechanics of small-sized materials is mostly different as compared to bulk counterparts. The response of micro and nano materials depends on various factors, in addition to feature size. Therefore, the performance of electronics devices highly depends on how their mechanical properties are changing. These devices include flexible microheater, sensors, actuators, batteries, piezoelectric. The efficacy is dictated by materials, designs, fabrication methods [1,2]. To achieve the set goal, the micro/nano mechanics of these devices need to be explored. This work will discuss how the numerical modeling, using Abaqus and COMSOL, can reveal the governing mechanics of Li-ion battery, piezoelectric, and solar cells. The properties of various micro/nanostructures were revealed by numerical and experimental methods. The advanced fabrication techniques will also be introduced and how they impact the associated mechanics of fabricated electronic devices.

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Abstract ID: 219

HIGH PRESSURE DYNAMICS: SHOCK WAVES EFFECT ON MATERIAL PROPERTIES AT NANOSCALE

Hassnain Abbas Khan, Mohammad Abou-Daher, S. Janardhanraj, Aamir Farooq

King Abdullah University of Science and Technology (KAUST), Clean Combustion Research Centre, Physical Sciences and Engineering Division, Thuwal 23955-6900, SAUDI ARABIA
E-mail: hassnain.khan@kaust.edu.sa

To achieve higher performance, multiple applications necessitate stable material qualities for a broader variety of operating conditions. Therefore, to investigate the effect of extreme conditions like very high pressure and temperature, shockwaves are generated in shock tubes. As a model materials, anatase titania nanoparticles was investigated under exposure to repeated loading of shockwaves produced in a diaphragm-driven high-pressure shock tube. The titania samples were exposed to 20 shocks with pressure, temperature, and steady exposure time in the range of 20.5 – 26 bar, 1399 – 2101 K, and 1.74 – 1.83 ms, respectively. The crystal structure and surface morphology were analyzed before and after the shockwave treatment using various characterization techniques. After repeated shock exposure, there was reduction in crystallite size by ~ 40%, modification in the surface charge, and an increase in the hydroxyl groups in titania. The onset of phase transformation from anatase to rutile was observed after 20 shocks. This work gives insights into the structural changes induced by shockwaves in anatase nanoparticles which can help improve their performance as a catalytic support in heterogeneous catalysis, photochemical and sensing applications.

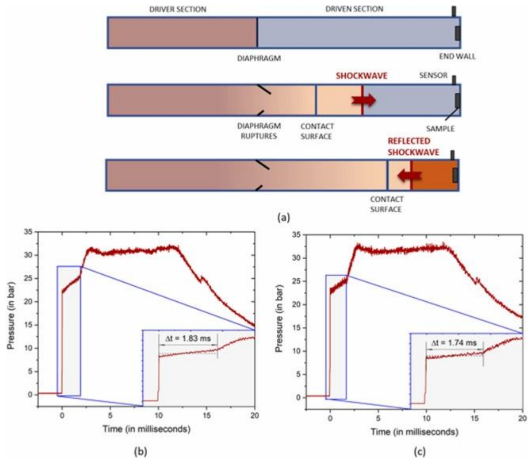

Fig 3: A schematic diagram showing the location of titania samples in the shock tube. The thickness of the sample is exaggerated in the schematic diagram. (b) Typical pressure profile near the end-wall of the shock tube when driven gas is argon. The steady time portion of the signal is enlarged and shown in the inset plot. (c) Typical pressure profile near the end-wall of the shock tube when driven gas is mixture of 50% argon and 50% nitrogen.

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New Superconductors I-II

10.05.2023 WEDNESDAY

Abstract ID: 177

TIME-REVERSAL SYMMETRY-BREAKING CHARGE ORDER IN A KAGOME SUPERCONDUCTOR

Z. Guguchia[1], C. Mielke III[1, 2], D. Das[1], J.-X. Yin[3], H. Liu[4,5], R. Gupta[1], Y.-X. Jiang[3], M. Medarde[6], X. Wu[7], H.C. Lei[8], J.J. Chang[2], P. Dai[9], Q. Si[9], H. Miao[10], R. Thomale[11], T. Neupert[2], Y. Shi[4,5], R. Khasanov[1], M.Z. Hasan[3], H. Luetkens[1]

[1]*Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institute, Villigen PSI, SWITZERLAND*
[2]*Physik-Institut, Universität Zürich, Winterthurerstrasse 190, Zürich, SWITZERLAND*
[3]*Laboratory for Topological Quantum Matter and Advanced Spectroscopy (B7), Department of Physics, Princeton University, Princeton, New Jersey 08544, USA*
[4]*Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, CHINA*
[5]*School of Physical Sciences, University of Chinese Academy of Sciences, Beijing, CHINA*
[6]*Laboratory for Multiscale Materials Experiments, Villigen PSI, SWITZERLAND*
[7]*Max-Planck-Institut für Festkorperforschung, Heisenbergstrasse 1, Stuttgart, GERMANY*
[8]*Department of Physics and Beijing Key Laboratory of Opto-electronic Functional Materials and Micro-nano Devices, Renmin University of China, Beijing 100872, CHINA*
[9]*Department of Physics and Astronomy, Rice University, Houston, Texas 77005, USA*
[10]*Material Science and Technology Division, Oak Ridge National Laboratory, USA*
[11]*Institut für Theoretische Physik und Astrophysik, Universität Wurzburg, GERMANY*
E-mail: zurab.guguchia@psi.ch

The kagome lattice, the most prominent structural motif in quantum physics, benefits from inherent nontrivial geometry to host diverse quantum phases [1-5], ranging from spin-liquid phases, topological matter to intertwined orders, and most rarely unconventional superconductivity. Recently, charge sensitive probes have suggested that the kagome superconductors AV_3Sb_5 (A = K, Rb, Cs) [3-5] exhibit unconventional chiral charge order. However, direct evidence for the time-reversal symmetry-breaking of the charge order remained elusive. We utilized muon spin relaxation to probe the kagome charge order and superconductivity in KV_3Sb_5 and RbV_3Sb_5 [6,7]. We observe a striking enhancement of the internal field width sensed by the muon ensemble, which takes place just below the charge ordering temperature and persists into the superconducting state. Remarkably, the muon spin relaxation rate below the charge ordering temperature is substantially enhanced by applying an external magnetic field. We further show the nodal nature of superconducting gap in KV_3Sb_5 and RbV_3Sb_5 and that the T_c/λ^{-2}_{ab} ratio is comparable to those of unconventional high-temperature superconductors. Our results point to unprecedented time-reversal symmetry breaking charge order intertwining/competing with unconventional superconductivity in the correlated kagome lattice. While low-temperature time-reversal symmetry-breaking superconductivity has been discussed for many systems, high-temperature time-reversal symmetry-breaking charge order is extremely rare.

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Abstract ID: 325

SHIBA STATES IN THE SYSTEMS WITH DENSITY OF STATES SINGULARITIES

S. Basak, A. Ptok

Institute of Nuclear Physics Polish Academy of Sciences, PL-31342 Kraków, POLAND
E-mail: aptok@mmj.pl

Magnetic impurities placed in the superconductor can lead to the emergence of Yu-Shiba-Rusinov bound states. Coupling between the impurity and the substrate depends on the density of states (DOS) at the Fermi level and can be tuned by DOS singularities. Here, we study the role of DOS singularities using the real space Bogoliubov–de Gennes equations for chosen lattice models. To uncover the role of these singularities (Dirac point, van Hove singularity, or the flat band), we study honeycomb, kagome, and Lieb lattices. We show that the properties of the Shiba state strongly depend on the type of lattice. Nevertheless some behaviors are generic, e.g., dependence of the critical magnetic coupling on the DOS at the Fermi level. However, the Shiba states realized in the Lieb lattice exhibit extraordinary properties, which can be explained by the presence of a few nonequivalent sublattices. Depending on the location of the magnetic impurity in the chosen sublattice, the value of critical magnetic coupling J_c can be reduced or enhanced when the flat band is located at the Fermi level. In this context, we also present differences in the local DOS and coherence lengths for different sublattices in the Lieb lattice.

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Abstract ID: 573

HIGH-PRESSURE PHASE DIAGRAM OF *Ln*HO (*Ln* = LANTHANIDES)

Ryo Terada, Yumi Tsuchiya, Zefeng Wei, Hiroki Ubukata, Hiroshi Kageyama

Kyoto University, Dept. of Energy and Hydrocarbon Chemistry, Graduate School of Engineering, Kyoto 615-8510, JAPAN

E-mail: terada.ryo.32w@st.kyoto-u.ac.jp

*Ln*HO (Ln = lanthanide) with a fluorite-type structure undergoes an anion ordered-disorder transition depending on the Ln^{3+} size (i.e., ‘chemical pressure’), while external pressure in LaHO leads to phase transitions to the $PbCl_2$-type and then the anti-Fe_2P-type structure, reversing anion-centered coordination. In this study, we investigate the phase transition behavior in *Ln*HO (*Ln* = Nd, Gd, and Er) at external pressures up to 5 GPa. In contrast to LaHO, we observed a direct phase transition from fluorite-type structure to anti-Fe_2P-type structure in all of them. In anti-Fe_2P-type structure, above 3 GPa, with H^- and O^{2-} coordinated four-fold and five-fold, respectively. The absence of the $PbCl_2$-type structure suggests that the smaller Ln^{3+} ions destabilize the five-coordinate hydride and four-coordinate oxide in this structure, which was partially supported by DFT cal-culations. We further found a tendency for the fluorite-type structure to stabilize toward the higher pressure side in order of *Ln* = Nd, Gd, and Er, suggesting chemical pressure plays a different role than physical pressure.

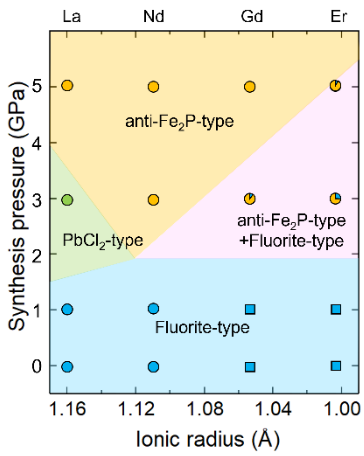

Fig. 1: *Phase diagram for LnHO (Ln = La, Nd, Gd, and Er) synthesized at ambient pressure, 3 GPa and 5 GPa, plotted as a function of the Shannon radius of Ln^{3+} cations. All data for Ln = La and 0 and 1 GPa data for Ln = Nd, Gd, and Er are taken from the literatures.*[1-4]

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Abstract ID: 185

POLARONIC CHARGE CARRIERS AND SUPERCONDUCTIVITY IN OXYGEN-DEFICIENT TUNGSTEN OXIDES

A. Shengelaya[1,2]

[1]*Department of Physics, Tbilisi State University, 0128 Tbilisi, GEORGIA*
[2] *Andronikashvili Institute of Physics, Tbilisi State University, 0177 Tbilisi, GEORGIA*
E-mail: alexander.shengelaya@tsu.ge

Oxygen deficiency in tungsten oxide WO_3 leads to a strong increase in conductivity as W^{5+} ($5d^1$) ions are induced, which are a source of the charge carriers. In the octahedral oxygen coordination, W^{5+} hosts one 5*d* electron in a triply degenerate orbital and therefore is a Jahn-Teller ion. Several experimental studies demonstrated that these charge carriers have a polaronic character and form bipolarons in WO_{3-x}. However, magnetic and transport properties of oxygen-deficient tungsten oxides were not sufficiently studied especially at low temperatures.

In this talk I will present results of our studies of oxygen reduced tungsten oxides WO_{3-x}. In the samples with composition $WO_{2.9}$ the signatures of superconductivity with the transition temperature T_c = 80 K were registered by means of magnetization measurements. After lithium intercalation the T_c further raised to 94 K [1]. The small superconducting volume fraction and the absence of transition in resistivity measurements indicate that the superconductivity is localized in small regions which do not percolate. Performed resistivity and magnetoresistance measurements show that $WO_{2.9}$ has also unconventional normal state properties, which can be understood by considering bi-polaronic nature of charge carriers in this compound [2].

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Abstract ID: 576

RICH NATURE OF VAN HOVE SINGULARITIES IN KAGOME SUPERCONDUCTOR CsV_3Sb_5

Yong Hu

Photon Science Division, Paul Scherrer Institut, Villigen, SWITZERLAND
E-mail: yong.hu@psi.ch

The recently discovered layered kagome metals AV_3Sb_5 (A=K, Rb, Cs) exhibit diverse correlated phenomena, which are intertwined with a topological electronic structure with multiple van Hove singularities (VHSs) in the vicinity of the Fermi level. As the VHSs with their large density of states enhance correlation effects, it is of crucial importance to determine their nature and properties. Here, we combine polarization-dependent angle-resolved photoemission spectroscopy with density functional theory to directly reveal the sublattice properties of 3d-orbital VHSs in CsV_3Sb_5. Four VHSs are identified around the M point and three of them are close to the Fermi level, with two having sublattice-pure and one sublattice-mixed nature. Remarkably, the VHS just below the Fermi level displays an extremely flat dispersion along MK, establishing the experimental discovery of higher-order VHS. The characteristic intensity modulation of Dirac cones around K further demonstrates the sublattice interference embedded in the kagome Fermiology. The crucial insights into the electronic structure, revealed by our work, provide a solid starting point for the understanding of the intriguing correlation phenomena in the kagome metals AV_3Sb_5.

Abstract ID: 624

SUPERCONDUCTIVITY BEYOND THE PAULI LIMIT IN HIGH-PRESSURE $CeSb_2$

Oliver Squire, Stephen Hodgson, Jiasheng Chen, Vitaly Fedoseev, Christian de Podesta, Theodore Weinberger, Patricia Alireza, F. Malte Grosche

Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, UK
E-mail: fmg12@cam.ac.uk

We report the discovery of superconductivity at a pressure-induced magnetic quantum critical point in the Kondo-lattice system $CeSb_2$, sustained up to magnetic fields that exceed the conventional Pauli limit eight-fold [1] (Fig. 1). Like $CeRh_2As_2$, $CeSb_2$ is locally non-centrosymmetric around the Ce-site, but the evolution of critical fields and normal state properties as $CeSb_2$ is tuned through the quantum critical point motivates a fundamentally different explanation for its resilience to applied field.

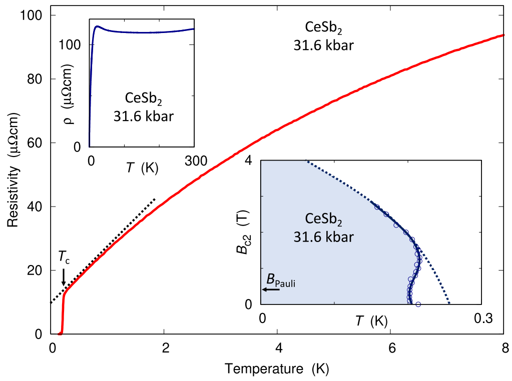

Fig. 1: *Superconductivity and anomalous normal state in high pressure* $CeSb_2$.

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Novel Functional Magnetic Materials – Basic Approach and Applications III-IV

10.05.2023 WEDNESDAY

Abstract ID: 1

DIELECTRIC PERMITTIVITY IN $Ho_xMn_{1-x}S$ SOLID SOLUTIONS

A.M. Kharkov, A.V. Gelgorn, R.V. Runov, R.A. Sitnikov

Reshetnev Siberian State University of Science and Technology, Krasnoyarsk, RUSSIA
E-mail: khark.anton@mail.ru

With an increase in the substitution concentration, the complex permittivity increases sharply in the temperature range of 230-320K and the imaginary part of the permittivity has a maximum (Figure 5). The temperature dependence Re(ε)/Re(ε, T=115K) is described in the Debye model [1]: $Re(\varepsilon)=A/(1+(\omega\tau)^2)$; $Im(\varepsilon)=B\omega\tau/(1+(\omega\tau)^2)$, where A, B are the parameters, τ is the relaxation time, which is described by the Arrhenius law with $\tau=\tau_0\cdot\exp(\Delta E/kT)$. In the Debye model, the maximum relaxation is associated with the ratio $\omega\tau=1$. The temperatures of the maxima in Im(ε) shift to the high temperature region with increasing frequency. From the ratio $\omega\tau=1$, the relaxation time is found and the dependence on the inverse temperature is shown in the insert to figure 5a. All points lie on a straight line, the slope of which gives the activation energy ΔE=0.5eV. For the composition $Ho_xMn_{1-x}S$ c x=0.1, the dielectric permittivity is due to localized electrons in the sublattice of manganese ions and conduction electrons, which are given to the conduction band by holmium ions. In the temperature range of 230-320K, electrons are pinned on holmium ions, above this temperature, electron delocalization occurs. As a result, the dielectric permittivity and losses increase when heated.

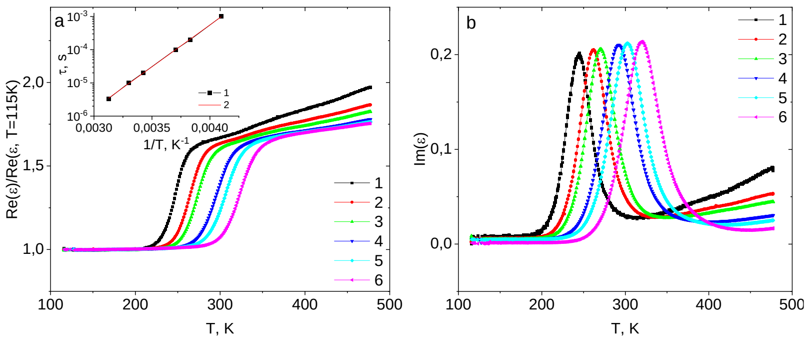

Fig. 1: *(a) – the normalized value of the real part dielectric permittivity Re(ε)/Re(ε, T=115K) and (b) – the imaginary part dielectric permittivity Im(ε) for $Ho_xMn_{1-x}S$ with x = 0.1 at frequencies ω = 1 kHz (1), 5 kHz (2), 10 kHz (3), 50 kHz (4), 100 kHz (5), 300 kHz (6) of temperature. Insert: dependence of relaxation time on the inverse temperature.*

Dielectric losses can be caused by the interaction of electrons with magnons, phonons and charged centers. The energy of the alternating electric field will transfer to the magnetic and elastic systems [2]. The type of interaction in the $Ho_xMn_{1-x}S$ system depends on the substitution concentration and temperature. At low substitution concentrations, impurity electrons are localized in potential wells and it is necessary to provide high energy for electron delocalization. In a system with concentrations exceeding x=0.05, clusters of holmium ions are formed in which electrons move during observation. In this case, the dielectric characteristics can be described in the Debye model.

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Abstract ID: 458

STUDY OF THE CURIE TEMPERATURE IN THE D0_3 STRUCTURE $Fe_{75}Al_{25}$ AS A FUNCTION OF THE EXCHANGE CONSTANTS OBTAINED WITHIN THE FRAMEWORK OF THE DLM FORMALISM

M. Matyunina, M. Zagrebin, V. Sokolovskiy, V. Buchelnikov

Chelyabinsk State University, 454001, Chelyabinsk, RUSSIA
E-mail: matunins.fam@mail.ru

The classical Heisenberg model is widely used to describe the ground state properties and phase transitions in magnetic systems. The constants of magnetic exchange interactions J_{ij} and magnetic moments μ obtained from *ab initio* calculations are used as input parameters in Heisenberg model to simulate the temperature dependencies of magnetization by Monte Carlo (MC) method. However, the problem here originates from the fact that magnetic degrees of freedom in ferromagnet materials cannot be accurately described by a localized Heisenberg model suitable for the most rare-earth magnets or transition-metal insulators. In particular, the Curie temperatures T_C estimated for Fe-Al and Fe-Ga alloys in [1,2]. The T_C values obtained as a function of the concentration of the nonmagnetic element (Al/Ga) for $Fe_{100-x}Al_x$ and $Fe_{100-x}Ga_x$ alloys with different cubic structures were overestimated compared to the experimental data. These results may be related to the use of only ordered ferromagnetic (FM) spin magnetic configurations in the J_{ij} calculation procedure, which can hardly provide a correct representation of the high-temperature paramagnetic (PM) state with randomly oriented spin moments. This problem has been discussed in papers [3,4], and the authors have proposed several approaches to solve it for Fe, Co, Ni, Mn, and Cr 3*d* magnets. The main idea uniting the listed methods is based on the formalism of disordered local moments (DLM).

In the present work, we tested the method proposed in [3] using the spin-polarized relativistic Korringa-Kohn-Rostoker code (SPR-KKR) [5] for *ab initio* calculations. For the $Fe_{75}Al_{25}$ alloy with the D0_3 structure (Fm-$3m$ space group, No. 225) the Curie temperature was estimated as a function of the Heisenberg exchange coupling constants within the framework of the DLM formalism. The magnetization and J_{ij} were calculated from first principles for different concentration of c magnetic constituents. The FM state was corresponding to c=1 where all spin of Fe atoms oriented along z direction. To create the PM state, the magnetic spins of the Fe atoms at each of the Wyckoff sites of the D0_3 structure were oriented in an equal proportion of 50% along z and 50% opposite z (c=0.5). Intermediate configurations with spins opposite to the z-axis in the concentration range c=0.1-0.4 were also considered. The J_{ij} for different magnetic states were used in MC simulations to calculate the temperature dependence of magnetization for a given concentration c.

Support by the Ministry of Science and Higher Education of the Russian Federation within the framework of the Russian State Assignment under contract No. 075-01391-22-03 is acknowledged.

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Abstract ID: 627

MURUNSKITE: A BRIDGE BETWEEN CUPRATES AND PNICTIDES

D. Tolj[1], T. Ivsic[2]

[1]*EPFL, 1015 Lausanne, SWITZERLAND*
[2]*TU Wien, 3071060, Vienna, AUSTRIA*
E-mail: trpimir.ivsic@tuwien.ac.at

Exploring novel materials as the candidates for unconventional superconductors can help to understand the mechanism of this exotic phenomenon but also lead to synthesis of compounds with important technological applications. The main compound of interest is murunskite ($K_2FeCu_3S_4$), a material isostructural to iron-based superconductors with iron and copper occupying the same crystal site. I will discuss the synthesis methods of single crystals and measurements of structural, electronic and magnetic properties. [1]

Although iron and copper are randomly distributed at the same crystallographic position, ordered complex antiferromagnetic structure with spin-density wave is present in the system. The current study shows that murunskite is a Mott insulator with sulfur orbitals partially open and electronically active, similar to oxygen orbitals in cuprates. DFT calculations, corroborated by ARPES measurements, indicate the conduction band is ligand dominated while the valence band is iron dominated, positioning murunskite as an interpolation compound between two main families of high-temperature superconductors.

Murunskite structure has been successfully altered by substitution and doping on all three crystallographic positions. Effects on the electronic and magnetic properties leading towards the metallization will be discussed.

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Abstract ID: 290

SELECTIVE LASER SINTERING OF PERMANENT MAGNETS BASED ON Sm-Fe-Ti AND Nd-Fe-B ALLOYS

A.S. Volegov[1], V.E. Maltseva[1], S.V. Andreev[1], N.V. Selezneva[1], N.M. Nosova[1], E.I. Patrakov[2], D.S. Neznakhin[1], O.A. Golovnia[1,2]

[1] *UrFU, Inst. of Natural Sciences and Mathematics, 620002, Yekaterinburg, RUSSIA*
[2] *Institute of Metal Physics, 620108, Yekaterinburg, RUSSIA*
E-mail: aleksey.volegov@gmail.com

Additive manufacturing of functional materials has a number of advantages over subtractive manufacturing and molding, consisting in the possibility of creating products of near-net-shape and local tuning of properties. The latter advantage is unique for additive manufacturing. The transition to additive technologies in the field of construction materials has largely already taken place. However, products made of functional materials cannot yet be obtained by new methods because of the strong dependence of their properties on microstructure. Establishing the relationship between the starting material and substances for 3D-printing and the methods of influencing them in the process of producing new functional materials is one of the main physical and materials science challenges at the current stage of additive technology development. The aim of the work is to prove the concept of additive manufacturing process of permanent magnets with selective laser sintering.

We have prepared permanent magnets from Sm-Fe-Ti alloys with ThMn12-type structure and magnets from Nd-Fe-B alloys based on $Nd_2Fe_{14}B$-type phase by selective laser sintering. The magnets were obtained using $Sm_{75}(Cu,Co)_{25}$ and $Nd_{75}(Cu,Co)_{25}$ low-melting alloys. The coercivity of the obtained Sm-Fe-Ti magnets reached 2.2 kOe, the coercivity of Nd-Fe-B magnets reached 19 kOe.

In the report the reasons for the choice of such alloys will be explained and the dependences of the magnetic properties of the obtained magnets on the synthesis parameters will be presented.

The research was financially supported by Russian Science Foundation (Grant Number 21-72-10104).

Abstract ID: 303

A MODIFIED KONDORSKY MODEL FOR DESCRIBING THE MAGNETIZATION REVERSAL PROCESSES IN Nd–Fe–B PERMANENT MAGNETS

A. Urzhumtsev, V. Maltseva, A. Volegov

Ural Federal University, Institute of Natural Science and Mathematics, Kuibysheva st., 48, Yekaterinburg, 620026, RUSSIA

E-mail: andrej707@bk.ru

The majority of the magnets used in the field of high-tech devices are related to Nd–Fe–B magnets. Despite long-term research, the issue of the magnetization reversal mechanisms in different types of permanent magnets still remains unanswered. Understanding the mechanisms governing the process of magnetization reversal is of both fundamental and practical interest due to expanding the possibilities of additive technologies for the manufacture of products, such as functional materials and, in particular, magnetic materials.

A modified Kondorsky model of the magnetization reversal processes based on the mechanism of domain-wall pinning is described, which takes the magnetostatic interaction between grains into account. The angular dependences of the coercivity in Nd–Fe–B permanent magnets are estimated based on the Stoner–Wohlfarth and Kondorsky models, as well as on a modified Kondorsky model. The aim of this study was to correct the Kondorsky model by taking the influence of local magnetic fields that arise during magnetization reversal of individual grains in permanent magnets into account. The results demonstrate that the proposed model better describes the angular dependences of the coercivity in the magnets under study.

Sintered permanent Nd–Fe–B magnets of grades N35, N35SH and N48 were chosen as samples for testing the proposed approach. The choice of magnets is determined by the need to check the proposed modification of the model on several samples with different magnetization and coercivity values and to study their relationships. The results of measuring angular dependences $H_c(\theta)$ of the coercivity of magnets and the angular dependences predicted within the Kondorsky and Stoner–Wohlfarth models, and the proposed modification of Kondorsky model on the basis of the k parameter defined in expression are given in Fig. 1. The k parameter is the ratio of coercivity to internal field of the grains. Magnetic measurements were performed on a KVANS-1 vibration magnetometer at room temperature.

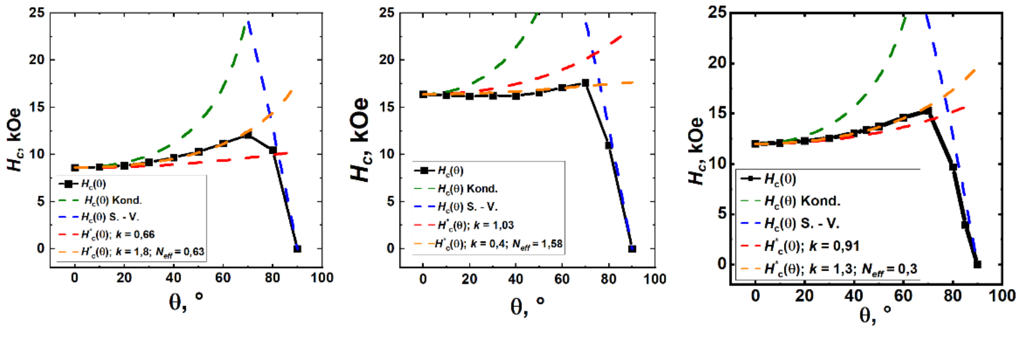

Fig. 1: *The angular dependences of the coercivity for the magnet of grade N35, N35SH, N48.*

This work was financially supported by RSF grant № 21-72-10104.

Abstract ID: 443

MAGNETOSTRICTIVE ALLOYS Fe-Ga: STRUCTURE, PROPERTIES AND RECENT ADVANTAGES IN MANUFACTURING FOR HIGH-FREQUENCY APPLICATIONS

V.A. Milyutin, R. Bures, M. Faberova

Institute of Materials Research, Slovak Academy of Sciences, Watsonova 47, 04001 Košice, SLOVAKIA
E-mail: v.a.milutin@gmail.com

Fe-Ga alloys, in addition to high magnetostriction, have a unique set of useful properties, which makes them promising for use in various electrical applications. Over the years of research, the structure of Fe-Ga alloys has been studied in detail, and ways have been developed to increase magnetostriction through its control, mainly by heat treatment. However, in order to begin to widely use this material in industry, it is still necessary to solve a number of technological problems. One of the main areas of use of magnetostrictive materials are high-frequency devices. For use in such conditions, it is necessary to reduce the continuous volume of material in order to prevent formation of eddy currents and to combat eddy current losses. In the case of magnetostrictive alloys, two possible ways of creating materials for high-frequency applications are being studied in parallel: the creation of laminated packages and polymer-metal composites (Fig. 1). Each of these approaches has its own problems, advantages and disadvantages. Laminated stacks has higher magnetostriction, and appropriate for contact applications.

Disadvantages are the difficulties in creating desired crystallographic texture and technological problems that arise during the rolling of the alloy. Composites are more isotropic; moreover, it is possible to orient particles by application of magnetic field. However, in general, the level of magnetostriction in composites is lower than in sheets; in addition, they suffer from a low allowed operating temperature. In our work, we study the features of the formation of the structure and properties of both Fe-Ga sheets and composites based on it. We are developing new approaches to solve technological problems and improve the functional properties in such objects. In particular, the influence of various modes of deformation and annealing on the structure and crystallographic texture of the samples is studied. In the field of composites, the possibility of using a wide range of both organic and inorganic compounds as a matrix is being investigated, as well as the influence of the conditions for creating composites on their final structure and properties.

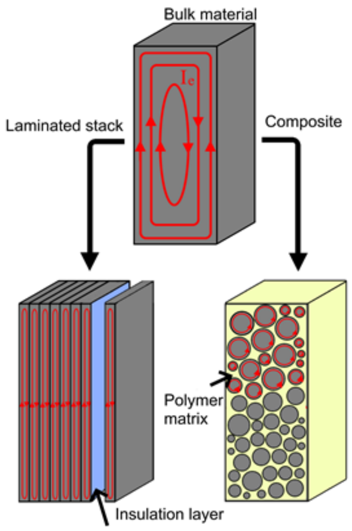

Fig. 1: *Scheme of approaches for eddy current losses minimization in Fe-Ga alloys.*

Acknowledgment

The research was supported by Mobility and Reintegration Programme of the Slovak Academy of Sciences (MoRePro) number 19MRP006.

Superconductivity in Lower Dimensions II-III

10.05.2023 WEDNESDAY

Abstract ID: 186

SUPERCONDUCTING DIODE PHASE IN DIFFUSIVE TOPOLOGICAL HYBRID STRUCTURES

T. Karabassov[1], I.V. Bobkova[1], A.A. Golubov[2], A.S. Vasenko[1,3]

[1]*HSE University, 101000 Moscow, RUSSIA*
[2]*University of Twente, 7500 AE Enschede, THE NETHERLANDS*
[3]*I.E. Tamm Department of Theoretical Physics, P.N. Lebedev Physical Institute, Russian Academy of Sciences, 119991 Moscow, RUSSIA*
E-mail: avasenko@hse.ru

Currently the superconducting diode effect (SDE) has become an active area of research due to its large application potential. Typically, the helical superconducting state is responsible for the SDE. Helical state is widely discussed in materials with two-dimensional (2D) superconductivity, spin-orbit coupling and induced in-plane magnetic field [1]. Here we report the presence of the SDE (helical) phase in the diffusive hybrid structures 2D superconductor/ ferromagnet (S/F) on top of the topological insulator surface (TI), see **Fig. 1**. In such a case nonuniform superconducting state is realized by means of a proximity effect [2]. This proximity induced helical state causes noticeable current nonreciprocity in the system. We provide the calculations for the SDE going beyond linear approximation. Employing the nonlinear quasiclassical approach we investigate the SDE quality factor for a wide range of temperatures and in-plane fields [3]. Moreover, we calculate the upper critical field and demonstrate its dependence on the current direction. Summarizing the results of the calculations we present the phase diagram of the SDE [3]. We also provide comparison between linear and nonlinear approaches.

T.K and A.S.V. acknowledges support from the Basic Research Program of the HSE University.

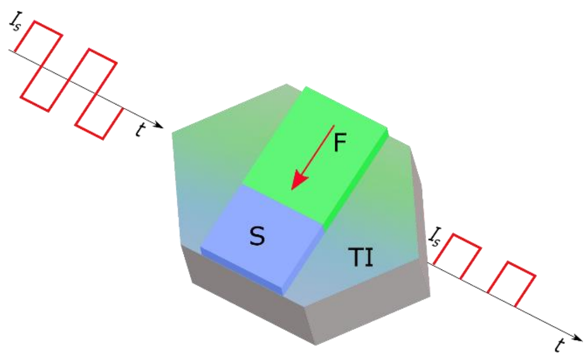

Fig. 1: *Schematic illustration of the superconducting diode effect in S/F/TI hybrid structure.*

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Abstract ID: 224

EFFECT OF ELECTROMAGNETIC COUPLING ON CRITICAL AND TRANSPORT PROPERTIES IN A SYSTEM OF CAPACITIVELY COUPLED SUPERCONDUCTING NANOWIRES

A. Latyshev[1,2], A.G. Semenov[2,3], A.D. Zaikin[2,3]

[1]*Departement de Physique Theorique, Universite de Geneve, CH-1211 Geneve, SWITZERLAND*
[2]*National Research University Higher School of Economics, 101000 Moscow, RUSSIA*
[3]*I.E. Tamm Department of Theoretical Physics, P.N. Lebedev Physical Institute, 119991 Moscow, RUSSIA*
E-mail: Aleksandr.Latyshev@unige.ch

The present work is devoted to study the quasiclassical dynamics of Mooij-Schön plasma modes and superconductor-insulator phase transition (SIT) in a system of two capacitively coupled superconductor nanowires. It was demonstrated that in the presence of inter-wire electromagnetic coupling plasma modes in each of the wires get split into two "new" modes propagating with different velocities across the system [1]. These plasma modes form an effective dissipative quantum environment interacting with electrons inside both wires and causing a number of significant implications for the transport properties of the systems under consideration. We also derived a set of coupled Berezinskii-Kosterlitz-Thouless-like renormalization group equations demonstrating that interaction between quantum phase slips in one of the wires gets modified due to the effect of plasma modes propagating in another wire [2]. The corresponding phase diagram is depicted in **Fig. 1**. As a result, the SIT in each of the wires is controlled not only by its own parameters but also by those of the neighboring wire as well as by mutual capacitance. We argue that superconducting nanowires with properly chosen parameters may turn insulating once they are brought sufficiently close to each other.

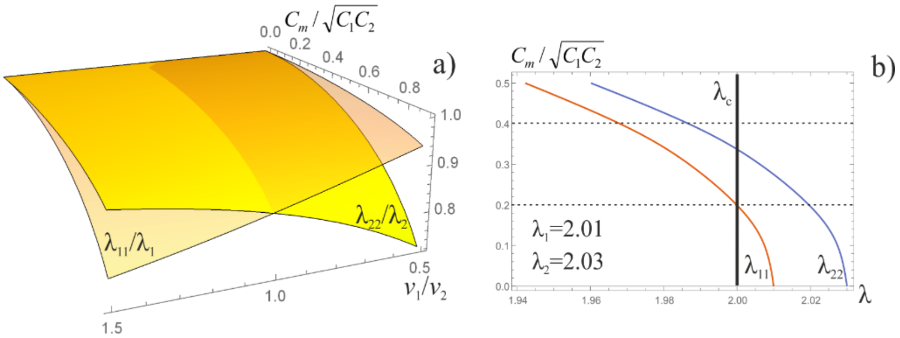

Fig. 1: *Critical surfaces corresponding to SIT at λ_{11} and λ_{22}. b) Phase diagram for two capacitively coupled superconducting nanowires with λ_1= 2.01 and λ_2=2.03.*

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Abstract ID: 375

COHERENT QUANTUM PHASE-SLIP EFFECT IN SUPERCONDUCTING NANO-WIRES

O. V. Astafiev[1,2]

[1]*Skolkovo Institute of Science and Technology, 121205, Moscow, RUSSIA*
[2]*Moscow Institute of Physics and Technology, 141701, Dolgoprudny, RUSSIA*
E-mail: O.Astafiev@skoltech.ru

The Coherent Quantum Phase Slip (CQPS) effect is exactly dual to the Josephson effect, when electric charge is replaced by magnetic flux. The duality has been demonstrated first in the superposition of magnetic flux quanta [1] and later in the interference of two tunnelling amplitudes through nanowires similar to SQUIDs [2]. However, the AC CQPS effect dual to the AC Josephson effect was not clearly achieved in the direct observation of current steps (dual to the Shapiro steps) for more than 30 years since it was theoretically predicted. The difficulty was in the material choice as well as in the design of a peculiar environment – high but compact (ten-micron-size) series inductance – dual to the parallel shunting capacitance in Josephson junctions. We experimentally demonstrate the observation of sharp current steps (inverse Shapiro steps) in NbN nanowires exposed by a microwave radiation (see Fig. 1) [3]. The steps take place at currents $I = 2efn$ (where e is the electron charge, f is the microwave frequency, n is an integer number) and are results of photon assisted magnetic flux tunnelling. The current steps are visible up to 30 GHz, corresponding to nearly 10 nA current. This observation will be a basis for the development of quantum current standards for metrological applications.

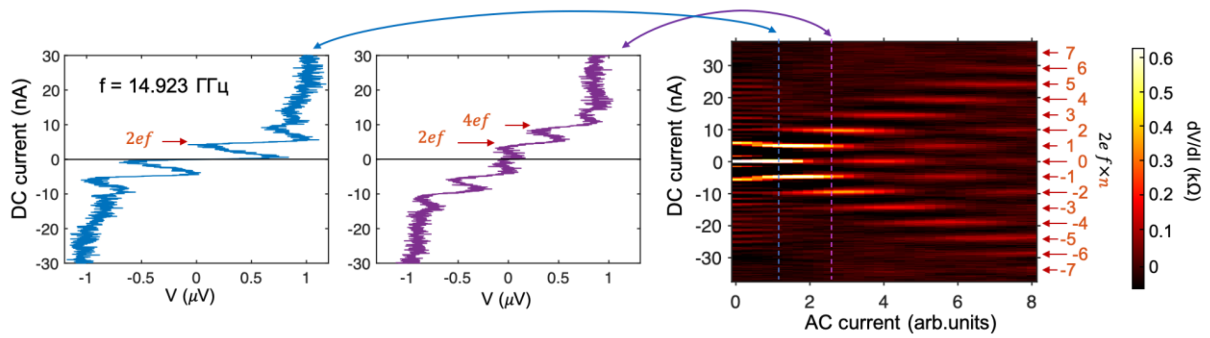

Fig. 1: *DC current steps under microwaves at f = 14.923 GHz and two different AC current amplitudes. Right panel: dV/dI as a function of DC and AC currents. Bessel-like oscillations appear at the positions of the current steps: $I = 2efn$.*

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Abstract ID: 83

DEBYE MECHANISM OF GIANT MICROWAVE ABSORPTION IN SUPERCONDUCTORS

Boris Spivak

University of Washington, USA
E-mail: spivak@uw.edu

I will discuss a mechanism of microwave absorption in conventional and unconventional superconductors which is similar to the Debye absorption mechanism in molecular gases. The contribution of this mechanism to AC conductivity is proportional to the inelastic quasiparticle relaxation time rather than the elastic one and therefore it can be much larger than the conventional one. The Debye contribution to the linear conductivity arises only in the presence of a DC supercurrent in the system and its magnitude depends strongly on the orientation of the microwave field relative to the supercurrent. The Debye contribution to the non-linear conductivity exists even in the absence of the supercurrent. It provides an anomalously low non-linear threshold.

I will also discuss closely related problems of resistance of superconductor-normal metal-superconductor junctions, and the resistance of superconductors in the magnetic flux flow regime.

Abstract ID: 103

THE CONDUCTIVITY OF CARBON NANOTUBE FIBERS AND DEPENDENCE ON DENSIFICATION

Hassaan A. Butt[1], Margarita R. Chetyrkina[1], Mikhail O. Bulavskiy[1], Dmitry V. Krasnikov[1], Fedor S. Fedorov[1], Bjørn Mikladal[2], Sergey D. Shandakov[3], Albert G. Nasibulin[1]

[1] *Laboratory of Nanomaterials, Skolkovo Institute of Science and Technology, 121205 Moscow, RUSSIA*
[2] *Canatu ltd, Tiilenlyöjänkuja 9 A, FI-01720 Vantaa, FINLAND*
[3] *Kemerovo State University, Krasnaya 6, 650000, Kemerovo, RUSSIA*
E-mail: hassaan.butt@skoltech.ru

Carbon nanotube fibers (CNTFs), macro-scale fibers created through the assembly of carbon nanotubes (CNTs), have shown electrical conductivities ranging from ~250 to 5000 S/cm [1,2]. They hold potential for application in low weight wiring [3], specialized sensors and conductors [4,5], and advanced composites [6]. The wet pulling technique [7], a novel, laboratory-scale method of creating high conductivity CNTFs, has been shown to produce conductive fibers with values reaching as high as 1500 S/cm [2]. The special technique also allows a step-wise identification and understanding of the microstructural changes that occur during the fabrication process. Here we identify the changes in microstructure of CNTFs produced from the novel wet pulling technique using two types of samples. One sample type was placed on a substrate immediately after fabrication to hinder densification and the second sample type was standard free-standing fibers used for comparison. The first sample type showed that the fibers densify starting on the outer perimeter, with the hinderance causing a hollow shape paired with large areas of inhomogeneous densification. This causes a variation in the diameter of the fibers along with porosity, reducing density and conductivity. The conductivity ranged between ~10 to 30 S/cm, while density was ~2.0×10^3 µg cm^{-3}. Free standing fibers with conductivity values of ~150 to 750 S/cm showed a more homogenous diameter, reduced internal defects and higher densities of 6.3×10^4 µg cm^{-3}. Further enhancing techniques show an increase to ~4000 S/cm. The work displays that there is a clear relation between the degree of densification and the quality of the fibers produced in terms of electrical conductivity and allows identification of methods for producing CNTFs with high values of electrical conductivity, leading to possible applications in fields where non-metallic high conductivity fibers are required.

Acknowledgements

The authors would like to acknowledge the support for this work through the Council on grants of Russian Federation (No. НШ-1330.2022.1.3)

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Abstract ID: 380

ROBUST SUPERCONDUCTIVITY IN QUASI-ONE-DIMENSIONAL MULTIBAND MATERIALS

A.A. Shanenko[1], T.T. Saraiva[2], A. Vagov[1], A.S. Vasenko[2], L.I. Baturina[3], A. Perali[4]

[1]*Centre for Quantum Metamaterials, HSE University, Moscow, 101000, RUSSIA*
[2]*HSE University, Moscow, 101000, RUSSIA*
[3]*RTU MIREA, Lomonosov Institute of fine chemical technologies, 119454, Moscow, RUSSIA*
[4]*School of Pharmacy, Physics Unit, University of Camerino, I-62032 Camerino, ITALY*
E-mail: ashanenko@hse.ru

Recently it has been demonstrated that the pair-exchange coupling of quasi-one-dimensional (Q1D) bands with conventional higher-dimensional bands in one multiband superconducting material can result in the formation of robust aggregate pair condensate. In particular, it has been found that the Q1D thermal pair fluctuations are suppressed in the presence of deep conventional band(s), where the Fermi level is much larger than the characteristic cut-off energy [1]. Here we report that the impact of the Q1D fluctuations is significantly weakened even in the presence of nearly shallow higher-dimensional band(s) [2,3], which sheds new light on the robust superconducting state observed in the emerging chain-like-structured superconducting materials $A_2Cr_3As_3$ (A = K, Rb, Cs).

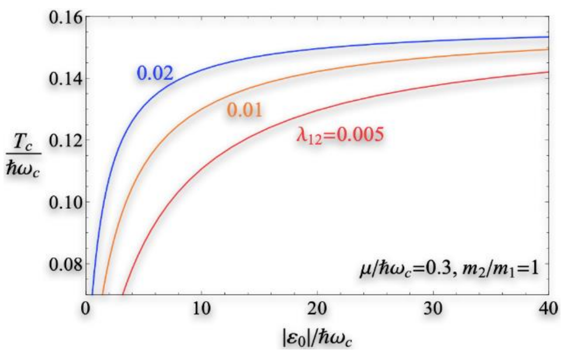

Fig. 1: *The fluctuation-shifted critical temperature T_c of the two-band s-wave superconductor with Q1D and 3D bands versus the 3D band-depth ε_0 (the difference between the lower edges of the shallow Q1D and deeper 3D bands). The results are calculated for the three different values of the dimensionless pair-exchange coupling constant λ_{12} =0.005, 0.01, 0.02. For the intraband couplings we have chosen the typical metallic values λ_{11} =0.18 (deeper 3D band) and λ_{22} =0.2 (shallow Q1D band). The chemical potential measured from the lower edge of the Q1D band is 0.3 (in units of the cutoff energy) and the ratio of the charge-carrier masses is taken as m_2/m_1=1. The mean-field results are recovered when $\varepsilon_0 \to \infty$. One can see that the fluctuations are "screened" for $\varepsilon_0 \to \infty$ as T_c approaches the mean-field result. When $\varepsilon_0 \to 0$, T_c is suppressed as compared to the mean-field one due to the proliferation of thermal pair fluctuations in the 3D band. However, the "screening" of the Q1D fluctuations due to the coupling of the Q1D band to the 3D one is still significant even for nearly shallow regime of the 3D condensate.*

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Poster Sessions

05.05.2023 FRIDAY - 06.05.2023 SATURDAY

Abstract ID: 84

STUDY OF CRITICAL CURRENT DENSITY IN SUPERCONDUCTING TAPES WITH CONFORMAL PINNING ARRAYS

S. Zoveydavi, M. Hosseini

[1]*Department of physics, Shiraz University of Technology, Shiraz, 313-71555, IRAN*
E-mail: pqmehdi@gmail.com

Artificial vortex pinning with different geometries has been attracted by researchers due to the possibility of increasing the critical current [1-6]. Conformal pining arrays that are produced by applying a conformal transformation on square or triangular or other standard lattices have some interesting properties [6]. In this work, the effect of conformal pinning arrays produced by suitable conformal mapping of square lattice on critical current density is investigated. The critical current density versus the number of vortices (or magnetic field) is obtained by solving the equation of motion of vortices in a viscose media using molecular dynamic simulation [6]. By optimization of the parameters of conformal transformation, the optimized parameters could be obtained so that the critical current density has maximum improvement in high magnetic fields.

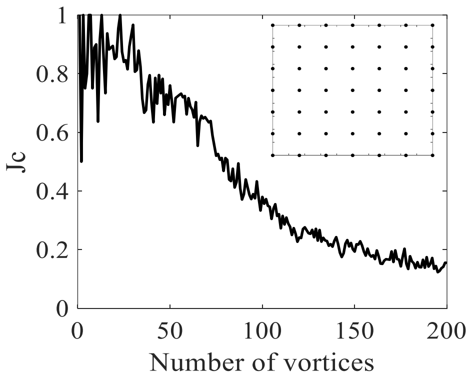

Fig. 1: *Critical current for square lattice.*

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Abstract ID: 106

SUPERSPINTRONICS FOR NEXT-GENERATION INFORMATION AND QUANTUM TECHNOLOGIES

Alex Bregazzi[1], Arthur Coveney[1], Niladri Banerjee[2,1]

[1]*Department of Physics, Loughborough University, Epinal Way, Loughborough LE11 3TU, UNITED KINGDOM*
[2]*Experimental Solid State Physics, Blackett Laboratory, Imperial College London, SW7 2AZ, UNITED KINGDOM*
E-mail: n.banerjee@imperial.ac.uk

In the past decade there have been renewed interests in superconductor/ferromagnet S/F structures following the discovery of spin triplet superconductivity which combines the potential of spintronics and superconductivity enabling a range of phenomena that do not exist in the normal state [1]. In the first part of this talk, I will discuss the development of superconducting spintronics highlighting key experiments and our work in this field [1,2].

In the second part of the talk, I will focus on recent theoretical and experimental progress, including our work, which incorporates spin-orbit coupling in S/F hybrids [3-5]. These advances transform the landscape of superconducting spintronics enabling a range of devices: from active control of magnetic states with superconductivity to devices relevant for quantum technologies.

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Abstract ID: 147

FORCES ON QUANTUM VORTEX IN TYPE II SUPERCONDUCTORS

Yusuke Kato

Department of Basic Science, The University of Tokyo, Tokyo 153-8902, JAPAN
E-mail: yusuke@phys.c.u-tokyo.ac.jp

Dynamics of topological defects play crucial roles in many condensed matters such as, magnets, liquid crystals, superfluids (Helium and cold atoms) and superconductors. Among them, vortex motion in type II superconductors are particularly important in the sense that it is relevant to the magnetization curves, pinning effects, critical currents and stability of two-dimensional systems (Kosterlitz-Thouless transition). However, the character of force on vortices in type II superconductors has not been clearly identified for long terms; One called the driving force on the vortex "the Lorentz force" and another called it "Magnus force". In this presentation, we show theoretically [1,2] that

- The driving force $J \times \varphi_0$ is neither purely magnetic nor purely hydrodynamic for SC with finite λ.
- Only the sum of the hydrodynamic force and magnetic force is physically meaningful as the driving force on vortex.
- Underlying physics are the path-independency of London's fluxoid.
- Our results are valid for dirty SC where conventional and generalized TDGL can be used.

We also dicuss the interplay between quantum vortices with heat/spin currents, which is relevant to spintronics in superconductors.

This work has been done in collaboration with Chun-Kit Chung, Shunki Sugai, and Noriyuki Kurosawa.

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Abstract ID: 168

CHARGE DENSITY ORDER AND TIME-REVERSAL SYMMETRY BREAKING IN CsV_3Sb_5

Rustem Khasanov[1], D. Das[1], R. Guprta[1], C. Mielke III[1], M. Elender[1], Q. Yin[2], Z. Tu[2], C. Gong[2], J. Lei[2], E.T. Ritz[3], R.M. Fernandes[4], T. Birol[3], Z. Guguchia[1], H. Lunetkens[1]

[1] *Laboratory for Muon Spin Spectroscopy, Paul Scherrer Institut, CH-5232 Villigen PSI, SWITZERLAND*
[2] *Department of Physics and Beijing Key Laboratory of Opto-Electronic Functional Materials & Micro-Nano Devices, Renmin University of China, Beijing 100872, CHINA*
[3] *Department of Chemical Engineering and Materials Science, University of Minnesota, Minnesota 55455, USA*
[4] *School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455, USA*
E-mail: rustem.khasanov@psi.ch

The recently discovered vanadium-based kagome metals AV_3Sb_5 (A=K, Rb, Cs) exhibit superconductivity at low-temperatures and charge density wave (CDW) order at high-temperatures [1]. A prominent feature of the charge ordered state in this family is that it breaks time-reversal symmetry (TRSB), which is connected to the underlying topological nature of the band structure [2,3]. In this work, a powerful combination of zero-field and high-field muon-spin rotation/relaxation is used to study the signatures of TRSB of the charge order in CsV_3Sb_5, as well as its anisotropic character. By tracking the temperature evolution of the in-plane and out-of-plane components of the muon-spin polarization, an enhancement of the internal field width sensed by the muon-spin ensemble was observed below $T_{\rm TRSB}=T_{\rm CDW}$ = 95 K. Additional increase of the internal field width, accompanied by a change of the local field direction at the muon site from the *ab*-plane to the *c*-axis, was detected below $T^* \sim 30$ K. Remarkably, this two-step feature becomes well pronounced when a magnetic field of 8 T is applied along the crystallographic *c*-axis, thus indicating a field-induced enhancement of the electronic response at the CDW transition (see Fig.1).

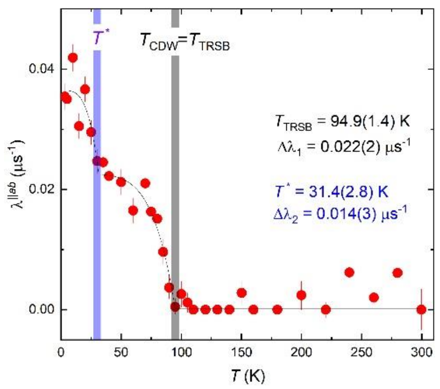

Fig. 1: *Temperature evolution of the λ obtained in transverse field muon-spin rotation/relaxation experiments. An external magnetic field B_{ext} = 8 T was applied perpendicular to the initial muon-spin polarization and parallel to the crystallographic c axis of the CsV_3Sb_5 sample.*

Our results point to a TRSB in CsV_3Sb_5 by charge order with an onset of 95 K, followed by an enhanced electronic response below ~30 K [4]. The observed two-step transition is discussed within the framework of different charge-order instabilities, which, in accordance with density functional theory calculations, are nearly degenerate in energy.

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Abstract ID: 172

A UNIFIED DESCRIPTION OF SUPERCONDUCTIVITY: ELECTRON DENSITY DYNAMIC'S RESPONSE TO PHONONS AT THE BRILLOUIN ZONE BOUNDARY DRIVEN A REAL SPACE ELECTRON-HOLE PAIRING CHARACTERIZED BY CPT SYMMETRY

T. Guerfi [1,2]

[1]Department of Physics, Faculty of Sciences, M'Hamed Bougara University, Boumerdes, ALGERIA
[2]Unité de développement, Matériaux, Procédés et Environnement, University M'Hamed Bougara Boumerdes, ALGERIA
E-mail: tarek.guerfi@gmail.com

It is argued that electron density dynamic's response to longitudinal acoustical phonon modes at the Brillouin zone boundary is the key factor in the superconducting mechanism in MgB_2 compound as well as in all superconducting compounds leading to a real space electron-hole pairing characterized by CPT symmetry (Charge, Parity and Time reversal symmetries) that enables a unified treatment of superconductivity phenomenon. By means of first principle calculation, the electron density difference is determined by subtracting the electron density of the crystal distorted by longitudinal acoustical frozen-phonon mode at the Brillouin zone boundary from that of the perfect crystal (undistorted). The origin of this electron density response to this kind of distortion, that leads to a real space electron-hole pairing characterized by CPT symmetry, is discussed in terms of local polarizabilities and delocalized transfer of charge caused by phonon-distortion driven dynamical change of orbital hybridizations.

This approach also provides clear and quick guidelines in the search for new superconductors.

Abstract ID: 216

A NEW SUPERCONDUCTING INDUCTOR TOPOLOGY FOR A SYNCHRONOUS MACHINE

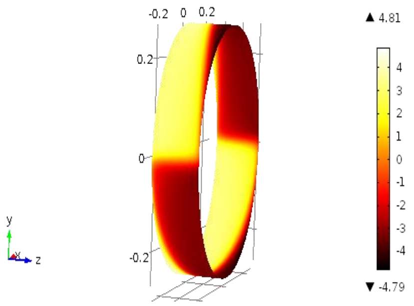
M. Kelouaz[1], K. Berger[2], J. Lévêque[2]

[1]*University of Science and Technology Houari Boumediene, Dept. of electrical engineering LSEI laboratory, 16111, Algiers, ALGERIA*

[2]*Université de Lorraine, GREEN, F-54000 Nancy, FRANCE*

E-mail: kelouaz_moussa@yahoo.fr

Superconducting materials, whether in wire or bulk form, have many applications in electrical engineering. Several theoretical and experimental studies have shown the suitability of these materials to be used in superconducting inductors [1-4], we propose a new structure of a radial flux superconducting inductor in a four-pole configuration. This topology is clearly unconventional compared to the other inductors of superconducting machines. The difference lies in the inductors built on the basis of two forms of superconductors, the wire form is used for the excitation coils creating an axial magnetic flux and the bulk form to modulate and redirect the axial magnetic flux created by the coils to the radial direction. A 3D analysis of the magnetic field is performed by a 3D finite element calculation to study the performance of the proposed inductor. Fig. 1 represents the distribution of the radial flux density on the active surface created by the proposed new topology, while Fig. 2 shows the calculated magnetic flux density in terms of spatial distribution and intensity compared with those of the two-pole version (p = 1) realized and tested in [4]. The proposed new topology will enrich the number of models of superconducting machines with special topologies and may be suitable for special applications in a near future.



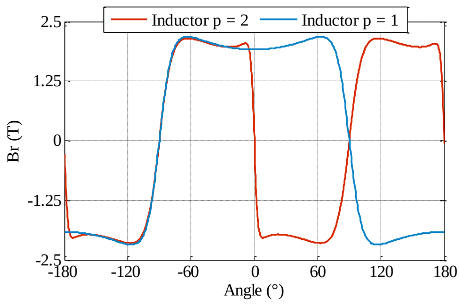


Fig. 1: *Radial flux density on the active surface.* **Fig. 2:** *Comparison of the radial flux densities.*

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Abstract ID: 245

ELECTRICAL STUDY OF PVDF/SiO_2 COMPOSITE FOR FLEXIBLE ELECTRONICS APPLICATION

Fizah Dilshad[1], Sehrish Gul-e-Rana[2], M. Anis-ur-Rehman[3]

Applied Thermal Physics Laboratory (ATPL) Department of Physics, COMSATS University Islamabad, Islamabad 44000 PAKISTAN

E-mail: sehrishgul03435453195@gmail.com

In the recent year's polymer composite are used in variety of application from aerospace industry to microelectronic applications. The polymer is used because of their good electrical properties, and they are flexible in nature. PVDF is a fluoro polmer having good piezoelectrical properties [1]. PVDF/$(SiO_2)_x$ (x=0.03,0.06, 0.12) composite are prepared by solution casting method. Fourier transform Infrared Spectroscopy (FTIR) confirms the presence of functional group in the composite. For morphological Analysis of polymer membrane SEM is used which shows the silica are dispersed in polymer matrix. The dielectric properties are studied by using Wayne Kerr precision analyzer in the range of 1kHz-3MHz. It is observed from the graph that Figure 1 show high dielectric constant value of $P_{0.97}S_{0.03}$. From the capacitance response of composite it is observed that $P_{0.88}S_{0.12}$ have high sensitivity at low pressure range. These composite are prepared so that it can be used in flexible electronic applications such as pressure sensors.

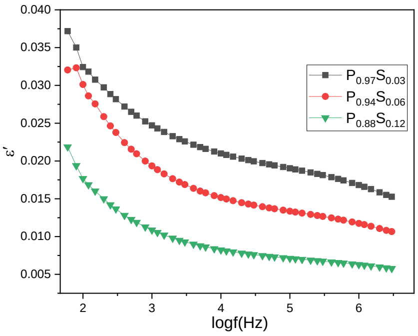

Fig.1: *Dielectric constant (ε′) versus frequency of composite $(SiO_2)_x$ (x=0.03, 0.06, 0.12).*

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Abstract ID: 249

LOCAL AND GLOBAL SUPERCONDUCTIVITY IN DISORDERED MATERIALS

V.D. Neverov[1,2], A.E. Lukyanov[1,2], A.V. Krasavin[1,2], A. Vagov[1,3], M.D. Croitoru[1,4]

[1]*HSE University, 101000, Moscow, RUSSIAN FEDERATION*
[2]*National Research Nuclear University MEPhI, Moscow, RUSSIAN FEDERATION*
[3]*University of Bayreuth, 95447, Bayreuth, GERMANY*
[4]*Universidade Federal de Pernambuco, 50670-901, Recife-PE, BRAZIL*
E-mail: slavesta10@gmail.com

A microscopic model of a superconducting film in the presence of a correlated disorder potential is studied at finite temperatures. Significant qualitative differences between the characteristics of superconductivity on the local and global scales are found. These differences are clearly manifested in the opposite dependence of the order parameter and the superconducting current on the characteristics of the disorder potential, which can be used to optimize the characteristics of superconductivity by adjusting the amplitude and length of the disorder correlations.

All characteristics of the superconducting state are found from the solution of the Bogolyubov – de Gennes mean field equations [1] with the use of the correlated disorder model, in which the spatial correlations of the disorder potential in the reciprocal space obey the power law $S_V(q) \sim q^{-\alpha}$, where α is the *degree of correlation*.

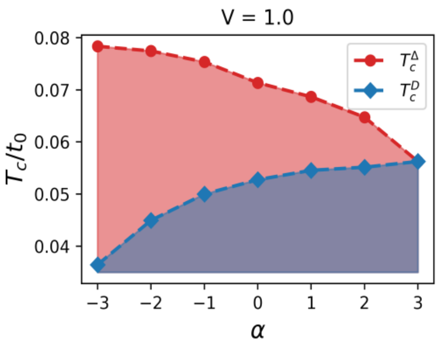

Fig. 1: *Local and global critical temperatures as functions of* α.

The ability of a material to have a supercurrent can be characterized by the superfluid stiffness D_s. Unlike the parameter Δ, which characterizes the local absolute values of the superconducting gap, and which corresponds to the critical temperature T_c^Δ determining the disappearance of this gap, D_s is a global value showing whether the material can withstand the supercurrent flowing through the entire sample. Its disappearance determines another critical temperature of the superconductor, T_c^D. In pure and weakly disordered materials, both temperatures coincide. On the contrary, in highly disordered systems, the presence of a nonzero gap and condensate at some local points of the sample does not mean that there is a global supercurrent in the system, and therefore T_c^Δ and T_c^D can differ, and quite significantly.

The main result of the work is shown in Fig. 1. The dependence of T_c^Δ and T_c^D and α, which determine the disorder potential, is completely opposite. There is also a significant difference between the two critical temperatures when there are no correlations in the disorder potential (α=0). In the limit of large positive α, the two critical temperatures become close and eventually coincide at α≃3.

The work was supported by the HSE University Basic Research Program and the MEPhI Program Priority 2030.

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Abstract ID: 252

TERAHERTZ CONDUCTIVITY OF $YBa_2Cu_3O_{7-\delta}$ THIN FILMS OF VARIOUS DOPING

M. Šindler[1], C. Kadlec[1], Wen-Yen Tzeng[2], Ting-Yu Hsu[3], Jiunn-Yuan Lin[3], Chih-Wei Luo[2,3]

[1]Institute of Physics, Academy of Sciences, Cukrovarnická 112, 16253 Prague 6, CZECH REPUBLIC
[2]Department of Electrophysics, National Yang Ming Chiao Tung University, Hsinchu 30010, TAIWAN
[3]Institute of Physics, National Yang Ming Chiao Tung University, Hsinchu 30010, TAIWAN
E-mail: sindler@fzu.cz

We measured the real and imaginary parts of the conductivity in $YBa_2Cu_3O_{7-\delta}$ thin films of various doping (optimally doped, underdoped and overdoped samples) using time domain terahertz spectroscopy between 5 and 220 K. We observed a peak in the temperature dependence of the real part σ_1 of the conductivity similar to the coherence peak in classical s-wave superconductors. The imaginary part σ_2, dominated by the$1/\omega$ term, allows us to determine their penetration depths and their temperature dependence.

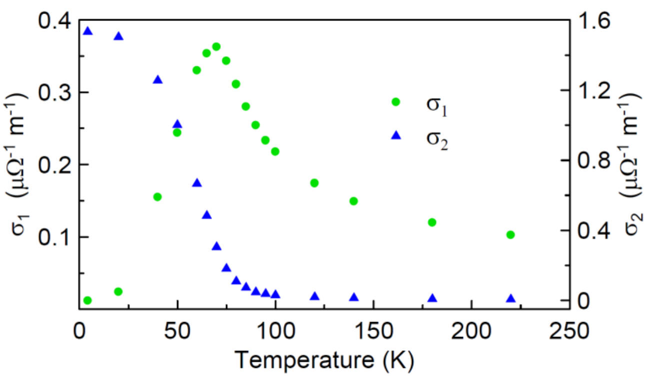

Fig. 1: *Real (green circles) and imaginary (blue triangles) parts of conductivity of underdoped $YBa_2Cu_3O_{7-\delta}$ sample (T_c=77 K) at 0.43 THz.*

Abstract ID: 261

PROXIMITY EFFECT IN S/AF BILAYERS AND AF/S/AF SPIN VALVES

V.M. Gordeeva[1], G.A. Bobkov[1], I.V. Bobkova[1,2], A.M. Bobkov[1]

[1]*Moscow Institute of Physics and Technology, Dolgoprudny, 141700 RUSSIA*
[2]*National Research University Higher School of Economics, Moscow, 101000 RUSSIA*
E-mail: gordeeva.vm@phystech.edu

Superconducting devices based on proximity effect in superconductor/magnetic material heterostructures are important objects for superconducting spintronics. While proximity effect in structures with superconductor/ferromagnet interfaces is well-studied, our present work proposes theoretical description of antiferromagnet/superconductor/antiferromagnet spin valves and superconductor/antiferromagnet bilayers and unveils the important role of the recently reported Néel triplet correlations [1] in the proximity physics of these heterostructures.

In AF/S/AF case we consider a heterostructure with fully compensated interfaces. We evaluate the dependence of superconducting critical temperature as a function of angle between Néel vectors of the antiferromagnets, which is caused by angle-dependent Néel triplet correlations induced in the superconductor. In particular, we demonstrate that the absolute spin-valve effect can be realized. For S/AF bilayer system we report the oscillations of the critical temperature as a function of the thickness of the antiferromagnetic layer, which are caused by the presence of the proximity-induced Néel triplet correlations in the antiferromagnetic layer.

The calculations are performed numerically by solving Bogolubov – de Gennes equations and analytically in the framework of the quasiclassical Green's functions approach, which has been generalized recently for treating S/AF hybrids with atomically oscillating staggered AF magnetic order [1]. The effects are considered in clean case as well as in the presence of impurities.

The work was supported by RSF project № 22-22-00522.

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Abstract ID: 263

PROXIMITY EFFECT IN SUPERCONDUCTOR/ANTIFERROMAGNET HYBRIDS: NEEL TRIPLETS AND IMPURITY SUPPRESSION OF SUPERCONDUCTIVITY

G.A. Bobkov[1], I.V. Bobkova[1,2], A.M. Bobkov[1]

[1]*Moscow Institute of Physics and Technology, Dolgoprudny, 141700 RUSSIA*
[2]*National Research University Higher School of Economics, Moscow, 101000 RUSSIA*
E-mail: bobkov.ga@phystech.edu

By now two possible physical mechanisms of superconductivity suppression at superconductor/antiferromagnet (S/AF) interfaces, which work even for interfaces with compensated antiferromagnets, were reported. One of them suggests that the Neel order of the AF induces rapidly oscillating spin-triplet correlations in the S layer [1]. They are called Neel triplets and they suppress singlet superconductivity. The Neel triplets are formed due to interband pairing. Nonmagnetic disorder destroys this interband pairing. As a result, the critical temperature of the S/AF bilayer grows with impurity strength. The second mechanism, on the contrary, suggests that nonmagnetic impurity scattering suppresses superconductivity in S/AF hybrids [2]. The predictions were made in the framework of two different quasiclassical approaches. Here we suggest the unified theory of the proximity effect in thin-film S/AF structures, which incorporates the both pictures as limiting cases and study the proximity effect at S/AF interfaces for arbitrary impurity strength, chemical potential and the value of the Neel exchange field.

The work was supported by RSF project № 22-22-00522

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Abstract ID: 271

PREREQUISITES OF PAIR DENSITY WAVE IN A DOPED FeSe MONOLAYER

A.E. Lukyanov[1,2], Ya.V. Zhumagulov[3], V.D. Neverov[1,2], I.A. Kovalev[1,2], A.V. Krasavin[1,2], D. Kochan[3]

[1]*HSE University, 101000, Moscow, RUSSIAN FEDERATION*
[2]*National Research Nuclear University MEPhI, Moscow, RUSSIAN FEDERATION*
[3]*Institute for Theoretical Physics, University of Regensburg, Regensburg 93040, GERMANY*
E-mail: lukyanov9567@gmail.com

In this work, we study the response to the pair density wave (PDW) phase in systems based on a FeSe-monolayer by solving the linearized Eliashberg equation of the two-orbital Kanamori model [1] with the use of fluctuation-exchange approximation [2]. The main results show a strong response to the formation of the PDW phase at the interface between the superconducting phase (SC) and the one-dimensional spin density wave (SDW) phase.

The first mention of the possible formation of PDW is attributed to the works of Larkin and Ovchinnikov, as well as Ferrel and Fulde [3, 4], who studied the superconducting state in which Cooper pairs were formed by pairing of electrons with a nonzero angular momentum in the presence of a strong external magnetic field. A characteristic feature of PDW is the superconductivity order parameter oscillating in space which distinguishes this phase from the ordinary superconducting state. PDW also occurs in strongly correlated superconductors based on cuprates, even without an external magnetic field [5].

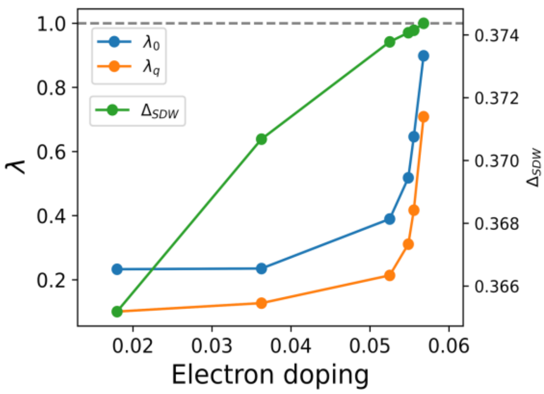

Fig.1: *Dependence of the principal eigenvalue for $q = (0, 0)$ (blue line), $q = (0, \pi)$ (orange line), and SDW gap amplitude (green line) on electron doping.*

Although in our results, the PDW phase is not dominating concerning SC in the system based on FeSe monolayer (Fig. 1), it has a strong response, a prerequisite for its eventual formation under external influence. The presence of the one-dimensional SDW can be a possible precursor for the appearance of PDW in systems based on a FeSe monolayer.

The work was supported by the HSE University Basic Research Program and by the Ministry of Science and Higher Education of the Russian Federation (state task project No. FSWU-2023-0031).

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Abstract ID: 273

HTSC HELICAL ARMATURE WINDINGS FOR CRYOGENIC ALTERNATORS

L. Chubraeva, S. Timofeyev

Institute of Electrophysics and Electric Power Engineering of Russian Academy of Sciences, 191186, Saint-Petersburg, RUSSIA

E-mail: sergio121@yandex.ru

The progress in high-temperature superconductor (HTSC) tape manufacturing and the increase of its bending radius permits to return to the armatures with helical winding geometry, developed in the end of 80-s and 90-s of the previous century. On the stage of low temperature superconductivity there were manufactured and tested several alternators with helical armature windings (Japan, Russia, USA) [1]. The main advantages of helical windings are: decreased amount of the wire and as a result decreased loss value, highly sinusoidal output emf form independent of the main flux curve form in the air-gap.

Helical winding represents a distributed wave winding without the straight portion. One layer of the armature bars is positioned along the left-hand helix and the other – along the right-hand helix (Fig. 1, a). In case of copper winding bars electrical connections were performed for each bar. It is impossible to have numerous electrical connections in HTSC windings.

Fig: 1: *Three-phase 4-pole alternator helical armature winding: a) one turn, b) full lay out of the winding.*

To minimize the amount of electrical connections we have developed a technological process of continuous laying out of helical winding along a part of a phase equal to $1/p$, where p – number of pole pairs (Fig. 1, b). It was applied successfully to the manufacturing of a cryogenic high-purity aluminum armature winding which is very sensitive to bending. The similar process may be proposed for HTSC armature windings. The larger is the D/l_a ratio (D - average armature winding diameter), the less are the problems of the continuous winding. The winding coefficient of helical winding equals:

$$k_h = \frac{\sin\frac{\pi}{2}\frac{s}{\tau}\sin\nu\frac{\pi}{2}\frac{l_a}{l_h}}{\left(\nu\frac{\pi}{2}\right)^2\frac{\pi}{2}\frac{s}{\tau}\frac{l_a}{l_h}},$$

where s – length of the arc, occupied by one phase zone; τ – pole pitch, l_a – active length, l_h – full helical winding axial length.

For the 1-st harmonic and $l_a = l_h$ the coefficient k_h equals 0.608. Therefore the active length is to be increased, but the total amount of HTSC in the field and armature windings is decreased. If the rotor of electrical machine contains highly coercive permanent magnets, their volume increases as well, but the gain in HTSC volume remains.

Acknowledgement: The researches are being supported by the Ministry of Education and Science of the Russian Federation.

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Abstract ID: 277

CHARACTERISTICS OF THE DC CIRCUIT BREAKER ACCORDING TO SUPERCONDUCTING RESISTANCE AND CRITICAL CURRENT

J.S. Jeong, J.H. Kim, G.W. Kim, H.S. Choi

Chosun University, Dept. of Electrical Engineering, 61452, Gwangju, REPUBLIC OF KOREA
E-mail: wlthfqkqh@gmail.com

High Voltage Direct Current (HVDC) system does not naturally generate zero current, so the DC circuit breaker is essential unlike the AC system. This paper proposed the superconducting DC circuit breaker to solve this problem. The superconducting DC circuit breaker consists of a resistive superconducting current limiting module and a resonant DC interrupting module. The resistive superconducting current limiting module can theoretically limit the fault current by generating resistance within about 2 ms. The resonant DC interrupting module can stably interrupt by generating an artificial zero point through the LC divergence oscillation circuit. However, the resonant DC interrupting module has a disadvantage in that the interruption time is slow compared to various modules. In this paper, we tried to shorten the interruption time of the resonant DC interrupting module by limiting the fault current through the superconducting current limiting module. We compared and analyzed the power burden of the superconducting current limiting module and the resonant DC interrupting module according to the resistance and critical current of the superconducting current limiting module.

Abstract ID: 278

COMPARISON OF CHARACTERISTICS ACCORDING TO DIFFERENT SUBSTRATE LAYERS IN MULTI-FILAR MEANDER TYPE R-SFCL

G.W. Kim, J.H. Kim, J.S. Jeong, H.S Choi

Chosun University, Dept. of Electrical Engineering, 61452, Gwangju, REPUBLIC OF KOREA
E-mail: kgw1119@nate.com

Currently, multi-terminal HVDC and microgrids connected to renewable energy are in the spotlight all over the world. Accordingly, the protection method of the DC system is a very important topology. Many loads and sources are connected in multi-terminal and microgrid systems, so when a fault occurs, the fault current spreads to the connected equipment and adversely affects them. Resistive superconducting fault current limiters represent one of the most promising types of current limiters and have great application potential. Generally, resistive SFCLs are non-inductive, and they can be found in diverse shapes meander, multifilar pancakes, spiral or bars, and coils. This research team proposed a multi-filar meander type. The multi-filar meander type has a structure in which superconducting tapes are wound around a plurality of cylindrical insulators. However, if the superconducting tape has an abrupt bending radius, the critical current may decrease. This can be alleviated depending on the material of the substrate layer [1]. In this study, the GdBCO superconducting tape was applied to the multi-filar meander method. In addition, a comparative analysis according to the substrate layer material was performed. Hastelloy or stainless steel was used for the substrate layer. As a result, the Hastelloy substrate is more advantageous when a frequent bending radius of the superconducting tape is required.

Fig. 1: *Multi-filar meander type R-SFCL.*

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Abstract ID: 288

PROBING QUANTUM MATERIALS BY COMBINING SQUID-ON-TIP IMAGING WITH SCANNING TUNNELING SPECTROSCOPY

M. Rog, M.P. Allan, K. Lahabi

Leiden Institute of Physics, Niels Bohrweg 2, 2333CA, Leiden, NETHERLANDS
E-mail: rog@physics.leidenuniv.nl

Describing the physics of strongly correlated quantum systems requires a deep understanding of the interplay between dissipation, magnetism and electronic structure. Probing their correlations is a major challenge, as most forms of microscopy focus on imaging only one parameter at a time. We have been developing a hybrid microscope, combining SQUID-on-tip with STS, to simultaneously image magnetic field, temperature and density of states.

SQUID-on-tip microscopy is a powerful type of scanning probe imaging where a nanostructured superconducting magnetometer is directly scanned over the surface of a sample. Both magnetic and thermal images can be extracted from the acquired data. This allows for mapping transport, dissipation and magnetism. SQUID-based microscopy has been successfully applied to imaging vortex matter, quantum phase fluctuations and electron hydrodynamics. On the other hand, STS is a well-established technique for measuring the local density of states. It is a common tool for the study of unconventional superconductors and other forms of quantum matter. Combining SQUID-on-tip with STS will allow for versatile studies of quantum phase transitions, time-reversal symmetry breaking in superconductors, and exotic transport phenomena.

We have succeeded in fabricating SQUIDs at the apex of a commercial silicon tip using focused-ion-beam milling. Using this approach, we have fabricated on-tip sensors with excellent magnetic and thermal sensitivity, and with a 120 nm device diameter. As the device diameter is the limiting factor in the magnetic resolution, these probes are promising for high-resolution hybrid imaging.

On this poster, we present our efforts towards the practical realization of SOT-STS microscopy.

Abstract ID: 289

SPIN-TORQUE FERROMAGNETIC RESONANCE AS A WAY TO PROBE THE EFFECTS OF LOCAL ELECTROMIGRATION ON PERMALLOY-TANTALUM BILAYERS

N. Lejeune, E. Fourneau, S.K. Sing, A.V. Silhanek

Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, Université de Liège, B-4000 Sart Tilman, BELGIUM

E-mail: nlejeune@uliege.be

The manipulation of magnetization through electric current is a significant area of research in modern spintronics, which involves understanding the interplay between conventional electronics and the growing field of magnonics [1]. Spin currents, generated from the conversion of charge to spin through spin Hall effects (SHE) in normal metals with strong spin-orbit coupling, can apply torques to the oscillating magnetization, either in the precession or damping direction, in ferromagnetic (FM) layers. This torque can modify the effective magnetic damping of the FM layer or trigger the resonance. SHE-based spin-torque ferromagnetic resonance (ST-FMR) technique has been used to evaluate the main spin properties of normal metal/ferromagnetic (NM/FM) bilayer systems. It has also been shown that magnetic auto-oscillations can be driven by injecting pure DC spin currents, eliminating the need for radiofrequency excitation. However, generating precession modes through spin Hall effects requires high current densities ($\sim 10^8 - 10^9$A/cm² [2]), leading to substantial Joule heating and possibly triggering electromigration. This can cause various material phase changes, such as inter- and intra-layer diffusion, grain growth, alloying, and oxidation. Our study investigates the impact of localized high-density current pulses [3] on Py/Ta heterojunctions patterned for ST-FMR with various nanoconstriction geometries (see Fig. 1 for example). The results show a decrease in the Gilbert damping and out-of-plane anisotropy whereas an increase in magnetization in the Py layer is observed. The Ta layer exhibits an improved efficiency in spin-charge conversion, as characterized by its effective spin Hall angle, and a reduction in stack resistance, reducing losses in the sample. These effects are observed in the final electromigration cycles before a permanent damage is produced to the sample, emphasizing the importance of controlling the electromigration procedure in bilayer systems for future applications implying spin-Hall nano-oscillators.

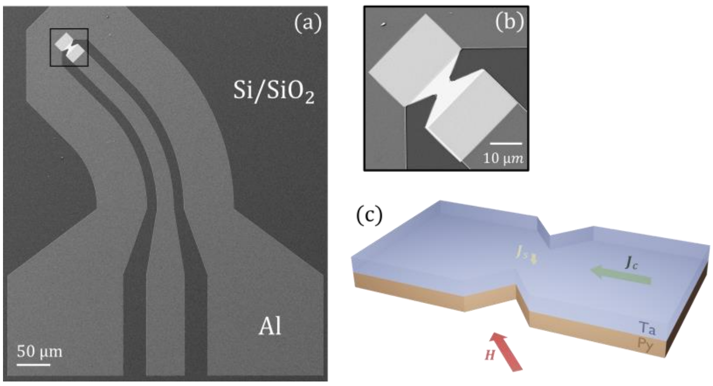

Fig. 1: *(a) SEM image of the experimental STFMR device connected to a coplanar waveguide. (b) Closer view on the junction and (c) direction of the magnetic field as well as both spin and charge currents.*

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Abstract ID: 291

NOVEL IRON-BASED SUPERCONDUCTOR $Ca_{0.5}Sm_{0.5}FeAsF$

V.A. Vlasenko1, L.F. Kulikova2, K.S. Pervakov[1]

[1] *V.L. Ginzburg Centre for High-Temperature Superconductivity and Quantum Materials, P.N. Lebedev Physical Institute of the Russian Academy of Sciences (LPI RAS), 53, Leninsky Ave., 119991 Moscow, RUSSIA*
[2] *L.F. Vereshchagin Institute for High Pressure Physics, Russian Academy of Sciences, Troitsk, 108840 Moscow, RUSSIA*

E-mail: pervakovks@lebedev.ru

Here we report on a novel superconducting compound $Ca_{0.5}Sm_{0.5}FeAsF$ with a superconducting transition temperature T_c=54.2 K, which was synthesized for the first time using a combined method of mechanical activation and synthesis under high pressure [1].

In this study, to increase the material homogeneity for producing $Ca_{0.5}Sm_{0.5}FeAsF$ (CaSm-1111), we used the mechanical activation method (high-energy milling) similar to one we used in previous works [2]. The basic idea of the method consists in combined grinding of primary components and their activation by high-energy ball impacts within the grinding volume, which causes mechanical alloying of components and the formation of an amorphous phase before the heating stage.

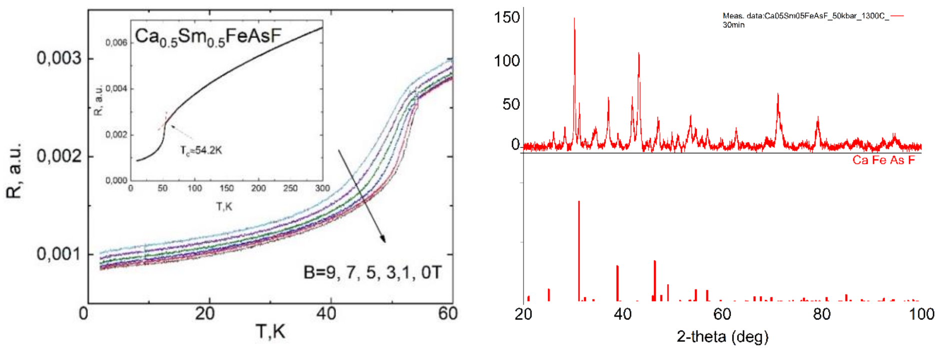

Fig. 1: *Resistivity measurements (left panel) and XRD pattern (right panel) [1].*

CaSm-1111was synthesized from CaF_2 and preliminary synthesized precursors Fe_2As, SmAs which were mixed in the ratio CaF_2:SmAs:Fe_2As=1:1:1 and loaded into a milling jar for subsequent treatment. Then treated material was pressed into 5-mm-diameter pellets and annealed under high pressure. High-pressure synthesis was performed using a Conac pressure equipment in boron nitride crucibles and annealed at 1350°C for 30 min at a pressure of 50 kbar. Then the temperature was slowly decreased to 1200°C for 60 min, and a heater was turned off. The treated pellets were studied using a Rigaku MiniFlex 600 diffractometer and a JEOL-7001F electron microscope with an INCA X-Act elemental analysis attachment. The diffraction pattern (XRD) of samples after annealing under high pressure is shown in Fig. 1, which confirms the presence of reflections corresponding to the Ca-1111 phase. At the same time, the phase content estimated from the diffraction pattern is 3–5%, which indicates the difficult formation of such compounds even using synthesis under high pressure.

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Abstract ID: 298

SUPERCONDUCTING PHASE DIAGRAM IN 1144 SYSTEM WITH MAGNETIC ATOMS

V.A. Vlasenko, A. Yu. Degtyarenko, A.V. Sadakov, O.A. Sobolevskiy, K.S. Pervakov

V.L. Ginzburg Centre for High-Temperature Superconductivity and Quantum Materials, P.N. Lebedev Physical Institute of the Russian Academy of Sciences (LPI RAS), 53, Leninsky Ave., 119991 Moscow, RUSSIA

E-mail: vlasenkovlad@gmail.com

We successfully synthesized $EuRbFe_4As_4$ single crystals by a "self-flux" technique and systematic AC susceptibility and magnetic moment M(H, T) measurements were performed. It was found that the position of the maximum on the real part of the AC susceptibility was frequency independent which points to long-range magnetic interactions [1]. The presence of the χ'' component is evidence of the non-AFM ordering of the Eu^{2+} atoms. This fact consistent with helicoidal magnetic structure of this system. From the AC susceptibility we also found irreversibility line (H_{irr}) using lnf = 0 (1 Hz) criteria. The magnetization measurements of H_{c1} were performed using MPMS squid magnetometer [2]. The H_{c1} curve exhibits a rather sharp minimum at T~15K, similar to ref. [3], which may be the evidence of changing in Cooper pairs density.

From the M(H, T) data we evaluate J_c(T,H) curves using the Bean's critical state model [4] which did not show any significant changes before and after magnetic transition similar to ones for the 122 system without a magnetic transition [5]. The J_c versus μ_0H plot in a log-log scale at different temperatures using the scaling law provide us possibility to estimate H_{irr}(T) values. Summarizing the experimental data, we built the magnetic phase diagram of the $EuRbFe_4As_4$ superconductors, and the lower critical field, upper critical field, irreversibility, and Eu^{2+} magnetic ordering lines were found.

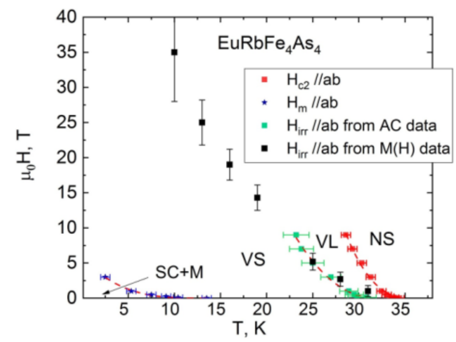

Fig. 1: *Vortex phase diagram of the $EuRbFe_4As_4$ single crystal [3].*

This research was funded by the RSF 21-12-00394. The work was performed using equipment of the Lebedev Physical Institute's Shared Facility Center.

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Abstract ID: 301

RESONANCE CURRENT ANALYSIS OF SUPERCONDUCTING LC DIVERGENT OSCILLATORY DC CIRCUIT BREAKER

Ji-hye Kim, Hyo-sang Choi

Chosun University, Dept. of Electrical Engineering, 61453, Gwangju, SOUTH KOREA
E-mail: tkdzho06@naver.com

For grid connection of renewable energy sources, it is important to stably interrupt DC accidents. In this paper, a DC circuit breaker based on a resistive superconducting fault current limiter(SFCL) is proposed to reduce the fault current and improve the transient operation of the system. The proposed DC circuit breaker is a hybrid circuit breaker composed of resistance type SFCL and LC divergence oscillation DC interrupting module. SFCL is quenched by the fault current, generating resistance and affecting the operating characteristics of the DC interrupting module. Therefore, the effect of the resistance type SFCL on the LC divergent oscillation DC interrupting module was analyzed. Based on the interruption time, the resonance current of the LC divergence oscillation circuit, the initial amplitude of the resonance current, and the number of current reversals were analyzed. For that, the operating characteristics of the existing interrupting system without SFCL and the proposed DC circuit breaker were compared. A VSC-HVDC system was modeled using PSCAD/EMTDC and the proposed DC breaker was applied. As a result, it was confirmed that the more the fault current is reduced, the more the number of current reversals increases and the amplitude of the current increases, shortening the interrupting time.

Abstract ID: 313

DIRECT TUNNELING PROBE OF THE SUPERCONDUCTING ORDER PARAMETER IN $EuCsFe_4As_4$

A. Yu. Degtyarenko[1], S.A. Kuzmichev[2,1], S. Yu. Gavrilkin[1], K.S. Pervakov[1], V.A. Vlasenko[1], T.E. Kuzmicheva[1]

[1] *V.L. Ginzburg Centre for High-Temperature Superconductivity and Quantum Materials P.N. Lebedev Physical Institute of the Russian Academy of Sciences (LPI RAS), 53, Leninsky Ave., 119991 Moscow, RUSSIA*
[2]*Faculty of Physics, Moscow State University, 1, Leninskiye Gory 119234, Moscow RUSSIA*
E-mail: degtyarenkoayu@lebedev.ru

$EuCsFe_4As_4$ compound related to a so-called 1144 family shows a set of unique properties differing from other Fe-based superconductors (SC) [1]. $EuCsFe_4As_4$ superconducts in the stoichiometric state with maximum critical temperature $T_c \approx 37$ K, whereas a magnetic ordering in the Eu planes develops below T_c at $T_m \approx 15$ K. The Fermi level is crossed by about 10 bands forming hole barrels near the Γ point and electron barrels near the M point of the first Brillouin zone, where several SC condensates develop below T_c. In order to directly determine the structure of the SC order parameter, we used incoherent multiple Andreev reflection effect (IMARE) spectroscopy. Andreev nanojunctions of the SC–thin normal metal–SC (SnS) type were formed at T = 4.2 K by a planar "break-junction" technique [2]. Generally, IMARE causes an excess current at I(V) curve of SnS junction at any bias voltage *eV*, zero-bias conductance peak, and a series of SC gap features in the dI(V)/dV-spectrum. The positions of the latter directly relate with the SC gap magnitude at any temperature until T_c [3].

Below T_c, we directly determined three SC energy parameters Δ_L^{out}, Δ_L^{in}, and Δ_S with the characteristic ratios $2\Delta_i(0)/k_BT_c \approx 5.3$, 3.2, and 1.3, respectively [4]. Δ_L^{out} and Δ_L^{in} could be either two distinct and isotropic SC gaps developing at different Fermi surface sheets, or the edges of a single, anisotropic SC gap Δ_L developing at one and the same Fermi surface sheet. In the latter case, the determined gap edges correspond to the maximum and the minimum Cooper pair coupling energies in the momentum space. The degree of the possible Δ_L anisotropy $A_L \approx 40\%$ points to an extended *s*-wave symmetry without nodes. The detected small SC gap Δ_S could be either isotropic (nodeless *s*-wave), or, contrary, strongly anisotropic with $A_S > 50\%$ or even nodal. The directly measured the temperature dependences of the SC gaps are typical for a moderate interband interaction. The anisotropy degree of the large SC gap A_L remains almost constant with temperature until T_c. The SC gap structure of $EuCsFe_4As_4$ (the shape of dI(V)/dV spectra of SnS junctions, the values of A_L and the characteristic ratios) and its temperature behaviour ($\Delta_i(T)$, $A_L(T)$) resemble those for $Ba(Fe,Ni)_2As_2$ pnictides studied by us earlier [5]. Above T_c we reproducibly observed a residual nonlinearity of the d(V)/dV spectra of tunneling junctions, showing a normal-state dI(V)/dV hump at zero bias and dips at eV >> $2\Delta_L$. Such normal-state features could originate from the electron density of states (DOS) features in the vicinity if the Fermi level, or its renormalization by a resonant electron-phonon interaction.

The work was performed using equipment of the Lebedev Physical Institute's Shared Facility Center. This research was funded by the RSF project number 22-22-00776.

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Abstract ID: 315

EFFECT OF LOCAL COULOMB INTERACTION ON MAJORANA CORNER MODES

S.V. Aksenov, A.D. Fedoseev, M.S. Shustin, A.O. Zlotnikov

Kirensky Institute of Physics, FRC KSC SB RAS, 660036, Krasnoyarsk, RUSSIA
E-mail: zlotn@iph.krasn.ru

The development of the concept of topologically non-trivial systems has led in recent years to an active study of high-order topological insulators and superconductors (HOTSC) [1,2]. It is known that in 2D HOTSC Majorana modes are localized at corners (these modes are abbreviated as MCM). In contrast to first-order Majorana edge modes in 2D systems, MCM are well separated by an energy gap from other edge states, insensitive to finite size effects, and they can be good candidates for braiding. However, the problem of influence of Coulomb correlations on MCM in 2D HOTSC remains unresolved.

In this study it is shown that the topologically nontrivial phase on the phase diagram of HOTSC proposed in [3] is widened by the Coulomb repulsion in the weak interaction regime. The boundary effect, resulting in an inhomogeneous spatial distribution of the correlators, leads to the appearance of the crossover from the symmetric spin-independent solution to the spin-dependent one characterized by a spontaneously broken symmetry. In the former the energies of corner states are determined by the overlap of the wave functions localized at the different corners. In the latter the corner excitation energy is defined by the Coulomb repulsion intensity with a quadratic law (see Fig. 1). The crossover is a finite size effect, i.e. the larger the system the lesser the critical value of the Coulomb repulsion. In the strongly correlated regime we show that MCMs still can be realized, although the boundaries of the topologically nontrivial phase are strongly renormalized by Hubbard corrections.

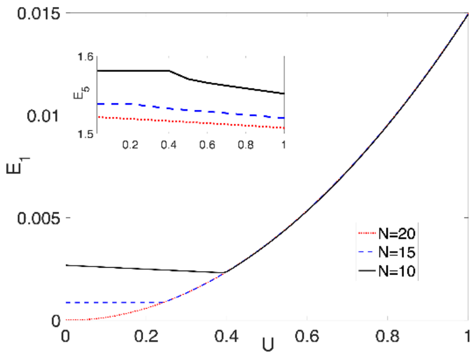

Fig. 1: *Dependence of the first excitation energy E_1 on the parameter of Hubbard repulsion U for different sizes N of the system. Inset: the energy of the first out-of-gap state as a function of U.*

The reported study was supported by Russian Science Foundation, project No. 22-22-20076, and Krasnoyarsk Regional Fund of Science.

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Abstract ID: 322

INVESTIGATING HYDRODYNAMIC ELECTRON FLOW IN NANOSTRUCTURED STRANGE METALS

T.J. Blom[1], M. Visscher[1], J.N. van Stralen[1,2], W.O. Tromp[1], M.P. Allen[1], K. Lahabi[1]

[1]*Leiden University, Leiden Institute of Physics, 2333 CA Leiden, THE NETHERLANDS*
[2]*Eindhoven University of Technology, Department of Applied Physics, 5600 MB Eindhoven, THE NETHERLANDS*
E-mail: blom@physics.leidenuniv.nl

The "strange metal" phase, famously observed in (normal state) high-temperature superconductors, has been among the greatest mysteries of condensed matter physics since its discovery. The issue is that many of its features, especially the notorious linear resistivity in temperature, are wholly incompatible with Fermi liquid theory, because of the very strongly correlated nature of these systems.

A powerful tool that is used to tackle this problem is holographic duality, which states that certain quantum field theories are mathematically equivalent to gravitational theories of one higher dimension. This correspondence can be applied to navigate very strongly interacting theories by dealing with the weakly interacting gravitational equivalent instead.

One of the key predictions of this theoretical description is that transport in strange metals follows hydrodynamic theory, with the resistivity being determined by a "minimal" viscosity.

Our research explores experimental signatures of this hydrodynamic electron transport. Using simulations, we have designed nano-scale devices that could exhibit tell-tale signs of fluid dynamics, such as viscous current flow and vortices. After nanostructuring these geometries in strange metal crystal flakes using focused-ion-beam milling, we can investigate the possibility of hydrodynamics with transport experiments, as well as magnetic and thermal imaging using SQUID-on-tip microscopy.

Abstract ID: 323

TIME-DEPENDENT GINZBURG-LANDAU SIMULATIONS ON CURVED 3D STRUCTURES

A.J.M. Deenen[1], A.E.S. Nizet[1], D. Grundler[1,2]

[1]*Ecole Polytechnique Fédérale de Lausanne (EPFL), Institute of Materials, Laboratory of Nanoscale Magnetic Materials and Magnonics, 1015, Lausanne, SWITZERLAND*
[2]*EPFL, Institute of Electrical and Micro Engineering, 1015, Lausanne, SWITZERLAND*
E-mail: axel.deenen@epfl.ch

Recent advances in nanofabrication have spurred interest in the field of superconductivity in (curvilinear) 3D nanoarchitectures [1]. Additionally, simulations using Time-Dependent Ginzburg-Landau (TDGL) theory have become an essential tool for interpreting experiments on superconductors. However, common implementations focus on problems that are either mappable to 2D systems or make use of finite-difference methods which are not well suited for curved geometries. Here, we present finite-element simulations of 3D superconducting geometries using the TDGL formalism. We implement the formalism in COMSOL multiphysics and, following Ref. [2], fully takes into account the effect of screening currents by computing the magnetic field in both the superconductor and the surrounding vacuum (Fig. 1a). This approach allows us to capture the dynamic behavior of flux-vortices in type-II superconductors beyond planar geometries. In our simulations, We place 4 interconnected Nb tubes inside a volume of vacuum (Fig. 1a) whose boundaries are sufficiently far such that effects of screening are negligible there. We show the order parameter distribution as well as the screening current profile in a magnetic field *B* in (Fig. 1b). Our approach is general and can be used to simulate archetypical topologically non-trivial geometries such as a Möbius strip (Fig. 1c).

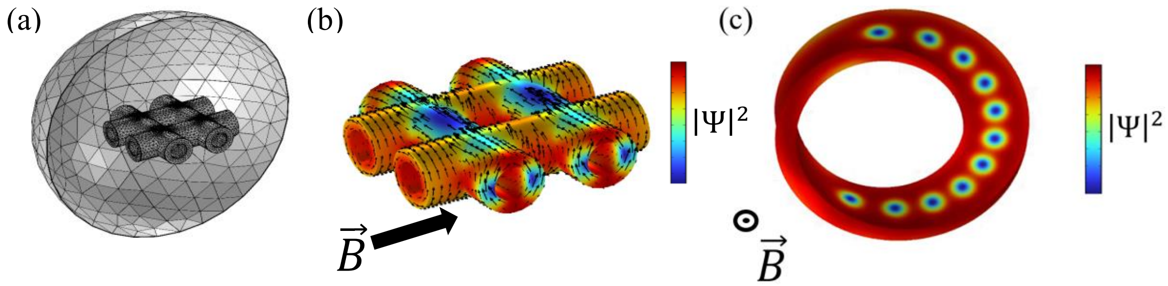

Fig. 1: *(a) Mesh of a (type-II) Nb superconducting structure of intersecting tubes surrounded by vacuum. The length of the tubes is 3.28* μm *and their inner and outer radii are 270* nm *and 464* nm*, respectively. (b) The color-coded modulus of the order parameter in steady state obtained by solving the TDGL for an applied field of 20* mT*. Arrows on the structure indicate the direction of supercurrents. (c) The steady state of a Nb Möbius strip in an external field of 20* mT.

To conclude, by using the finite-element method and a two-domain simulation setup, we model the behavior of superconductors in non-trivial 3D nanoarchitectures. The implementation is an important step towards a better understanding of new phenomena at the mesoscopic scale in the field of 3D superconductivity.

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Abstract ID: 329

EFFECT OF BOUNDARIES ON THE SURFACE SUPERCONDUCTING CRITICAL TEMPERATURE

M.D. Croitoru[1,2], R.H. de Bragança[2], A.A. Shanenko[1], J. Albino Aguiar[2]

[1]National Research University Higher School of Economics, Moscow 101000, RUSSIA
[2]Departamento de Fisica, Universidade Federal de Pernambuco, 50670-901, Recife-PE, BRAZIL
E-mail: mikhail.croitoru@uni-bayreuth.de

As early as 1964 L. N. Bulaevsky and V. L. Ginzburg proposed the concept of "surface ordering" [1], in which surface coupling between the bulk quasiparticle states occurs. The "surface ordering" is based on the assumption that all quasiparticles on the surface contribute to a superconducting state.

Recently, it has been theoretically revealed [2, 3], based on the solution of the tight-binding version of the Bogoliubov-de Gennes (BdG) equations, a sufficient elevation of the superconducting critical temperature at the surface (superconducting surface effect). Surface superconductivity survives even far above the bulk critical temperature [3]. It has been shown that the surface induced enhancement of the superconductivity and the survival of superconducting correlations at the surface proximity above the bulk critical temperature could be attributed to the surface localized quantum constructive interference between BdG bulk eigenstates due to the surface ordering.

The current understanding of the effect is based on studies of superconducting critical temperature at the surface within the model for a clean sample with infinite potential barrier placed at the metal surface. However, it remains still an open question whether the superconducting surface effect reacts to changes in surface/boundary conditions and how.

In this work we have used a detailed description of the surface potential within the self-consistent Lang-Kohn effective potential [4] and studied its influence on the critical temperature of surface superconducting in the framework of the tight-binding Bogoliubov-de Gennes formalism. It turned out that the details of the surface barrier potential in some materials can be a very important factor. It can change the entire spectrum of superconducting properties at the surface and cannot be ignored when discussing real consequences of the surface/interface in such materials. Nevertheless, the estimate based on the Lang-Kohn effective potential suggests that in real samples, the deviations of the surface potential from the most optimal shape do not lead to a significant decrease in the surface critical temperature in materials with a low carrier density. We expect that its manifestation is minor in such samples, especially in narrow-band materials.

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Abstract ID: 333

THE ROLE OF ($Y_3Fe_5O_{12}$) GARNET ON THE DIELECTRIC RESPONSE OF (Bi,Pb)-2223 SUPERCONDUCTORS

Marwa H. El Makdah[1], Mohammad H. El-Dakdouki[1], M. Anas[2], R. Awad[2], N.A. Hassan[3]

[1] *Department of Chemistry, Faculty of Science, Beirut Arab University, Beirut, LEBANON*
[2] *Department of Physics, Faculty of Science, Beirut Arab University, Beirut, LEBANON*
[3] *Department of Physics, Faculty of Science, Alexandria University, Alexandria, EGYPT*
E-mail: sama_mak@hotmail.com

To investigate the impact of yttrium iron garnet ($Y_3Fe_5O_{12}$; YIG) on the dielectric properties of (Bi,Pb)-2223 superconducting phase. Superconducting samples of type $(YIG)_x$/(Bi,Pb)-2223, ($0.00 \leq x \leq 2.00$ wt.%), were synthesized using the solid-state reaction regimen. The X-ray diffraction (XRD) was used to identify the crystal structure for the synthetized samples. The morphological characterization was conducted via scanning electron microscopy (SEM). The dielectric measurements in frequency range (50 Hz to 5 MHz) were performed at different temperature (100 K to 300 K). The XRD data confirmed that the recorded peaks for $(YIG)_x$/(Bi,Pb)-2223 were almost well indexed to tetragonal structure with space group *P4/mmm*. The outcomes showed that in the investigated frequency and temperature range, the compounds do not exhibit any dielectric anomaly. It is practical as co-fired dielectric component devices due to the improvement of nano-superconductor composites' dielectric characteristics. Additionally, the power law was used to study the ac conductivity, and it revealed that the frequency exponent was larger than one. ($1.0543 \leq n \leq 1.6379$) for all the prepared samples.

Abstract ID: 335

STRUCTURAL, ELECTRICAL AND MECHANICAL PROPERTIES OF THE (Tl,Hg)-1223 SUPERCONDUCTOR PHASE SUBSTITUTED BY LANTHANUM AND SAMARIUM FLUORIDES

Rola F. Khattar[1], K. Habanjar[1], R. Awad[1,2], M. Anas[1,2]

[1] *Department of Physics, Faculty of Science, Beirut Arab University, Beirut, LEBANON*
[2] *Department of Physics, Faculty of Science, Alexandria University, Alexandria, EGYPT*
E-mail: rola.khattar@gmail.com

The current study investigates the impact of samarium and lanthanum fluorides (SmF_3 and LaF_3) on the physical properties of $Tl_{0.8}Hg_{0.2}Ba_2Ca_{2-x}R_xCu_3O_{9-\delta}$ superconducting phases (Tl,Hg)-1223, (where R = Sm and La), with $0.00 \leq x \leq 0.10$. The superconducting samples are prepared using the solid-state reaction regimen. From structural analysis, X-ray diffraction (XRD) confirms that the (Tl,Hg)-1223 phase has formed without any alteration of its tetragonal structure. Scanning electron microscope (SEM) micrographs reveal the improvement of the grain size and inter-grain connectivity as Sm and La contents increased up to x=0.025. From energy-dispersive X-ray (EDX), the elemental compositions of the samples show that Sm and La elements were successfully incorporated and substituted for calcium in the crystal structure of (Tl,Hg)-1223. X-ray photoelectron spectroscopy (XPS) spectra expose the oxidation states for the elements in the prepared samples. The impact of Sm and La substitutions on the electrical properties of (Tl, Hg) was studied using I-V and electrical resistivity measurements. The findings demonstrate that the superconducting transition temperature (T_c) and the transport critical current density (J_c) improve consistently with Sm and La replacements up to x = 0.025, beyond which they decrease substantially. Vickers microhardness (H_v) measurements on the samples were performed at room temperature to investigate their mechanical performance in relation to various applied loads and times. For both substitutions, the mechanical properties were enhanced up to an optimal value at x = 0.025. All the fabricated samples exhibit the normal indentation size effect (ISE) behavior. Furthermore, five distinct theoretical models were investigated and compared with the H_v data. The best theoretical analysis for explaining H_v values was provided by the proportional sample resistance (PSR) model. Several electric power applications, high-field magnet applications, and large scientific initiatives can benefit from these superconudctors because of their high T_c and J_c values as well as their excellent mechanical properties.

Abstract ID: 338

DISSIPATION EFFECTS IN SUPERCONDUCTING THIN FILMS AT THE VICINITY OF THE BOGOMOLNY POINT

V.D. Pashkovskaia, T.T. Saraiva, A.S. Vasenko

HSE University, Moscow 101000, RUSSIA
E-mail: vdpashkovskaya@edu.hse.ru

In the last decade, there has been special interest in mesoscopic superconductivity due to the improving of nanofabrication of thin films with a few layers with short characteristic relaxation times. This allows some unique applications, for example, Superconducting Single-Photon Detectors (SSPDs). In this work, we use the Generalized Time-Dependent Ginzburg-Landau Equations (GTDGL) with the link variables method in a 3D square mesh to investigate numerically different dissipation mechanisms and analyze films where the effective GL parameter is in the vicinity of the boundary between types I and II, i.e., $\kappa \sim 1/\sqrt{2}$. By calculating the magnetization and the voltage pulses around the film, we could study how their characteristic times depend on the thickness of the film and check how it would affect the photon counting in a SSPD. Also, we could observe how the Bean-Livingston barriers are different from usual type-II materials [1-3].

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Abstract ID: 351

SUPERCONDUCTING ELECTRIC MACHINES FOR TRANSPORT SYSTEMS

N. Ivanov, V. Kaderov, N. Malevich

Moscow Aviation Institute, 125993, Moscow, RUSSIA
E-mail: Strelok690@yandex.ru

Electric machines are the main component of the electric power industry and are widely used in the production of industrial structures, transport systems, etc. With the progress of global industrialization and urbanization, the demand for electricity is growing rapidly, which has a negative impact on the global environment due to the consumption of natural resources such as hydrocarbon fuels. Thus, today, the efficiency of electromechanical energy conversion and the efficiency of energy use by electric machines are becoming more important than ever. The existing technologies of electric cars meet the requirements of the development of electric vehicles, but they cannot provide the required power to create fully electric aircraft and marine vessels. Superconducting machines, characterized by high specific power, open the way to zero-emission transport and energy systems. But in order to switch to superconducting machines, it is necessary to create design approaches that should include taking into account losses at alternating current, calculating critical parameters of the HTS tape and a cryogenic system. This paper presents a project of a synchronous HTS machine with a capacity of 2 MW and a rotation speed of 6000 min-1 for aircraft. A feature of this machine is the use of windings based on high-temperature superconductivity on the rotor and stator, as well as taking into account losses in the HTS winding at alternating current. In the course of the work, a finite element analysis was carried out, taking into account the influence of an external magnetic field on the superconducting state of HTS coils.

Abstract ID: 359

SUPERCONDUCTING ELECTRIC MACHINES FOR TRANSPORT SYSTEMS

N. Ivanov, V. Kaderov, N. Malevich

Moscow Aviation Institute, 125993, Moscow, RUSSIA
E-mail: malevich3331@mail.ru

Electric machines are the main component of the electric power industry and are widely used in the production of industrial structures, transport systems, etc. With the progress of global industrialization and urbanization, the demand for electricity is growing rapidly, which has a negative impact on the global environment due to the consumption of natural resources such as hydrocarbon fuels. Thus, today, the efficiency of electromechanical energy conversion and the efficiency of energy use by electric machines are becoming more important than ever. The existing technologies of electric cars meet the requirements of the development of electric vehicles, but they cannot provide the required power to create fully electric aircraft and marine vessels. Superconducting machines, characterized by high specific power, open the way to zero-emission transport and energy systems. But in order to switch to superconducting machines, it is necessary to create design approaches that should include taking into account losses at alternating current, calculating critical parameters of the HTS tape and a cryogenic system. This paper presents a project of a synchronous HTS machine with a capacity of 2 MW and a rotation speed of 6000 min-1 for aircraft. A feature of this machine is the use of windings based on high-temperature superconductivity on the rotor and stator, as well as taking into account losses in the HTS winding at alternating current. In the course of the work, a finite element analysis was carried out, taking into account the influence of an external magnetic field on the superconducting state of HTS coils.

Abstract ID: 385

THE EFFECTS OF DIFFERENT HEAT TREATMENT ON AXIAL TENSILE PROPERTIES OF Bi-2212 ROUND WIRES

Mengliang Zhou, Jinggang Qin, Dongsheng Yang, Zhenchuang Zhang, Min Yu

Applied Superconductivity Center, Institute of Plasma Physics, CAS, Hefei City, 230031, CHINA
E-mail: mengliang.zhou@ipp.ac.cn

Due to the excellent critical current density (J_C) and the ultru-high upper critical magnetic field (H_{c2}), $Bi_2Sr_2CaCu_2O_x$ (Bi-2212) has become one of the most potential candidates among the high-temperature superconducting (HTS) materials for the manufacture of the next generation of superconducting magnets. As a kind of brittle phase, Bi-2212 is extremely sensitive to strain. Therefore, the mechanical property is a key factor for its application. In order to investigate the effect of different heat treatment processes on mechanical properties of Bi-2212 round wires (RWs), axial tensile measurements on Bi-2212 RWs were performed with different heat treatments, including with no heat treatment (NHT), atmospheric heat treatment (AHT), overpressure heat treatment (OPHT), pre-overpressure heat treatment (pre-OPHT) and pre-overpressure heat treatment followed by overpressure (pre-OP+OP) heat treatment. It was found that the wires with heat treatment had higher mechanical strength than that with no heat treatment. Besides, the wires with pre-overpressure heat treatment had the highest mechanical strength. The wires that were overpressure heat-treated had excellent performance compared to the ones with atmospheric heat treatment.

Abstract ID: 422

NONVOLATILE SWITCHING OF BERRY CURVATURE DIPOLE IN A TOPOLOGICAL CRYSTALLINE INSULATOR AT ROOM TEMPERATURE

T. Nishijima[1,3], T. Watanabe[2], H. Sekiguchi[2], Y. Ando[1], E. Shigematsu[1], R. Ohshima[1], S. Kuroda[2], M. Shiraishi[1]

[1] *Kyoto University, Depart. of Electronic Science and Engineering, 6158510, Kyoto, JAPAN*
[2] *University of Tsukuba, Inst. of Materials Science, 3058573, Tsukuba, JAPAN*
E-mail: nishijima.taiki.65s@st.kyoto-u.ac.jp

The physics related to Berry curvature is now a central research topic in condensed matter physics. The Berry curvature dipole (BCD) is a significant and intriguing physical parameter that characterizes the antisymmetric distribution of Berry curvature. The BCD exists under inversion symmetry breaking, which induces current-driven out-of-plane magnetization and nonlinear Hall effect (NLHE) [1,2]. However, the creation and controllability of BCDs have been limited to far below room temperature (RT) and nonvolatile (i.e., ferroic) BCDs have not yet been discovered, hindering further progress in topological physics. We focus on a topological crystalline insulator, $Pb_{1-x}Sn_xTe$ (PST), as an ideal material to realize the ferroic BCD for the following reasons [3]. (a) The (001) surface of PST shows the ferroelectric distortion of atoms resulting in inversion symmetry breaking. (b) The PST possesses a topological surface state with four gapless Dirac cones, two of which open a small band gap due to ferroelectric distortion that produces large BCD. (c) The ferroelectric distortion is expected to be controllable by the application of an electric field and nonvolatile.

In this work, we investigated NLHE induced by BCD in PST. $Pb_{0.48}Sn_{0.52}Te$ single crystal was grown with Sb-doping to compensate for the Sn site vacancies, resulting in an insulating behavior of increasing resistance with decreasing temperature. To evaluate NLHE, the second harmonic transversal voltage $V^{2\omega}_{\hat{x}-\hat{y}\hat{y}}$ was measured (Fig. 1). The result shows a quadratic dependence on applied current at 300K, which is a manifestation of the NLHE. As a control experiment, we selected PbTe (PT), a topologically trivial material. As a result, NLHE was not observed in the PT even at 5 K, which is evidence that the topological surface state of PST is the key to the NLHE. To explore the relevance of the NLHE and ferroelectric distortion in the PST, we performed NLHE measurement after applying pulsed electric fields to control the ferroelectric distortion and its direction. Sweeping the pulsed electric field in x, $V^{2\omega}_{\hat{x}-\hat{y}\hat{y}}$ shows a clear hysteresis loop, which is attributed to the ferroic behavior of the BCD. In the presentation, we will discuss the magnitude of BCD and the symmetry of NLHE, BCD and ferroelectric distortion

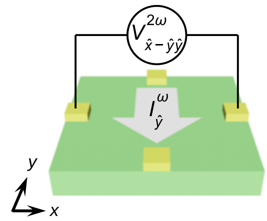

Fig. 1: *An experimental setup for NLHE measurement.*

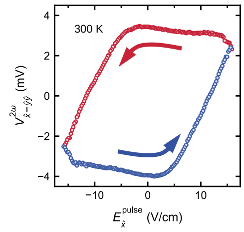

Fig. 2: *$V^{2\omega}_{\hat{x}-\hat{y}\hat{y}}$ measured with a sweeping pulsed electric field. Red (blue) circles show the down sweep (up sweep). $I^{\omega}_{\hat{y}}$ = 500 μA.*

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Abstract ID: 446

DENSITY OF STATES IN THE PRESENCE OF SPIN-DEPENDENT SCATTERING IN SF BILAYERS

A.V. Guravova[1], T. Karabassov[1], A.A. Golubov[2], A.S. Vasenko[1]

[1]*National Research University Higher School of Economics, 101000 Moscow, RUSSIA*
[2]*University of Twente, 7500 AE Enschede, THE NETHERLANDS*
E-mail: guravovaa@mail.ru

We present a quantitative study of the density of states (DOS) in SF bilayers (where S is a bulk superconductor and F is a ferromagnetic metal) in the diffusive limit. We solve the quasiclassical Usadel equations in the structure considering the presence of magnetic and spin–orbit scattering. For practical reasons, we propose the analytical solution for the density of states in SF bilayers in the case of a thin ferromagnet and low transparency of the SF interface. This solution is confirmed by numerical calculations using a self-consistent two-step iterative method. The behavior of DOS dependencies on the interface transparency parameter γ_B, the F-layer thickness d_f, the exchange field h, magnetic and spin–orbit scattering times is discussed [1].

A.V.G., T.K and A.S.V. acknowledge support from the Mirror Laboratories Project of HSE University.

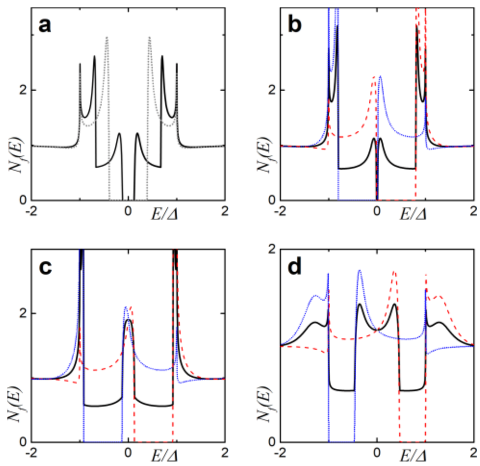

Fig. 1: *The evolution of the DOS plotted for increasing values of the exchange field h. Here,* $\gamma_B = 5$, $d_f = 0.5\xi_f$. *In plot (a), the gray dotted line represents the case of* $h = 0$ *(i.e., the NS bilayer). In plots (a)–(d), black solid lines correspond to the total DOS while red dashed lines show* $N_{f\uparrow}(E)$ *and blue dash-dotted lines show* $N_{f\downarrow}(E)$. *(a) Black solid line calculated for* $h = 0.4\Delta$, *and all lines are calculated for (b)* $h = 0.8\Delta$, *(c)* $h = \Delta$, *and (d)* $h = 1.6\Delta$ *[1].*

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Abstract ID: 503

ON THE EFFECT OF FILM'S THICKNESS ON T_c OF $La_{2-x}Sr_xCuO_4$ FILMS

D.G', Khajibaev, S.M. Otajonov, B.Ya. Yavidov

Nukus state pedagogical institute named after Ajiniyaz, 230105 Nukus, UZBEKISTAN
E-mail: d_xajibayev@ndpi.uz

It is experimentally established that T_c of $La_{2-x}Sr_xCuO_4$ (LSCO) films (LSCO-F) differ from that of bulk counterparts and it depends on several factors such as doping level (x), the thickness of the film (h_f) and type of substrate [1]. For the LSCO-F there are few theoretical works in the literature that qualitatively discuss correlation of T_c with h_f (at constant x) [2,3] in which T_c was determined by the standard BCS equation. Meanwhile, a huge amount of experimental evidences has been accumulated, showing that the superconducting state of cuprates "*cannot be described by the standard BCS theory, anywhere in the phase diagram*" [4]. In addition, they ignored the role apex oxygen atoms whose vibrations have a profound effect on T_c of LSCO-F [5].

Here, we would like to announce an alternative approach (model) for the interpretation of "h_f - T_c" relation in LSCO-F. The approach is based on bipolaronic mechanism of superconductivity and takes into account influence of apex ions to T_c considering LCSO-F within the framework of extended Holstein-extended Hubbard model (EHEHM). The approach was successfully applied for the explanation of doping dependencies of T_c and the uniaxial pressure derivatives of T_c of LSCO-F [6,7]. The EHEHM assumes formation of intersite bipolarons, their Bose-Einstein condensation (BEC) at certain temperature T_{BEC} and $T_c = T_{BEC}$. Our model convincingly predicts the existence of correlation between T_{BEC} and h_f. In order to show this explicitly we consider LSCO-F, grown on $LaSrAlO_4$ (LSAO) and $SrTiO_3$ (STO) substrates, and calculated the value of T_{BEC} as a function of h_f (Fig. 1).

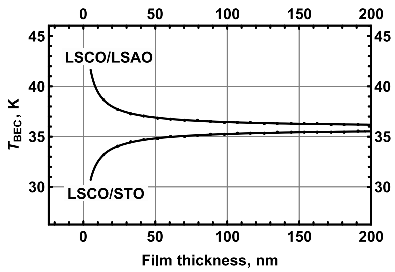

Fig. 1: *The value of T_{BEC} as a function of h_f for LSCO-F, grown on LSAO and STO substrates.*

Our preliminary findings clearly indicate the existence of relationship between SC of LSCO-F and BEC of intersite bipolarons. The detailed numerical work on the issue is in progress.

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Abstract ID: 536

THE INFLUENCE OF A SPIN-POLARIZED CURRENT ON MAGNETORESISTANCE COERCIVITY FIELDS

E. Yu. Beliayev

B. Verkin Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine, Kharkiv 61103, UKRAINE

E-mail: beliayev@ilt.kharkov.ua

Electron transport properties of a pressed powder composite consisting of spherical half-metal CrO_2 particles with mean diameter of 120 nm coated with β-CrOOH dielectric shells (3.6 nm thick) have been studied. The sample's conductivity is due to the spin-dependent electron tunneling between isolated grains of CrO_2 spin-polarized metal. At low temperatures, it acquires percolation character. By analyzing the changes in magnetoresistive (MR) hysteresis loops taken at different temperatures and values of the measuring current flowing through the sample, we show that the MR coercivity fields of percolation cluster, which formed in the sample at low temperatures, significantly depend not only on the degree of spin polarization (temperature of the sample) but also on the magnitude of measuring current flowing through the sample.

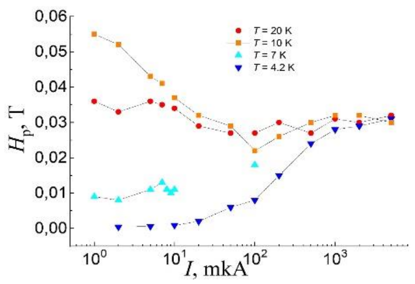

Fig. 1: *Dependencies of coercivity fields of* MR *hysteresis loops on measurement currents at T = 20, 10, 7, and 4.2 K.*

The dependence of coercivity fields on the measuring currents flowing through the sample is complex, as shown in Fig. 1. At T = 20 K, the measuring current is uniformly distributed over the sample. The I-V characteristic of the sample remains linear, and the dependence of coercivity field, H_p, on the measuring current I is weakly expressed. As the temperature decreases to T = 10 K, the MR coercivity increases. However, due to depletion of the percolation cluster, its critical links begin to overheat (I - V characteristics become nonlinear for I > 100 μA), and this leads to a decrease in the field H_p to the level corresponding to T = 20 K at $I \approx$ 100 μA. With a further increase in current, tunnel barriers between the percolation cluster's dead branches become suppressed by rising voltages. This leads to the increase in the number of current-carrying channels, and the influence of measuring current on the coercivity fields H_p weakens. Therefore, the curve $H_p(I)$ at T = 10 K with a further increase in the measuring current and voltage, reduces its slope and merges with the curve for T = 20 K. At T = 7 K, $H_p(I)$ drop sharply, which can be explained by the predominant influence in the overall MR behavior of large multidomain particles connecting the percolation chains in the conditions of increasing percolation conductivity. It should be noted that, according to [1], it is just those particles that lead to a decrease in the values of coercivity fields, Hp, with lowering temperatures. At T = 4.2 K, the corresponding H_p fields become even smaller. We believe that the found increase in H_p values with an increasing current that we observe for temperatures T < 7 K can be explained by the motion of the magnetic domain walls under the action of a spin-polarized current flowing through large multidomain nanoparticles [2], which usually present in critical links of a percolation cluster.

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Abstract ID: 537

INTERPLAY OF HOPPING CONDUCTIVITY AND SUPERCONDUCTIVITY IN $RuSr_2(Eu_{1.5}Ce_{0.5})Cu_2O_{10-\delta}$

E. Yu. Beliayev

B. Verkin Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine, Kharkiv 61103, UKRAINE

E-mail: beliayev@ilt.kharkov.ua

Temperature dependencies of resistance and magnetoresistance for two $RuSr_2(Eu_{1.5}Ce_{0.5})Cu_2O_{10-\delta}$ ceramic samples, one of which was left in the as-prepared state while another one was oxygen saturated, were studied soon after preparation, and the same measurements were repeated after 10 year storage in an ambient atmosphere. Having studied the widest possible range of oxygen concentrations, we are trying to clarify not only the questions of stability of superconducting state in ruthenocuprates, but also the interplay of various types of electronic hopping conductivity and superconductivity in granular magnetic material. Despite the significant progress made in understanding the properties of disordered conductors, the old question of mutual influence and competition between localization and superconductivity still not clear. We hope that the study of electronic transport properties while approaching the metal-insulator transition undertaken in the framework of this research will be useful in this regard.

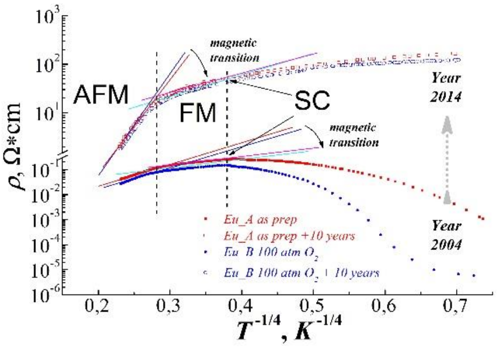

Fig. 1: *VRH and evolution of conductivity behavior with temperature and time.*

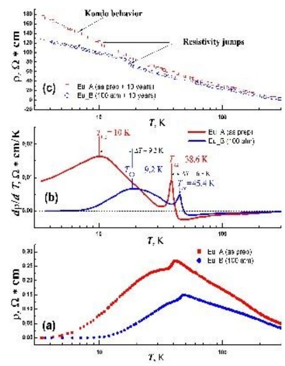

Fig. 2: *Low-temperature resistance behavior for the freshly prepared and the 10-year aged samples.*

The studying of temperature dependencies of resistance at high temperatures reveals two areas of manifestation of 3D VRH Mott's conductivity and leads to conclusion about the granular structure of the sample. This conclusion is confirmed by both electron microscopy data and the "shoulder" structure of superconducting transitions, which makes it possible to determine the temperatures of intragranular and intergranular superconductivity for the initially prepared samples. After 10 years of storage in ambient atmosphere, the $\rho(T)$ dependences have the same features that coincide in temperature with the initial intergranular and intragranular superconducting transitions and with unchanged AFM-WFM transition temperature. At the same temperatures, for our oxygen-deficient samples, a change in the magnitude and sign of magnetoresistance is observed. The temperature behavior of magnetoresistance corresponds to the general picture of intragranular and intergranular superconducting transitions, and a change in its sign witnessed a metal-insulator transition in granular samples. The logarithmic increase in resistance with decreasing temperature after the destruction of superconductivity in an intergranular medium by a supercritical current may be interpreted as Kondo-like behavior.

Abstract ID: 561

THz EMISSION SPECTROSCOPY OF EXCHANGE-BIASED SPINTRONIC HETEROSTRUCTURES

E. Karashtin[1,2], I. Pashen'kin[1], Y. Saito[3], F. Kholid[3], R. Mikhaylovskiy[3]

[1]*Institute for Physics of Microstructures RAS, GSP-105, 603950, Nizhny Novgorod, RUSSIA*
[2]*University of Nizhny Novgorod, 23 Prospekt Gagarina, 603950, Nizhny Novgorod, RUSSIA*
[3]*Department of Physics, Lancaster University, LA1 4YW, Brailrigg, Lancaster, UK*
E-mail: eugenk@ipmras.ru

We apply the THz emission spectroscopy method to the spintronic heterostructures with exchange bias between the constituent antiferromagnetic and ferromagnetic layers. The method is based on the emission of THz signal if a magnetic structure is irradiated by a strong femtosecond laser pulse, similar to spintronic terahertz emitters [1].

We investigate two kinds of structures: simple antiferromagnet / ferromagnet (AFM/FM) structures IrMn(10) / CoFeB(4) / Ta(5) and magnetic tunnel junctions (MTJ) IrMn(10) / CoFeB(4) / MgO(1.5) / CoFeB(4) / NM (NM is a normal metal, either Pt or Ta; thicknesses are in nm). We demonstrate that the intense laser excitation can switch and reversibly reset the direction of the pinning axis arising from the exchange bias in both AFM/FM and MTJ structures (Fig. 1). By applying the double pump THz emission spectroscopy to the AFM/FM structure (Fig.1 c), we reveal that this switching has a strongly nonlinear character in the pump intensity. MTJ structures show a conbination of signals from two magnetic layers which can be manipulated by a magnetic field and adjusted by selection of NM layer (Fig.2).

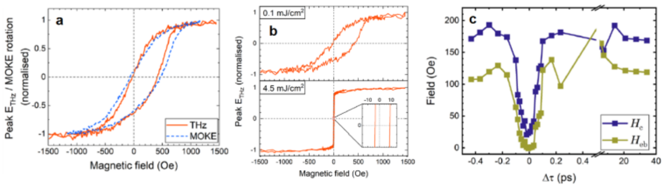

Fig. 1: *MOKE hysteresis loop (a), THz hysteresis at different pump fluence (b), time dependence of exchange field and coercive field measured by double pump method (c) in AFM/FM structure.*

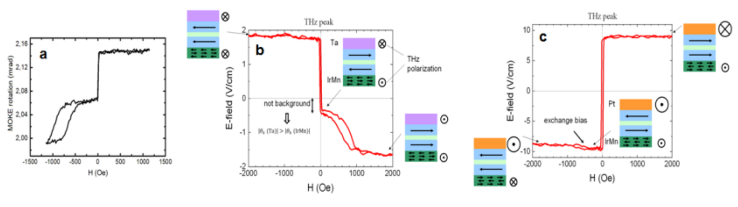

Fig. 2: *MOKE hysteresis loop (a), THz hysteresis for Ta (b) and Pt (c) normal layer in MTJ.*

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Abstract ID: 574

SEARCH FOR A NOVEL PHASE IN $YBa_2Cu_3O_X$ FAMILY

Danijel Djurek

Alessandro Volta Applied Ceramics (AVAC), 49247 Zlatar Bistrica, Augusta Šenoe 14., CROATIA
E-mail: avac@avac.hr

Arguments are presented for a possible novel insulating phase $YBa_2Cu_3O_5$. XRD data confirm the tetragonal crystal lattice, and it is isomorphous with $YBa_2Cu_3O_6$. $YBa_2Cu_3O_5$ is indicated by mutually orthogonal Cu-O-Cu…chains with all copper cations in the low oxidation state Cu^+. Weak doping by oxygen, $YBa_2Cu_3O_{5+\delta}$ (δ = 0.05–0.1), results to a semiconducting and metallic state, while further increase of doping results to original and insulating $YBa_2Cu_3O_6$ phase (δ = 1). Resistive and magnetic properties of $YBa_2Cu_3O_{5+\delta}$ are reviewed.

Abstract ID: 593

OPTIMIZATION OF SUPERCONDUCTING PROPERTIES OF F-DOPED GdFeAsO BY HIGH-PRESSURE TECHNIQUE

Mohammad Azam[1], Manasa Manasa[1], Tatiana Zajamiuk[2], Tomasz Cetner[1], Andrzej Morawski[1], Svetlana Stelmakh[1], Andrzej Wisniewski[2], Shiv J. Singh[1]

[1]*Institute of High-Pressure Physics (IHPP), Polish Academy of Sciences, Sokolowska 29/37, Warsaw, POLAND*
[2]*Institute of Physics, Polish Academy of Sciences, aleja Lotników 32/46, 02-668 Warsaw, POLAND*
E-mail: mohammadazam@unipress.waw.pl

*RE*FeAsO (*RE*1111; RE = rare earth) family of iron-based high T_c superconductors is particularly intriguing and can achieve high transition temperatures of up to 58 K [1]. Currently, we are focusing on Gd1111, which shows the highest T_c of 36 K in $GdFeAsO_{0.83}F_{0.17}$ bulks [2-3]. Since the reported polycrystalline samples were prepared using a high-temperature (~1200-1300°C) solid-state reaction method at ambient pressure, a lot of impurity phases were also observed due to the evaporation of lighter elements. To address these issues, we are optimizing the synthesis process of F-doped GdFeAsO at ambient and applied pressures using Hot Isostatic Pressing (HIP) technique, which can generate the inert gas pressures of up to 1.5 GPa in a cylinder chamber fitted with a furnace capable of reaching 1700°C. To optimize the growth process, we us a wide range of synthesis temperatures (300-1100°C) and conducted a series of physical property studies to assess the structure, microstructure, magnetization, and resistivity of different batches of these samples [4]. Our recent results show that pure phase formation occurs at ~900°C with an almost clean superconducting phase. Our recent samples show the highest T_c up to 45 K for the optimumally F-doped GdFeAsO. In this presentation, we will summarize our current key finding of F-doped GdFeAsO with respect to ambient and applied pressure growth methods [4].

Acknowledgments

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Abstract ID: 602

MULTI-WALL CARBON NANOTUBES (MWCNTS) DIFUSING EFFECT ON THE SUPERCONDUCTING LEAD FREE SOLDER SYSTEM

Şeref Berkay Gülten[1], Canan Aksoy[2], Bakiye Çakır[3], Ezgi Taylan Koparan[4], Müslüm Güven[5]

[1]*Department of Nanotechnology Engineering, Zonguldak Bülent Ecevit University, 67300 Zonguldak, TURKIYE*
[2]*Electronics and Communication Engineering, Faculty of Technology, Karadeniz Technical University, 61830 Trabzon, TURKIYE*
[3]*Vocational School of Health Services, Artvin Çoruh University, 08000 Artvin, TURKIYE*
[4]*Department of Mathematics and Science Education, Ereğli Faculty of Education, Zonguldak Bülent Ecevit University, 67300 Zonguldak, TURKIYE*
[5]*Department of Materials, University of Oxford, Parks Road, OX1 3PH Oxford, UNITED KINGDOM*
E-mail: Bucan80@gmail.com

Lead-free superconducting solder joints are crucial for the superconducting magnets, aerospace and cryogenic applications due to the restriction on hazardous materials as lead and cadminium. Recent studies illustrated that SnInBi superconducting solder showed best properties among the lead free superconducting solder. We focused on this study that whether any reinforcement material, diffusing in to the SnInBi ternary solder system, may enhanced its micrustructural, physical and superconducting properties. In this study, we have investigated that adding Multi-wall carbon nanotubes (MWCNTs) in to SnInBi solder system in a several ratios and we have investigated its physical, microstructural and superconducting properties.

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Abstract ID: 606

HIGH-PRESSURE SYNTHESIS EFFECTS ON THE SUPERCONDUCTING PROPERTY OF $FeSe_{0.5}Te_{0.5}$

Manasa Manasa[1], Mohammad Azam[1], Tatiana Zajamiuk[2], Tomasz Cetner[1], Andrzej Morawski[1], Svetlana Stelmakh[1], Andrzej Wisniewski[2], Shiv J. Singh[1]

[1]*Institute of High-Pressure Physics (IHPP), Polish Academy of Sciences, Sokolowska 29/37, Warsaw, POLAND*
[2]*Institute of Physics, Polish Academy of Sciences, aleja Lotników 32/46, 02-668 Warsaw, POLAND*
E-mail: manasa@unipress.waw.pl

High-pressure synthesis is a powerful method for improving the superconducting properties of iron-based superconductors [1]. Fe(Se, Te) belonging to 11 families of iron-based superconductors that have demonstrated a high transition temperature of ~14.5 K with 50% Te substitution at Se sites using a convenient synthesis method at ambient pressure (CSM) [2-4]. In this study, we synthesized $FeSe_{0.5}Te_{0.5}$ bulk samples at various pressures using high gas pressure techniques to better understand the effects on superconducting properties. Our HIP technique can generate an inert gas pressure of up to 1.5 GPa in a cylinder chamber fitted with three zones furnaces capable of reaching 1700°C. As starting bulk samples for HIP, we used precursors such as Fe, Se, and Te to direct synthesis of the $FeSe_{0.5}Te_{0.5}$ phase (direct sample) and annealing of the prepared $FeSe_{0.5}Te_{0.5}$ phase by CSM (indirect sample). These samples were placed in the high gas chamber either sealed in Ta-tube or without Ta-tube to study the gas pressure effects. These direct and indirect polycrystalline samples of $FeSe_{0.5}Te_{0.5}$ were studied through various characterizations, such as structural and microstructural analysis, and magnetic, and transport measurements to reach the conclusions. Our current findings show that the growth of $FeSe_{0.5}Te_{0.5}$ samples sealed in Ta-tubes at 1 GPa has a pure superconducting phase with improved grain connections and the superconducting temperature increases by 1-2 K. In this presentation, more details about our findings will be demonstrated under various gas pressure effects [5].

Acknowledgments

The work was supported by SONATA-BIS 11 project (Registration number: 2021/42/E/ST5/00262) funded by National Science Centre (NCN), Poland. SJS acknowledges financial support from National Science Centre (NCN), Poland through Project number 2021/42/E/ST5/00262.

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Abstract ID: 608

MAGNETO-TRANSPORT PROPERTIES OF THE FAMILY OF NEW MAGNETIC TOPOLOGICAL INSULATORS $(MnBi_2Te_4)(Bi_2Te_3)_m$ (m = 0, … 3)

N.A. Abdullayev[1,2], K.V. Aliguliyeva[1,2], Z.S. Aliev[1,2], I.R. Amiraslanov[1,2], V.N. Zverev[3], N.T. Mamedov[1], E.V. Chulkov[4,5]

[1] *Institute of Physics, National Academy of Sciences of Azerbaijan, Baku, AZERBAIJAN*
[2] *Baku State University, Baku, AZERBAIJAN*
[3] *Institute of Solid State Physics RAS, Chernogolovka, Moscow district, RUSSIA*
[4] *Saint Petersburg State University, Saint Petersburg, RUSSIA*
[5] *Donostia International Physics Center, Donostia-San Sebastián, Basque Country, SPAIN*
E-mail: zverev@issp.ac.ru

After our discovery [1] of a new antiferromagnetic (AFM) topological insulator (TI) $MnBi_2Te_4$, a large family of intrinsic magnetic TIs in the homologous compounds $(MnBi_2Te_4)(Bi_2Te_3)_m$ with m = 0, ..., 6 were studied [2]. The data on ARPES confirm the linear dispersion $E(k)$ for the surface states as well as the existence of the energy gap between the Dirac cones [1,2]. Here we present the data on the magneto-transport properties of this family for m=0,...3, namely, the temperature dependences of the resistivity $R(T)$, magnetoresistance $R_{xx}(B)$ and Hall effect $R_{xy}(B)$ at low temperatures. Magnetic and electronic transport properties of these materials depend strongly on the m value and are thus highly tunable. The crystals with m=0,..,2 are antiferromagnets. Their Neel temperature goes down from 25K for m=0 to about 11 K for m=2. Further increase in m leads to change of the overall magnetic behavior to ferromagnetic (FM) one for (m = 3). In this way, the AFM and FM TI states are, respectively, realized in the m = 0, 1, 2 and m = 3 cases respectively. For larger m numbers the non-interacting 2D ferromagnets, formed by the $MnBi_2Te_4$ building blocks, are disordered along the direction perpendicular to 2D layers. The variety of intrinsic magnetic TI phases in $(MnBi_2Te_4)(Bi_2Te_3)_m$ allows efficient engineering of functional van der Waals heterostructures for topological quantum computation, as well as antiferromagnetic and 2D spintronics.

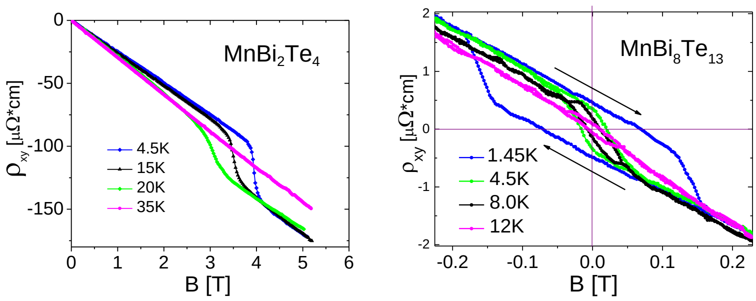

Fig. 1: *Hall effect on AFM (left) and FM (right) samples at different temperatures.*

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Abstract ID: 618

33 kVA SINGLE- PHASE TRANSFORMER WITH A NOVEL SUBCOOLED NITROGEN CRYOGENIC SYSTEM

Elvan Coskun[2], Yusuf Oznal[2], Ercan Ertekin[2], Serap Safran[1,2], Ali Gencer[1,2], Yasuharu Kamioka[2,3]

[1] *Ankara University, Faculty of Sciences, Physics Department, 06100-Tandogan-Ankara, TÜRKİYE*
[2] *Ankara University, Center of Excellence for Superconductivity Research, 50th Year Campus, 06830-Golbasi-Ankara, TÜRKİYE*
[3] *ColdTech Associates, 6-5, Takanodai, Kodaira,187-0024 Tokyo, JAPAN*
E-mail: elvan.coskun@yahoo.com.tr

This design with subcooling functionality can provide a single-phase (only liquid nitrogen) liquid nitrogen circulation feature between 65K and 95K. 33 kVA singe-phase transformer has been cooled by saturated liquid nitrogen, however; further cold subcooled liquid nitrogen has been more suitable for the system to obtain higher efficiency of the transformer. The refrigerator system has three units that are a main cryostat which is placed in the middle leg of the transformer, a heat exchanger and 150 litres nitrogen container. A single-phase transformer has been designed as a Fault Current Limiter (FCL) with a 2G HTS conductor winding loop.

This is a hybrid transformer which consists of copper, superconducting windings, an iron core and a main cryostat. The cryostat made of FRP material contains subcooled liquid nitrogen and YBCO superconducting coil is immersed in the liquid nitrogen. A heat exchanger unit contains saturated liquid nitrogen whose temperature is reduced from 77 K to 65 K by the copper winding. Nitrogen, which has a pressure of 1 atm and a boiling temperature of 77.3K under normal conditions, needs a pressure of 0.144 atm at 64K (vacuum). The cryostat produced to operate at 65K-77K has an advantage of cost-effectiveness when compared with other types of SCFCL systems. Both the cryostat and the transformer designs are compatible to operate in harmony and the system is shown to activate within 5 ms to limit the fault current.

Acknowledgement

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Abstract ID: 619

EVOLUTION OF THE SUPERCONDUCTING ORDER PARAMETER IN $Ba(Fe,Ni)_2As_2$ AND $(K,Na)Fe_2Se_2$ UNDER ELECTRON DOPING

T.E. Kuzmicheva[1], S.A. Kuzmichev[2,1], I.V. Morozov[3], A.I. Shilov[3,1], K.S. Pervakov[1], V.A. Vlasenko[1]

[1] *V.L. Ginzburg Centre for High-Temperature Superconductivity and Quantum Materials P.N. Lebedev Physical Institute of the Russian Academy of Sciences (LPI RAS), 53, Leninsky Ave., 119991 Moscow, RUSSIA*
[2] *Faculty of Physics, Moscow State University, 1, Leninskiye Gory 119234, Moscow RUSSIA*
[3] *Department of Chemistry, Moscow State University, 1, Leninskiye Gory 119234, Moscow RUSSIA*
E-mail: kuzmichevate@lebedev.ru

$Ba(Fe,Ni)_2As_2$ and $(K,Na)Fe_2Se_2$ relate to the 122 structural family of the iron-based superconductors. In the stoichiometric state, $BaFe_2As_2$ shows a spin density wave at T < 138 K which is suppressed under $(Fe_{2-x}Ni_x)$ electron doping with an emergency of the superconducting (SC) phase with the maximum critical temperature $T_c \approx 21$ K (x = 0.1). As compared to $Ba(Fe,Ni)_2As_2$, SC $(K,Na)Fe_2Se_2$ selenides have more electrons per Fe atom and therefore could be considered as strongly electron-overdoped 122 compounds [1]. The Fermi surface of $Ba(Fe,Ni)_2As_2$ consists of hole barrels near the Γ point of the first Brillouin zone and electron barrels near the M point, where several SC condensates develop below T_c. At the Fermi surface of $(K,Na)Fe_2Se_2$ only electron barrels are present, hence, a single-gap SC is typically supposed for these compounds [2].

Large single crystals of $BaFe_{2-x}Ni_xAs_2$ pnictides of underdoped (x = 0.07), optimally doped (x = 0.1) and overdoped compositions (x = 0.12–0.14) with $T_c \approx$ 15 K–21 K–11 K, respectively, and $(K,Na)Fe_2Se_2$ selenides with $T_c \approx$ 25–32 K were grown using "self-flux" technique.

In order to directly determine the SC order parameters, we used an incoherent multiple Andreev reflection effect (IMARE) spectroscopy of planar break-junctions of SC–thin normal metal–SC (SnS) type [3]. In $Ba(Fe,Ni)_2As_2$ we detected a two-gap SC: possibly anisotropic large SC gap (extended s-wave type without nodes) with characteristic ratio $2\Delta_L(0)/k_BT_c \approx 4$–6 (the range corresponds to the maximum and the minimum Cooper pair coupling energies in the k_xk_y-plane), and the small SC gap with $2\Delta_S(0)/k_BT_c \approx 2$. The directly measured temperature dependences of the SC gap are typical for a moderate interband coupling, whereas the possible Δ_L anisotropy remains almost constant with temperature until T_c. the observed SC gap structure is similar for $Ba(Fe,Ni)_2As_2$ with various doping degree: the determined $2\Delta_{L,S}(0)/k_BT_c$ values and the Δ_L anisotropy do not significantly change within the studied doping range [4–7].

In $(K,Na)Fe_2Se_2$ we observe a single SC gap with $2\Delta(0)/k_BT_c \approx 4.5 > 3.53$ which evolves with temperature similarly to a standard BCS-like function. The characteristic ratio is close to the lower edge of the $2\Delta_L(0)/k_BT_c$ range obtained for $Ba(Fe,Ni)_2As_2$.

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Abstract ID: 635

MICROSTRUCTURE AND SUPERCONDUCTING PROPERTIES OF THE $NaFe_{1-x}Co_xAs$ SINGLE CRYSTAL

A.Yu. Degtyarenko[1], IV. Morozov[2], E.O. Rakhmanov[2], A.V. Sadakov[1], A.I. Shilov[1], S.Yu. Gavrilkin[1], A.Yu. Tsvetkov[1], S.A. Kuzmichev[2,1], T.E. Kuzmicheva[1]

[1]*V.L. Ginzburg Centre for High-Temperature Superconductivity and Quantum Materials P.N. Lebedev Physical Institute of the Russian Academy of Sciences (LPI RAS), 53, Leninsky Ave., 119991 Moscow, RUSSIA*
[2]*Faculty of Physics, Moscow State University, 1, Leninskiye Gory 119234, Moscow RUSSIA*
E-mail: degtyarenkoayu@lebedev.ru

The iron-based superconductors of 111 family are interesting for its unique properties. The compound NaFeAs shows long-range antiferromagnetic ordering as well as structural phase transition along with superconductivity [1]. The substitution of Co atoms for Fe atoms in this compound leads to bulk superconductivity, whereby the superconducting transition temperature increases significantly from 10 K to ~22 K. The microstructure of the $NaFe_{1-x}Co_xAs$ compound by high resolution scanning transmission electron microscopy (HRSTEM) and the superconducting properties by vibration magnetometry and SQUID magnetometry in fields up to 9 T over a wide temperature range were studied in this work. $NaFe_{1-x}Co_xAs$ (x = 0.045) single crystals were grown by "self-flux" method in CoAs. It is possible to obtain a series of samples with a smaller substitution step and a higher homogeneity of superconducting properties by using the CoAs precursor as a dopant instead of the traditional pure Co element [2]. For example, it leads to high intensity and goodness-of-fit spectroscopic slot features on the spectra of tunneling contacts based on the obtained single crystals [3]. High quality of single crystallinity was confirmed by X-ray diffraction. The temperature dependence of the magnetic susceptibility of $NaFe_{0.095}Co_{0.045}As$ single crystal shows sharp superconducting transition with the critical temperature Tc~21 K. Along the *ab* plane, the planar defects were observed from high angle annular dark field (HAADF) STEM images, which can act as additional pinning centers. The M(H) hysteresis loops obtained over a wide temperature range from 2 to 16 K in fields from 0 to 9 Tesla at H||c show a second magnetization peak. The critical current density calculated from the Bean critical state model [4] is $J_c \sim 10^5$A/cm^2. Thus, since the obtained M(H) hysteresis loops are symmetrical, the samples are dominated by bulk pinning. Additionally, we performed low-field magnetization measurements and determined temperature dependencies of the lower critical field in both field directions (H||ab and H||c).

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Abstract ID: 121

CHARACTERIZATION OF THE TERAHERTZ RESONANCES IN GRAPHENE TRANSISTORS

Fatima Zohra Mahi[1], AbdelHamid Mahi[2], Luca Varani[3]

[1]*University of Bechar, Dept. of Materials sciences, Bechar, ALGERIA*
[2] *Nour El Bachir University Center, Institute of Sciences, ElBayadh, ALGERIA*
[3]*IES, University of Montpellier, CNRS, Montpellier, FRANCE*
E-mail: fati_zo_mahi2002@yahoo.fr

In several works, the results showed that the twodimensional (2D) layered materials is the best candidate for the terahertz devices [1], in particular for optical communications devices [2], nanodetectors coupled with THz antenna [3] and phototransistor based on black phosphorus material [4]. In other side, the High Electron-Mobility Transistors (HEMTs) present important electrical properties for several Terahertz applications as detectors, emitters and amplifiers [5]. Various studies show the existence of THz plasma-wave oscillations in the channel of the HEMTs [6] and therefore the appearance of Terahertz resonances in HEMTs response spectrum [7]. According to previous studies, the analytical [6] and experimental [8] studies demonstrate the possibility to amplifying the resonances by the InGaAs HEMTs when the resonant plasma frequency coincides with the frequency of the incoming monochromatic THz radiations. Moreover, the use of the twodimensional materials as channel of HEMTs leads to obtain a high quality of resonances [9]. Especially, the Graphene channel presents a high voltage gain in Terahertz range compared to the InGaAs HEMTs (see Fig. 1) due to their properties as a high electronic mobility, unique structure of massless Dirac fermion and unique ballistic transport [10].

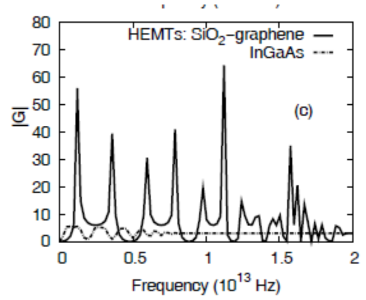

Fig. 1: *The voltage gain modulus* $|G|$.

The Fig. 1 shows the high contribution of Graphene HEMTs to amplifying the Terahertz frequencies due to the plasma resonances generated in the HEMTs channel. In this contribution, an analytical calculation describes the behavior of Graphene HEMTs in Terahertz frequencies will be presented. The calculations are based on the small-signal model developed for the InGaAs HEMTs in Ref.[5]. The model is used to determine the admittances spectrums and the voltage amplification of HEMTs Graphene channels. The influence of the dielectric substrates, the external load and the channel materials (InGaAs, Bilayer and monolayer Graphene) on the dynamic of HEMTs is investigated. This analysis improves the plasma modes behavior of Graphene HEMTs and amplifying the resonances appearing in the voltage gain spectrum.

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Abstract ID: 145

THE STRUCTURAL PHASE SIMULATION OF HIGH-T_c SUPERCONDUCTOR COMPOUND $YBa_2Cu_{3-y}Pb_yO_{6.5+\delta}$

Emad K. Al-Shakarchi[1], Salwan K.J. Al-Ani[2], Wedad M. Faysal[3]

[1]Al-Nahrain University, College of Science, Physics Department, P.O. Box 64055, Baghdad, IRAQ
[2]Al-Mustansiriya University, College of Science, Physics Department, Baghdad, IRAQ [3]Baghdad University, College of Science, Physics Department, Baghdad, IRAQ
E-mail: eks2000@hotmail.com

The simulation of possible change in a structural phase of superconducting compound $YBa_2Cu_{3-y}Pb_yO_{6.5+\delta}$ had been done for the samples prepared by solid-state reaction. The simulation was dependent on XRD patterns for all samples represented by (y=0-0.5). Theoretically, the possible structural phase was derived from a pure phase $YBa_2Cu_3O_{6.5+\delta}$, which was an orthorhombic phase with lattice constants (a=3.8203, b =3.8855, and c= 11.6835 Å) and space group Pmmm. The substitution ratio of Pb-ions made a partial variation in the orthorhombic unit cell from pure phase. The results showed the phase transition from orthorhombic to tetragonal phase at (y=0.2, 0.3). There is a limited variation in the lattice constant around the theoretical values with the orthorhombic phase. Principally, the Pb-atom has valency (+2), so the insertion of Pb-ions in the structure took the position of Cu^{+2}-ion as a substituted ion in the composition $YBa_2Cu_{3-y}Pb_yO_{6.5+\delta}$. There is a sharp increase in the lattice constants (b,c) at y=0.4 with the remaining of orthorhombic phase and space group Pmmm. The simulation exhibited the position of atoms within the unit cell, which is a function to the bonds nature between atoms and their effect on the conductivity behavior with Pb substitution. The results showed a linear relationship between the amount of substitution that was affected on the c-axis and oxygen excess (δ), it was organized by a certain equation.

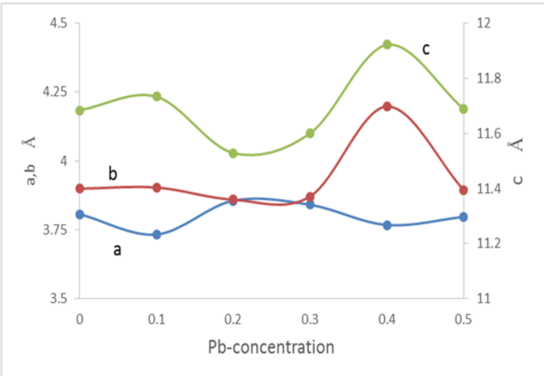

Fig. 1: *The variation of lattice constant as a function Pb-concentration.*

Abstract ID: 195

MgB_2 JOINT DESIGN WITH REACTED WIRES

M. Guven[1], C.R.M Grovenor[1], S. Speller[1], Serdar Atamert[2], Mehmet Nuri Kutukcu[2]

[1]*University of Oxford, Dept. of Materials, 21 Banbury Rd, OX2 6NN, Oxford, UK*
[2]*EPOCH Wires Ltd, Unit 8, Burlington Park, Foxton, CB22 6SA, Cambridge UK*
E-mail: muslum.guven@materials.ox.ac.uk

Due to its relatively high T_c and low production cost, MgB_2 wire is promising for various medium field – medium temperature superconducting applications [1]. However, for magnetic resonance imaging (MRI) applications, where excellent temporal stability is required, development of a reliable technology for manufacturing persistent-mode joints with $<10^{-12}$ W resistance is needed. Since MgB_2 magnets are typically made by the react-and-wind method, it is necessary to be able to make superconducting joints between fully reacted MgB_2 wires that are capable of carrying the full magnet current. Progress towards this goal has been hampered by poor connectivity in the microstructure [2]. The design of the joint, in addition, is also crucial, as it can affect the joint resistance as well. To create an effective MRI system, it is necessary to tackle both joint design and its microstructure matters.

Here we have studied the effect of processing conditions and joint assembly methods on the superconducting properties and microstructure of the joints using MgB_2 wires provided by EPOCH. We find that as processing temperature increases, T_c increases and the width of the transition (ΔT_c) decreases. However, joints subjected to the same optimised heat treatment show some variability in performance. The critical temperature values of the joints that are heat treated under different temperatures are given in the figure below. Low current transport measurements indicate that, within the sensitivity of the nanovoltmeter used, the joint is superconducting.

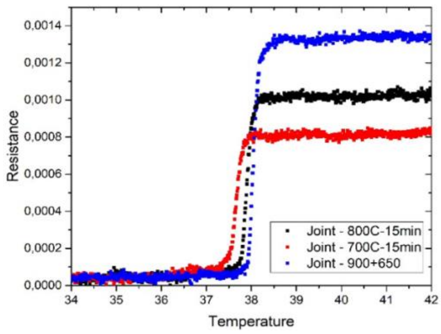

Fig. 4: *R-T plot of some joints heat treated under different temperatures.*

The underlying reasons for these data have been examined and continue to be developed. The I_c and resistance values of joints have been tested by assembling small, jointed coils and measuring the decay of induced currents.

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THE 8th INTERNATIONAL CONFERENCE on SUPERCONDUCTIVITY and MAGNETISM

ICSM2023, Ölüdeniz-Fethiye, TÜRKİYE, May 04-11 2023

Abstract ID: 214

HALL EFFECT ANISOTROPY IN THE PARAMAGNETIC PHASE OF $Ho_{0.8}Lu_{0.2}B_{12}$ INDUCED BY DYNAMIC CHARGE STRIPES

A.L. Khoroshilov[1], K.M. Krasikov[1], A.N. Azarevich[1,2], A.V. Bogach[1], V.V. Glushkov[1], V.N. Krasnorussky[1,3], V.V. Voronov[1], N.Yu. Shitsevalova[4], V.B. Filipov[4], S. Gabáni[5], K. Flachbart[5], N.E. Sluchanko[1]

[1]*Prokhorov General Physics Institute of RAS, 119991 Moscow, RUSSIA*
[2]*Moscow Institute of Physics and Technology, Moscow Region 141700 RUSSIA*
[3]*Vereshchagin Institute for High Pressure Physics of RAS, 142190 Troitsk, RUSSIA*
[4]*Institute for Problems of Materials Science, NASU, 3142 Kyiv, UKRAINE*
[5]*Institute of Experimental Physics SAS, 04001 Košice, SLOVAKIA*
E-mail: nes@lt.gpi.ru

A detailed study of charge transport in the paramagnetic phase of the cage-cluster dodecaboride $Ho_{0.8}Lu_{0.2}B_{12}$ with an instability both of the *fcc* lattice (cooperative Jahn-Teller effect) and the electronic structure (dynamic charge stripes) was carried out at temperatures 1.9–300 K in magnetic fields up to 80 kOe [1]. Four mono-domain single crystals of $Ho_{0.8}Lu_{0.2}B_{12}$ samples with different crystal axis orientation were investigated in order to establish the singularities of anomalous Hall effect (AHE), which develop due to (*i*) the electronic phase separation (stripes) and (*ii*) formation of the disordered cage-glass state below T^* ~ 60 K. It was demonstrated that a considerable intrinsic anisotropic positive component ρ^{an}_{xy} appears at low temperatures in addition to the ordinary negative Hall resistivity contribution in magnetic fields above 40 kOe applied along the [001] and [110] axes. A relation between anomalous components of the resistivity tensor $\rho^{an}_{xy} \sim {\rho^{an}_{xx}}^{1.7}$ was found for $\boldsymbol{H}||[001]$ below $T^* \sim 60$ K, and a power law $\rho^{an}_{xy} \sim {\rho^{an}_{xx}}^{0.83}$ for the orientation $\boldsymbol{H}||[110]$ at temperatures $T < T_S \sim 15$ K.

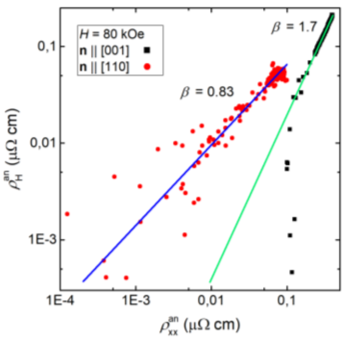

Fig. 1. *Anisotropic AHE components for* $\boldsymbol{H}||[001]$ *and* $\boldsymbol{H}||[110]$ *in magnetic field H = 80 kOe scaled in double logarithmic plot. Solid lines display the linear approximations and β denotes the exponents.*

It is argued that below characteristic temperature T_S ~ 15 K the anomalous odd $\rho^{an}_{xy}(T)$ and even $\rho^{an}_{xx}(T)$ parts of the resistivity tensor may be interpreted in terms of formation of long chains in the filamentary structure of fluctuating charges (stripes). We assume that these $\rho^{an}_{xy}(\boldsymbol{H}||[001])$ and $\rho^{an}_{xy}(\boldsymbol{H}||[110])$ components represent the intrinsic (Berry phase contribution) and extrinsic (skew scattering) mechanism, respectively. Apart from them, an additional ferromagnetic contribution to both isotropic and anisotropic components in Hall signal was registered and attributed to the effect of magnetic polarization of 5*d* states (ferromagnetic nano-domains) in the conduction band of $Ho_{0.8}Lu_{0.2}B_{12}$.

The study was supported by RSF Project No. 22-22-00243.

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Abstract ID: 236

MAGNETIC AND THERMODYNAMIC PROPERTIES IN THE DOPED $Ho_{1-x}Er_xNi_2$ SOLID SOLUTIONS

D. Gajda[1], J. Ćwik[1], Y. Koshkid'ko[1], K. Kowalska[1], B. Weise[2], N. de Oliveira[3]

[1]*Institute of Low Temperature and Structure Research, PAS, Okólna 2, 50-422 Wrocław, POLAND*
[2]*Leibniz IFW Dresden, Institute for Complex Materials, D-01069, Dresden, GERMANY*
[3]*Instituto de Física Armando Dias Tavares–Universidade do Estado do Rio de Janeiro, Rua São Francisco Xavier 524, 20550-013 Rio de Janeiro, RJ, BRAZIL*
E-mail: d.gajda@intibs.pl

Due to high localized magnetic moments and the low magnetic ordering temperatures, some of the RNi_2 compounds (R-rare earth) exhibit a high magnetocaloric effect (MCE) and, therefore, show promise as ideal materials-refrigerants at low temperatures [1-3]. Here, polycrystalline samples of $HoNi_2$, $ErNi_2$ and their solid solutions $Ho_{1-x}Er_xNi_2$ with x = 0.25-0.75 have been investigated using X-ray diffraction analysis and magnetic measurements. These compounds were synthesized using high-purity rare earth metals and nickel. The refinement results proved that the samples with x = 0.5 and 0.75 crystallize in the C15 superstructure (SG: *F*-43*m*), while the sample with x = 0.25 and their parent compounds, $HoNi_2$ and $ErNi_2$, crystallize with the formation of the cubic C15 structure (SG: *Fd*-3*m*).

The magnetization vs temperature has been measured in static magnetic fields using a superconducting quantum interference device (SQUID) magnetometer (Quantum Design). Magnetization vs magnetic field measurements were carried out using vibrating sample magnetometer with a step motor in applied fields using a Bitter-type magnet.

$HoNi_2$, $ErNi_2$ and their solid solutions $Ho_{1-x}Er_xNi_2$ with x = 0.25-0.75 are typical rare earth ferromagnets and are magnetically ordered at temperature below 13.5 K. The magnetic properties are mainly determined by rare earth interactions and the substitution of Ho for Er atoms has led to the weakening of exchange interactions and decrease in the ordering temperature. Their Curie temperatures decrease from 12 K for $Ho_{0.75}Er_{0.25}Ni_2$ to 7 K for $Ho_{0.25}Er_{0.75}Ni_2$. In the case of starting compounds $T_C \sim 13.5$ K for $HoNi_2$ and 6.5 K for $ErNi_2$ [3]. At high temperatures, all samples are Curie Weiss paramagnets. The magnetic transition in all the studied samples is found to be of the second-order character.

The isothermal magnetic entropy change, ΔS_{mag}, which is estimated to characterize the magnetocaloric properties of the pseudo-binary compounds, was analyzed using the thermomagnetic Maxwell relation. The relatively large reversible and close values of ΔS_{mag} allowed us to state that these pseudo-binary solid solutions show promise as materials for magnetic refrigerators operating within a specific low-temperature range.

The work was supported by the National Science Center, Poland through the OPUS Program under Grant No. 2019/33/B/ST5/01853.

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Abstract ID: 246

ELECTRICAL PROPERTIES OF RE-DOPED COBALT FERRITE EMBEDDED COMPOSITE FIBERS

Sehrish Gul-E-Rana, Fiza Dilshad, M. Anis-Ur-Rehman

Applied Thermal Physics Laboratory (ATPL) Department of Physics, COMSATS University Islamabad, Islamabad 44000, PAKISTAN

E-mail: sehrishgul03435453195@gmail.com

The incorporation of particles into polymers strongly influences the electrical properties of nanocomposite materials. The PVP/PVA-$CoFe_{2-2x}La_xSm_xO_2$ (x=0.0-0.1) composite fibers were successfully produced by electrospinning technique. Average fiber diameter was analyzed by scanning electron microscopy. Fourier transform infrared spectroscopy was observed for different bond vibrations in nanocomposite fibers. The electrical properties including dielectric constant, tangent loss and ac conductivity were measured by Wayne Kerr LCR meter 6440B within the frequency range 1 kHz-3 MHz. The composite fiber PVP/PVA-$CoFe_{2-2x}La_xSm_xO_2$ (x=0.1) showed low tangent loss. Ac conductivity of PVP/PVA-$CoFe_{2-2x}La_x Sm_xO_2$ (x=0.0, 0.05, 0.1) composite fibers showed general trend, i.e. it increased with frequency. The PVP/PVA-$CoFe_{2-2x}La_xSm_xO_2$ (x=0.05) have high value of dielectric constant among other composite fibers as shown in fig.1. Therefore, this work leads to an easy way to obtain promising composite fiber material for flexible electronic devices.

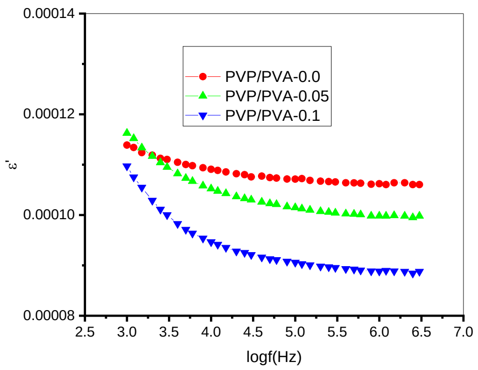

Fig.1: *Dielectric constant of PVP/PVA-$CoFe_{2-2x}La_xSm_xO_2$ (x= 0.0-0.1) composite fibers.*

Abstract ID: 256

NONLINEAR MICROWAVE MICROSCOPY OF SRF ACCELERATOR MATERIALS

Chung-Yang Wang, Steven M. Anlage

Quantum Materials Center, Physics Department, University of Maryland, College Park, MD 20742-4111, USA
E-mail: anlage@umd.edu

The microscopic origins of Superconducting Radio Frequency (SRF) cavity breakdown by surface defects are not completely understood. To locally study the electrodynamics of superconductors, a near-field magnetic microwave microscope was built [1-3]. Extensive studies of bulk Nb, and Nb thin film coatings, used for SRF accelerator cavities, show evidence of RF vortex semi-loop formation, as well as current-driven Josephson junction, nonlinear responses [4]. We are now studying the 3rd harmonic response of Nb_3Sn SRF materials as a function of rf field amplitude and temperature. Results on a Nb_3Sn film with T_c = 18.3 K show evidence for multiple superconducting transitions (around 4.8 K and 10.1 K), probably because there are different Sn concentrations in the sample. Moreover, for the 10.1 K impurity, the 3rd harmonic response exhibits a periodic feature in both the rf field amplitude-dependence, and the temperature-dependence. Such a signal can be understood in terms of vortex dynamics in an inhomogeneous medium, perhaps associated with grain boundaries. In particular, time-dependent Ginzburg-Landau modeling of the probe/sample interaction [5] is used to better understand the origins of the measured nonlinear signals.

This work is funded by US Department of Energy / High Energy Physics through grant # DE-SC0017931.

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Abstract ID: 267

STUDY OF TRANSPORT PROPERTIES OF PURE AND Gd-DOPED MAGNESIUM FERRITE AT FIXED FREQUENCIES

Haroon Mazhar, M. Anis-ur-Rehman

Applied Thermal Physics Laboratory, Department of Physics COMSATS University Islamabad, Islamabad 45550, PAKISTAN

E-mail: haroonmazhar1234@gmail.com & marehman@comsats.edu.pk

Spinel ferrites have gained more attention because of their vast range of applications in electric and magnetic fields. Magnesium ferrite with inverse spinel structure have attracted much attention because of their excellent structural, magnetic and electrical properties. $MgFe_2O_4$ and $MgFe_{1.8}Gd_{0.2}O_4$ was prepare by WOWS sol-gel method. X-ray diffraction (XRD) confirmed the spinel structure of the prepared compositions. XRD data was used to analysis the crystallite size, lattice parameters, experimental density, theoretical density, and volume of these samples. The electrical properties including the tangent loss, dielectric constant, dielectric loss, ac conductivity and real and imaginary part of impedance have been studied as a function of temperature from 40°C to 500°C by using precision analyzer at fixed frequencies. Tangent loss, dielectric loss, dielectric constant decreased by increasing temperature. AC conductivity increased as temperature increased. Impedance has progressively decreased at higher temperature. DC resistivity was measured using a two-probe method that showed a decreasing trend with increasing temperature revealing semiconductor nature of prepared samples. The $MgFe_{1.8}Gd_{0.2}O_4$ sample showed improved transport properties as compared to the $MgFe_2O_4$ sample.

Abstract ID: 268

TEMPERATURE DEPENDENT ELECTRICAL PROPERTIES OF $MgFe_2O_4$ AND $MgFe_{1.8}La_{0.2}O_4$ SPINEL FERRITES

Haroon Mazhar, M. Anis-ur-Rehman

Applied Thermal Physics Laboratory, Department of Physics COMSATS University Islamabad, Islamabad 45550, PAKISTAN

E-mail: haroonmazhar1234@gmail.com & marehman@comsats.edu.pk

Ferrite with spinel structure has unique technological importance because of numerous applications in electronics and biomedical industry. Spinel ferrites gain great attraction in view of their extraordinary properties such as low electrical conductivity, high magnetic permeability, low coercive force, high Curie temperature and low eddy current loss. In present work, WOWS sol-gel method was used to prepare $MgFe_2O_4$ and $MgFe_{1.8}La_{0.2}O_4$. X-ray diffraction (XRD) confirmed the spinel structure of the prepared compositions. XRD data was used to analysis the crystallite size, lattice parameters, experimental density, theoretical density and volume of these samples. The electrical properties including the tangent loss, dielectric constant, dielectric loss, ac conductivity and real and imaginary part of impedance have been studied in the frequency range of 20Hz-3MHz using precision analyzer at a temperature range from 100°C to 500°C. Tangent loss, dielectric loss, dielectric constant decreased by increasing frequency. AC conductivity increased at higher frequency. Impedance has progressively decreased at higher frequency. The $MgFe_{1.8}La_{0.2}O_4$ sample showed improved electrical properties as compared to the $MgFe_2O_4$ sample.

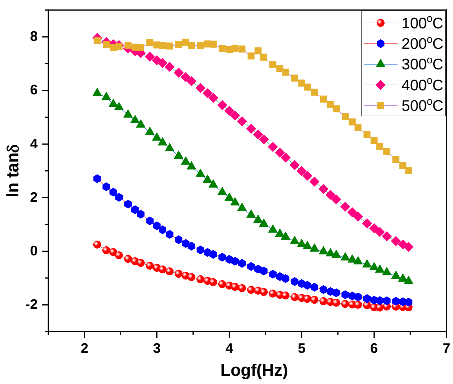

Fig. 1: *Tangent loss for different temperature of* $MgFe_{1.8}La_{0.2}O_4$.

Abstract ID: 294

ADDITIVE MANUFACTURING OF NdFeB PERMANENT MAGNETS

V. Maltseva, A. Urzhumtsev, S. Andreev, N. Nosova, A. Volegov

Ural Federal University, Institute of Natural Science and Mathematics, Kuibysheva st., 48, Yekaterinburg, 620026, RUSSIA

E-mail: viktoriamaltseva5@gmail.com

Hard magnetic materials and permanent magnets made from them are widely used in modern technical devices and in electronic devices that surround us every day. Because of the desire to reduce the size of devices in general, there is a need to significantly optimize permanent magnets and magnetic systems. Technologies that have been developed over the years for obtaining magnets are not always able to maintain the same magnetic characteristics when the magnets are reduced in size, or the magnets cannot be configured as required when the magnets are miniaturized. One option for creating magnets of complex shapes without losing their magnetic hysteresis characteristics is the use of additive manufacturing technologies. The aim of this work is to establish the relationship between the magnetic hysteresis properties of samples of single-layer permanent magnets of the *Nd-Fe-B* system and the conditions of their synthesis by selective laser sintering.

Magnetic hysteresis properties were measured on printed single-layer samples. Samples are look like squares and have a linear dimension about 10x10 mm and width less than 1 mm. A mechanical mixture of two powders was used for 3D – printing: MQP-B (manufactured by Magnequench Int.) and a eutectic alloy of $Pr(Nd)_{75}(Cu_{0,25}Co_{0,75})_{25}$ in proportion 80% – 20% wt. The alloys were milled in alcohol in a ball mill. A powder fraction with a particle size of up to 100 μm was used. Process of 3D-printing was made with use Orlas Creator RA. During the printing process, parameters such as the number of laser passes over the powder (*N*), laser power (*P*, W), hatch (*h*, μm), laser beam speed (*v*, mm/s), laser beam direction (α, deg), beam expander (*d*, μm) were varied to achieve improved hysteresis properties. All magnetic hysteresis properties were measured T = 300 K by a PPMS DynaCool T9. The possibility of obtaining the coercivity of 19.5 kOe on single-layer magnets without the use of heavy rare-earth metals was shown (Fig. 1).

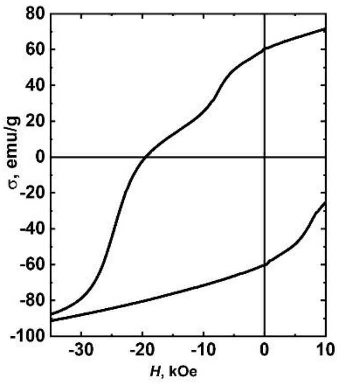

Fig. 1: *Major hysteresis loop of 3D-printed sample*

This work was financially supported by RSF grant № 21-72-10104.

Abstract ID: 306

CONTROL OF DYSPROSIUM MAGNETIC ANISOTROPY IN LUMINESCENT LANTHANIDE(III)–PLATINUM(II) MOLECULAR CHAINS

P. Bonarek, J.J. Zakrzewski, M. Zychowicz, S. Chorazy

Jagiellonian University, Faculty of Chemistry, Gronostajowa 2, 30-387 Krakow, POLAND
E-mail: pawel.bonarek@uj.edu.pl

Single-molecule magnets (SMMs) based on lanthanide complexes are promising candidates for magnetic materials of the future, yet their functionality may still be enhanced by adding other properties, e.g., luminescence, electrical conductivity, or non-linear optical effects. Such materials can combine the magnetic memory effect realized at the molecular level with strong emission applicable in LED devices and optical sensors.[1,2] We have recently found that emissive polycyanidometallates of transition metals are efficient metalloligands for functionalized luminescent lanthanide-based SMMs.[3,4] Here, we present dicyanido(2-phenylopyridynato)platinate(II), $[Pt^{II}(CN)_2(ppy)]^-$, a new promising building block for the construction of bimetallic d-f coordination polymers. These diamagnetic complexes exhibit charge-transfer luminescence and offer two cyanido ligands for bridging to lanthanide ions. Taking advantage of these promising prerequisites, we combined Dy(3+) ions with $[Pt^{II}(CN)_2(ppy)]^-$ obtaining a family of 1-D bimetallic assemblies, $\{[Dy^{III}(L)_2(NO_3)]\ [Pt^{II}(CN)_2(ppy)]_2\}\cdot n$(solvent) (L = MeOH, 4-pyridone, 4-pyridazone, 1-methylpyridin-4(1H)-one) of a vertex-sharing squares topology. The two axial O-donor ligands offer, tunable magnetic anisotropy for Dy^{III} providing its SMM behavior, while simultaneously the system exhibits strong thermosensitive Pt^{II}-centered photoluminescence.

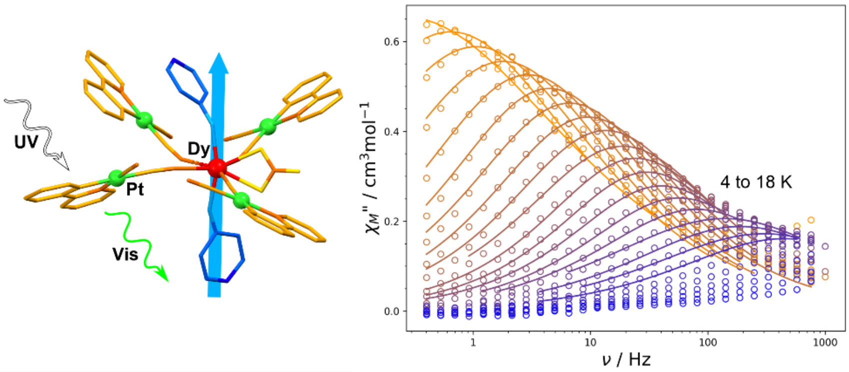

Fig. 1: *The molecular fragment of the selected Dy^{III}(1-methylpyridin-4(1H)-one)–Pt^{II} coordination chains and their representative ac magnetic characteristics under the optimal dc magnetic field.*

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Abstract ID: 328

DIELECTRIC AND CONDUCTIVE PROPERTIES OF $Ni_{1-x}M_xO$ NANOPARTICLES, WHERE M = Gd, Ru: A COMPARATIVE STUDY

A. M. Abdallah[1], M. Noun[2], R. Awad[1]

[1]*Physics Department, Faculty of Science, Beirut Arab University, Beirut, LEBANON*
[2]*Lebanese Atomic Energy Commission, National Council for Scientific Research, P.O. Box 11–8281, Riad El Solh, Beirut, LEBANON*
E-mail: a.mabdallah@bau.edu.lb

This comparative study investigates the difference between the rare earth element (Gd) and transition metal (Ru) as dopants in NiO nanoparticles, to unveil their suitability in various applications. Gd and Ru doped NiO nanoparticles have been synthesized by the chemical co-precipitation method, in the presence of polyvinylpyrrolidone, as a capping agent. The X-ray diffraction, transmission electron microscope and energy dispersive X-ray (EDX) characterized the phase formation, morphology and purity of the synthesized nanoparticles. Also, EDX pattern gave insight into the different nature of the doping in the lattice, being substitutional and forming vacancies. Moreover, the doping process has been shown to result in changes to the dielectric and conductive properties of the NiO nanoparticles, which are important factors in determining their suitability for electrical applications. The dc conductivity was examined at ranging temperatures to explore the conduction mechanism, by applying different models. The dielectric parameters, including real and imaginary dielectric constants, dielectric loss, Nyquist plot, ac conductivity, activation energy and relaxation process were studied, by varying the temperature and frequency. The dielectric and conductivity measurements have provided valuable insights into the electrical behavior of Gd and Ru doped NiO nanoparticles, and have helped to establish their potential for use in a range of applications, such as in energy storage and electronics.

Abstract ID: 339

THERMALLY ACTIVATED FLUX FLOW AND EXCESS CONDUCTIVITY ANALYSIS OF GO_x/(Bi,Pb)-2223 SUPERCONDUCTING COMPOSITES

Khulud Habanjar[1], R. Awad[1,2]

[1] *Department of Physics, Faculty of Science, Beirut Arab University, Beirut, LEBANON*
[2] *Department of Physics, Faculty of Science, Alexandria University, Alexandria, EGYPT*
E-mail: k.habanjar@bau.edu.lb

This work investigates the effect of graphene oxide (GO) addition on the structural and the superconducting properties of $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_{10+\delta}$ phase ((Bi,Pb)-2223). Standard solid-state reaction technique is used for the synthesis of bulk polycrystalline samples with compositions (Bi,Pb)-2223 + x of GO (x=0, 0.01, 0.02, 0.04, 0.08 and 0.1 wt.%). The X-ray diffraction (XRD) analysis confirms the formation of the tetragonal phase of (Bi,Pb)-2223 superconductors. All the peaks of (Bi,Pb)-2223 have been used for the estimation of volume fractions of the phase and the structural lattice parameters. The superconducting transition temperature (T_c) is determined from the DC-electrical resistivity, via the standard four-probe technique. Excess conductivity of all samples has been studied from the data of resistivity versus temperature from around $2T_c$ to the onset temperature. The obtained results are analyzed as a function of temperature using the Aslamazov and Larkin (AL) model. Four different fluctuation regions are observed from which the zero-temperature coherence length along c-axis, effective layer thickness of the two-dimensional system, and the inter-layer coupling strength are estimated as functions of GO addition. From the strong thermal fluctuations, the thermally activated flux flow (TAFF) model is used to examine the effect of GO addition, acting as artificial pinning centers, on the transport properties of (Bi, Pb)-2223 superconductors. The analysis of the vortex phases shows that all samples exhibit a transition from vortex glass to vortex liquid. The vortex glass to vortex liquid transition temperature (T_g) and the zero-temperature activation energy (U_0/k_B) are determined. Both T_g and U_0 show an alteration with the addition of GO. Consequently, strong pinning centers of GO could be used for the decrease of vortex motion for the enhancement of the flux pinning competences and the transport capacities of (Bi, Pb)-2223 superconductors.

Abstract ID: 340

THE EFFECT OF HEAT TREATMENT ON THE STRUCTURAL AND OPTICAL PROPERTIES OF Ru-DOPED ZnO NANOPARTICLES

Dema Dasuki, Khulud Habanjar, R. Awad

Department of Physics, Beirut Arab University, Beirut, LEBANON
E-mail: dima.dasuki@gmail.com

The aim of this study is to probe the effect of heat treatment, through chemical co-preparation technique, on zinc oxide nanoparticles doped with ruthenium. Pure ZnO and Ru-doped ZnO nanoparticles, with general formula $Zn_{1-x}Ru_xO$, were synthesized by co-precipitation for $0 \leq x \geq 0.04$; Following the same starting precursors, set A is heated at 60°C for heating and calcinated at 450°C, whereas, set B is heated at 80°C and calcinated at 550°C. For the structure investigation, X-ray powder diffraction (XRD) reveals that the crystalline size of (A) is smaller than that of (B). For $x=0.04$ of set B, the maximum value of crystalline size is attributed to the integration of Ru^{3+} ions into interstitial sites in the host causing this expansion. Fourier Transform Infrared Spectroscopy (FTIR) technique confirms the formation of zinc oxide nanoparticles by showing Zn-O bonding peak at 421 cm^{-1}. A second-wide peak is also observed at 551 cm^{-1} in Ru-doped ZnO of set A. For $x=0.04$ in set B, the divergence confirms the change in bonding properties of Zn^{2+} distributed by Ru^{3+} doping, which verifies the presence of secondary-phase RuO_2. By using UV-visible spectroscopy, the energy gap of set A swings as ruthenium doping increases. However, for set B, as the crystalline size decreases, the energy gap increases until reversing at the highest concentration of $x=0.04$. The transition from oxygen vacancy to interstial oxygen associated with the blue peak (469nm), increases in A under low heating conditions and decreases in B as Ru-doping increases, as noted by the optical technique photoluminescence spectrum. Ruthenium proves a useful surface defect as well as distortion centers in the lattice, leading to more adsorption and a remarkable advantage in sunscreen and painting products used for UV protection.

Abstract ID: 352

GENERATION OF SECOND-HARMONIC LIGHT USING POLYCYANIDOCUPRATE(I)-BASED MAGNETO-LUMINESCENT NETWORKS

J.J. Zakrzewski[1], J. Wang[2,3], M. Heczko[1], R. Jankowski[1], S. Ohkoshi[3], S. Chorazy[1]

[1]Jagiellonian University, Faculty of Chemistry, Gronostajowa 2, 30-387 Kraków, POLAND
[2]University of Tsukuba, Department of Materials Science, Faculty of Pure and Applied Science, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8573, JAPAN
[3]The University of Tokyo, Department of Chemistry, School of Science, 7-3-1 Hongo,Bunkyo-ku, Tokyo, JAPAN
E-mail: j.zakrzewski@uj.edu.pl

The purpose of studying functional solid materials that crystallize within polar space groups lies in their potential activity toward the generation of second-harmonic (SH) light. This non-linear optical effect may be applied to the construction of novel optical energy-converting systems and laser-light sources.[1] In this context, molecular magnetic materials were shown as potential candidates for the conjunction and even coupling of optical effects with magnetic phenomena such as magnetic ordering, spin-crossover transitions, and single-molecule magnetism.[2-4] Among them, the compounds built of polycyanidometallate complexes was found particularly promising. Lately, we uncovered that lanthanide(3+) ions and copper(I) cyanido metal complexes can form highly-dimensional coordination networks lacking the inversion center in the crystal lattice.[5] We have shown them to possess the capability to reveal single-molecule magnet behavior as well as vis-to-NIR emission. Having in mind the polar character of the obtained crystalline materials, we decided to focus on their potential in non-linear optical phenomena. As the result of our recent studies on lanthanide(III)-copper(I) materials, we present the results of their magnetic characterization accompanied by studies concerning luminescent thermometry, and finally, the generation of second-harmonic light, which were found to be f-block-metal-center - and crystallization-solvent-dependent.

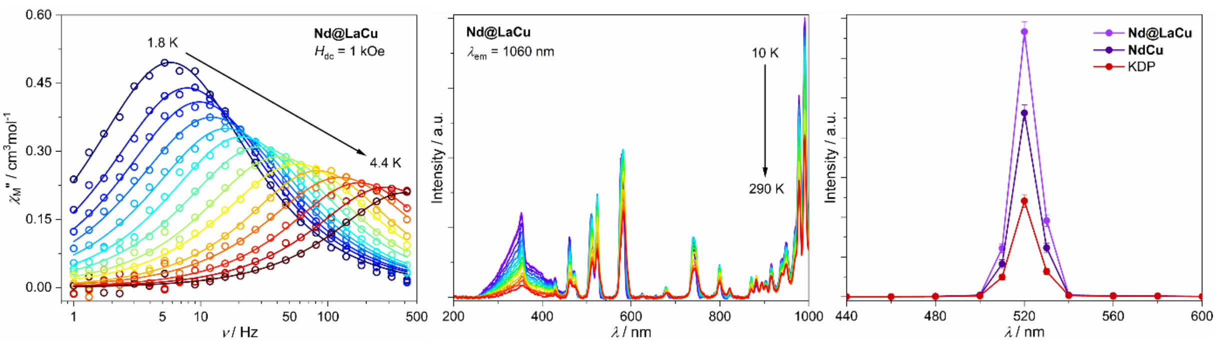

Fig. 1: *Magnetic, luminescent, and SHG properties of* ***Nd@LaCu*** *polar coordination framework.*

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Abstract ID: 357

TUNING MAGNETIC RELAXATION PROCESSES VIA NANOPARTICLE ORGANIZATION

A. Kuncser, C. Radu, N. Iacob, I.D. Vlaicu, G. Schinteie

[1]*National Institute of Materials Physics, Atomistilor 405A, Magurele, ROMANIA*
E-mail: andrei.kuncser@infim.ro

A broader perspective on fundamental aspects related to magnetic relaxation phenomena in magnetic nanoparticles (MNP) system is particularly desired in the field of magnetic hyperthermia as a promising supporting therapy against various types of cancer [1]. The heating up to 45 C of the tumoral tissue is accomplished using the power dissipated by MNPs under the influence of an oscillating magnetic field [2]. The mechanisms of power dissipation from the MNP to the environment is related to the magnetic relaxation phenomena inside the nanoparticles [3]. The present work explores the influence of MNP morphology and organization (e.g. spheres, stripes) on the magnetic relaxation constant and uniaxial anisotropy of individual entities within the system. An elementary proof of concept is provided in Fig1.

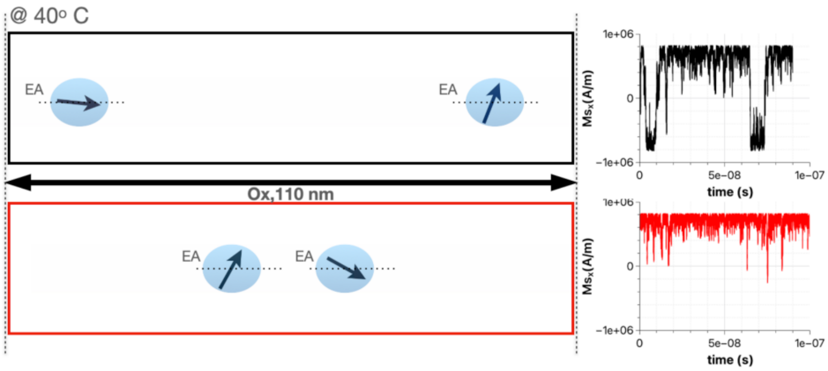

Fig. 1: *Thermal fluctuations of a Fe_3O_4 MNP magnetic moment as affected by the presence of another identical MNP.*

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Abstract ID: 373

SIMULATION OF A COMPACT TRAPPED FIELD MAGNET USING A (RE)BCO BULK AND AN HTS COIL DURING A PFM PROCESS

K. Berger[1], G. Hajiri[1], S. Guijosa[2], F. Trillaud[3], J. Lévêque[1]

[1]*Université de Lorraine, GREEN, F-54000 Nancy, FRANCE*
[2]*Instituto de Investigaciones en Materiales, Universidad Nacional Autónoma de México, Mexico City, 04510, MEXICO*
[3]*Instituto de Ingeniería, Universidad Nacional Autónoma de México, Mexico City 04350, MEXICO*
E-mail: kevin.berger@univ-lorraine.fr

A compact trapped field magnet (TFM), also called a superconducting permanent magnet, can be employed in a variety of applications, e.g. as flux-pinning docking interface (FPDI) for satellites in space [1], as active elements in robots and machinery. The TFM can be energized by high currents flowing through a high temperature superconducting (HTS) coated conductor wrapped around a (*RE*)BCO bulk. The magnetization of the unit, consisting of both the HTS bulk and the coil, is achieved by the so-called pulsed field magnetization (PFM) process, where pulsed currents are flowing in the coil, which is cooled together with the bulk to the operating temperature.

The simulation of the unit is achieved with a coupled thermal and magnetic finite element model solved with COMSOL Multiphysics. The magnetic model is based on an efficient coupling between the **A**-**H** and **T** formulations. The coupling with the thermal model is given by the dependence of the critical current density in the bulk and in the HTS tape on the temperature in addition to the dependence on magnetic flux density.

The main objective of this work is to accurately reproduce the measurements observed in the experiment. We will also highlight the conditions under which the coil contributes to reinforce the magnetic flux trapped by the bulk, where an example is given in Fig. 1.

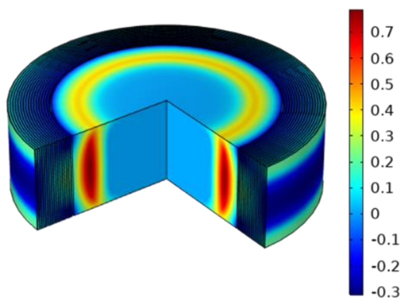

Fig. 1: *B_z component of the magnetic flux density over the unit after a pulsed field magnetization.*

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Abstract ID: 382

EXPERIMENTAL SIGNATURE OF ELECTRON-PHONON DECOUPLING IN ION DAMAGED InSb THIN FILMS

J. Gough, S.N. Holmes, G. Auton, H. Liu, M. Pepper

University College London, Dept. of Electronic and Electrical Engineering, WC1H 0AH, London, ENGLAND
E-mail: jonathan.gough.18@ucl.ac.uk

The existence of a perfect finite temperature insulator was first shown theoretically by Basko, Aleiner and Altshuler [1]. They theorized that the conductivity of an interacting many body system would drop to zero at some finite temperature given suitably high disorder and that the electrons were decoupled from an external bath. In typical solid-state systems, the electrons are coupled to an external heat bath via phonons. If the electrons are suitably decoupled from the phonons, we should observe a large mismatch between the electron temperature and the phonon (lattice) temperature. Such a mismatch experimentally manifests as large jumps in current when the electron temperature is sufficiently increased as to bring it out of equilibrium with the phonons. We report on possible experimental evidence of such an effect in ion-damaged Indium Antimonide thin films. Molecular beam epitaxy was used to form a 100nm InSb thin film grown on an insulating GaAs substrate. The wafers were then processed into 1400μm by 80μm hall bars. Controllable disorder was then introduced to the devices by selectively exposing them to a Neon ion beam. Two terminal DC current measurements were performed at temperatures between 1K and 25mK in a dilution refrigerator. At an applied voltage of ±0.065V we observe current jumps of over three orders of magnitude when the lattice temperature is 50mK (Fig. 1).

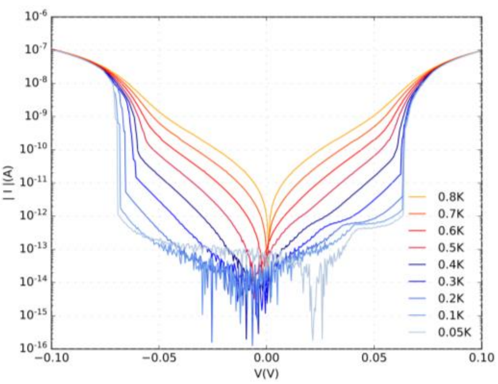

Fig. 1: *Absolute value of measured current against applied DC voltage for a range of lattice temperatures between 50mK and 800mK. At lower lattice temperatures we observe sharp jumps in current.*

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Abstract ID: 383

EFFECT OF Te SUBSTITUTION ON $(Tl_{0.8}Cr_{0.2})(Sr_{2-x}Te_x)CaCu_2O_{7-\delta}$ (x = 0.0 to 0.5) SUPERCONDUCTOR

E. Yusrianto[1], R. Abd-Shukor[2]

[1] *Universitas Islam Negeri Imam Bonjol Padang, 25153 Padang, West Sumatera, INDONESIA*
[2] *School of Applied Physics, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, MALAYSIA*
E-mail: efilyusrianto@uinib.ac.id

The $(Tl_{0.8}Cr_{0.2})(Sr_{2-x}Te_x)CaCu_2O_{7-\delta}$ (Tl-1212) superconductor for x = 0.0 to 0.5 has been prepared and studied by powder X-ray diffraction method and electrical resistance measurements. Small amounts of Te-substitution ($x \leq 0.1$) maintained the formation of the Tl-1212 phase but larger amounts led to the formation of the Tl-1201 phase. The resistance versus temperature curves showed onset transition temperature ($T_{c\ onset}$) between 86 and 102K. Our results indicated the effects of Te substitution on the formation and electrical behaviour of the $(Tl_{0.8}Cr_{0.2})(Sr_{2-x}Te_x)CaCu_2O_{7-\delta}$ (Tl-1212) superconductor.

Abstract ID: 387

A NEW APPROACH FOR PRODUCTION OF IMD MgB_2 WIRE

Doğan Avcı[1], Hakan Yetiş[1], Daniel Gajda[2], Michal Babij[2], Lan Maria Tran[2], Fırat Karaboğa[3], Andrzej Zaleski[2], İbrahim Belenli[1]

[1] Bolu Abant İzzet Baysal University, Department of Physics, 14030 Bolu, TURKEY
[2] Institute of Low Temperature and Structure Research PAS, Okólna 2, 50–422 Wroclaw, POLAND
[3] Bolu Abant İzzet Baysal University, Mehmet Tanrikulu Vocat. Sch. Hlth. Serv., 14030 Bolu, TURKEY
E-mail: davci.0209@gmail.com

IMD method allows forming a highly dense MgB_2 core structure and improvement in the grain connectivity for the superconducting MgB_2 wire. However, a big hole is formed at the center of the wire after heat treatment due to the chemical reaction between Mg rod and B powder. This hole limits the critical current (I_c) of the IMD wire despite its high J_c value. A thin layer of MgB_2 is challenging to achieve a good connection in the case of joining the IMD MgB_2 wires. Therefore, we proposed a new filling method to make the MgB_2 core surface more effective than the IMD wires. This method called half IMD method and the wire with an outer diameter of 0.81 mm has longitudinal semi-cylindrical magnesium and boron columns. The wire heat treated at 650 °C for 1, 2, 4 hours and 700 °C for 1 hour. The electrical transport measurements were carried out at 4.2 K, 20 K, and 25 K under different external magnetic fields. This undoped wire carried DC current of 64 A under 6 T at 4.2 K, 27 A under 3 T at 20 K, and 28 A under 2 T at 25 K. The results showed that MgB_2 wire with good transport properties could be produced using half IMD method.

Abstract ID: 392

SUPPRESSION OF MAGNETIZATION DAMPING IN ULTRATHIN Co FILMS BY CONTROLLING SURFACE MAGNETIC ANISOTROPY FIELD VIA INSERTION OF NONMAGNETIC BUFFER LAYERS

S. Yoshii, E. Shigematsu, R. Ohshima, Y. Ando, M. Shiraishi

Department of Electronic Science and Engineering, Kyoto University, JAPAN
E-mail: yoshii.shugo.88x@st.kyoto-u.ac.jp

Ultrathin ferromagnetic metals (FMs) have attracted attention because of its gate-tunability of magnetism [1]. To realize gate-tunable magnon systems, the study on magnetization dynamics in ultrathin FM films is inevitable. In FM thin films, the surface contribution to magnon damping, two-magnon scattering (TMS) [2], is dominant, which have hampered study on magnetization dynamics and magnon in ultrathin FM films. TMS was reported to be dependent on the surface state of FM films such as surface morphology and uniaxial magnetic anisotropy [3]. In addition, the modulation of interfacial magnetic anisotropy at FM/nonmagnetic metal (NM) with various NM layer via inducing interfacial spin-orbit interaction was reported [4]. Here, we investigated the magnon damping in ultra-thin Co film on various NM layers. Through the control experiment with changing NM layer, we established the guiding principle for realization of low-magnon damping in ultrathin FM film.

In this study, we selected Ti, Cu and Al as NM layers. As shown in Figure 1, the samples of Co film with NM buffer layers were prepared by electron beam deposition, and the thickness of Co film ($t_{\rm Co}$) varies from 2 nm to 20 nm. Here, we measured ferromagnetic resonance (FMR) of these samples with applying DC magnetic field along the in-plane direction to estimate the Gilbert damping constant α as magnon relaxation. Figure 2 shows the Co thickness dependence of *a*. The thickness dependence of α is expressed by the following equation [5], $\alpha = \alpha_{\rm int} + \alpha_{\rm SP} {t_{\rm Co}}^{-1} + \beta_{\rm TMS} {t_{\rm Co}}^{-2}$, where $\alpha_{\rm int}$, $\alpha_{\rm SP}$ and $\beta_{\rm TMS}$ are intrinsic, spin pumping, and TMS contributions, respectively. TMS contributions with various NM films are shown in Fig. 2 as the quadratic factor in broken lines. The TMS contribution was greatly suppressed in the samples with Ti layer, but not in the samples with Cu and Al. The NM layer dependence of the TMS contribution can be explained by the interfacial magnetic anisotropy at Co/NM interfaces [6].

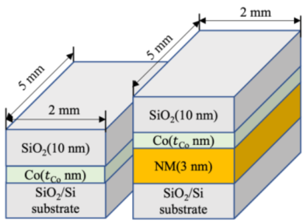

Fig. 1: *Sample structures.*

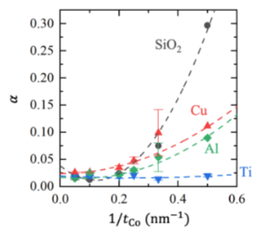

Fig. 2: *Co thickness dependence of Gilbert damping constant.*

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Abstract ID: 396

NONINVASITION CONTROL MAGNETIC NANOPARTICLES IN THE BIOLOGICAL MEDIUM

L.P. Ichkitidze[1,2], O.V. Filippova[1], A.Yu. Gerasimenko[1,2], D.V. Telyshev[1,2], S.V. Selishchev[2]

1Institute for Bionic Technologies and Engineering, I. M. Sechenov First Moscow State Medical University, 119991 Moscow, RUSSIA
[2]Institute of Biomedical Systems, National Research University of Electronic Technology, 124498 Zelenograd, Moscow, RUSSIA
E-mail: ichkitidze@bms.zone

There are more and more opportunities to use magnetic nanoparticles (MNPs) in orthopedics to detect, identify, quantify early osteoarthritis and track the effectiveness of treatment, i.e. theranostics of osteoarthritis [1,2]. In this work, we study the physicochemical properties of MNPs and the possibility of their detection at localization sites in a biological medium.

MNPs were synthesized in an aqueous medium by chemical co-precipitation (Massart reaction). The main product of the reaction was Fe_3O_4 magnetite nanoparticles, the sizes of which were in the range of 10–25 nm. The resulting MNPs powder was mixed with microcrystalline cellulose (MCC) powder in a ratio of 3 wt. % MNPs to 97 wt. % MCC. Tablets with a diameter of 13 mm and a thickness of 2.5-5.2 mm were made from this powder (samples 1). At the same time, suspensions were prepared containing: 3 wt.% MNPs and 97 wt.% PMS (liquid polymethylsiloxane with a viscosity of 5 mPa·s, samples 2). Sample 2 is considered a biological medium as its viscosity matches that of blood.

The magnetic field B_0 was recorded by a Honeywell HMR2300 magnetometer with a resolution of ±0.1 mG. The magnetic field ΔB, which is the difference between the fixed values of the magnetic fields without the sample and with the sample, was used to estimate the values of the magnetization M and the specific magnetic moment p_m inside the sample. It was believed that the measured ΔB is correlated with the values, i.e. $\Delta B \sim M$, p_m. A detailed procedure for measuring MNPs parameters is described in [3].

It has been established that in a weak magnetic field $B_0 \leq 2$ G, all samples exhibit the properties of superparamagnetism. In fields $B_0 \approx 2$-200 G, hysteresis was observed on the curves $M(B_0)$, from which various measured and estimated parameters were determined. With a magnetization field $B_0 \approx 200$ G for samples 1 and 2, the following values were obtained, respectively: coercive force H_c – 82 G and 56 G; ratios of residual magnetization to maximum magnetization – 0.91 and 0.95; p_m–0.45 emu/g and 0.15 emu/g; remanence relaxation time 81 min and 68 min (exponential scale). When vibrating for 1 min at a frequency of 2 kHz, samples 1 and 2 lost their residual magnetization by 10-15 % and 90-95 %, respectively.

Samples were reliably recorded at a distance of up to 5-6 cm from the magnetometer sensor, which can be used for noninvasive control of theranostics of osteoarthritis in small animals using MNPs loaded with various ligands.

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Abstract ID: 414

ON THE OCCASION OF 20th ANNIVERSARY OF THE FIRST EXPERIMENTAL OBSERVATION OF THE LEGGETT COLLECTIVE PLASMA OSCILLATION IN MgB_2

S.A. Kuzmichev[1,2], T.E. Kuzmicheva[2]

[1] *Faculty of Physics, Moscow State University, 1, Leninskiye Gory 119991, Moscow RUSSIA*
[2] *V.L. Ginzburg Centre for High-Temperature Superconductivity and Quantum Materials, P.N. Lebedev Physical Institute of the Russian Academy of Sciences, 53, Leninsky Ave., 119991 Moscow, RUSSIA*
E-mail: kuzmichevate@lebedev.ru

Superconductivity (SC) in MgB_2 was discovered occasionally in the end of 2000 [1]. It becomes the first-ever-known two-gap SC, where two weakly interacting SC condensates with the distinct coupling energies ($2\Delta\sigma$ and $2\Delta_\pi$) develop in the SC state below T_c. As early as in 1966 A.J. Leggett predicted that collective plasma oscillation caused by small fluctuations of the phase difference between two SC condensates ("internal Josephson effect in the *k*-space"), develop in two-gap (and at least two-band) superconductors [2]. The main result of the pioneer work [2] re-derived by Sharapov *et al.* [3] specially for MgB_2 is that the square of the massless term of the oscillation frequency $\omega_0^2 \equiv \omega_L^2(k\rightarrow 0)$ at $T = 0$ is proportional to the product of the large and the small SC gaps $\Delta_\sigma(0)\cdot\Delta_\pi(0)$. For the first time, Leggett plasmon in MgB_2 was experimentally detected in our laboratory by supervision of Prof. Ya.G. Ponomarev in 2002 [4].

At 4.2 K, using a planar "break-junction" technique we formed Josephson SIS and Andreev SnS nanojunctions (*S* is superconductor, *n* – thin normal metal, *I* – insulator). In I(V) and dI(V)/dV characteristics of the tunneling junctions, we reproducibly observed a fine structure caused by a resonant interaction of Josephson supercurrent with Leggett plasma mode (in SIS regime) or emission of Leggett plasmons during multiple Andreev reflections (in SnS regime), and determined the energy of the Leggett plasmon [4,5]. We showed that the observed fine structure is independent on the junction resistance and area, cannot originate from any geometric or exciton-type ($\Delta_\sigma+\Delta_\pi$) resonance, whereas the determined energy ω_0 coincide in both Josephson and Andreev regimes. In average, ω_0 does not exceed the small SC gap $2\Delta_\pi(0)$ value and reaches $\omega_0 \approx 4$–5 meV in MgB_2 with $T_c \approx 40$ K. Here we review our experimental results on Leggett plasma mode detection in disordered MgB_2 and electron doped (Mg,Al)B_2 compounds in a wide range of critical temperatures $T_c \approx 13.5$–40 K. Summarizing the data obtained by Josephson and Andreev spectroscopies, we demonstrate almost linear $\omega_0(\Delta_\sigma\cdot\Delta_\pi)$ dependence and an absence of a "dirty limit" transition within this T_c range [4,5] and present here an experimental temperature dependence of the Leggett plasma mode $\omega_0(T)$.

The authors are forever grateful to Prof. Ya.G. Ponomarev and S.N. Tchesnokov. We also thank B.M. Bulychev, L.G. Sevastyanova, and S.I. Krasnosvobodtsev for the provided MgB_2, (Mg,Al)B_2 and MgB_2+MgO samples. We thank P.I. Arseev and N.K. Fedorov for several fruitful discussions during 2010–2013.

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Abstract ID: 438

NEUTRON DIFFRACTION STUDIES OF THE $Cu(Cr_{2-x}Sn_x)S_2Se_2$ SPINEL-TYPE PHASES

M. Pardo-Sainz[1,2], S. Moris[3], C. Piquer[1], J.A. Rodríguez-Velamazán[4], A. Galdámez[5], J. Campo[1]

[1]*Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC - Universidad de Zaragoza, 50009, Zaragoza, SPAIN*
[2]*Osaka Metropolitan University, 599-8231, Sakai, JAPAN*
[3]*Centro de Investigación de Estudios Avanzados del Maule (CIEAM), Universidad Católica del Maule, 3480112, Talca, CHILE*
[4]*Institut Laue-Langevin, 38042, Grenoble, FRANCE*
[5]*Universidad de Chile, 7800003, Santiago de Chile, CHILE*

E-mail: miguel.pardo@csic.es

$CuCr_2Se_4$ and $CuCr_2S_4$ show a ferromagnetic behavior with Curie temperature T_C ~ 420 K and 380 K, respectively [1] and their physical properties can be modified by chemical substitution in the Cr sublattice with diamagnetic cations, such as Sn, Ti, Zr. For example, the experimental magnetic measurements on $(Cu)_{tet}[Cr_{2-x}Ti_x]_{oct}S_4$ systems showed that the evolution from ferromagnetic behavior to a spin-glass regime is due to magnetic frustrations triggered by the chemical substitutions of chromium by titanium diamagnetic ions [2]. Thus, $(Cu)_{tet}[Cr_{2-x}Sn_x]_{oct}S_2Se_2$ samples with x = 0.2 and 0.4 exhibited ferromagnetic behavior, whereas high transition temperature (AF) behavior was observed in the samples with x = 0.6, 0.8, and 1.0 [3,4] However, the origin of the magnetism for $CuCr_2X_4$ (X = S, Se) and its solid solutions has been in controversy. Lotgering and Goodenough proposed two different models for each end-member [5,6], which assumed electronic states of $Cu^{1+}[Cr^{3+}Cr^{4+}]Se_4$ or $Cu^{2+}Cr_2^{3+}Se_4$, respectively.

Neutron diffraction experiments were performed to study the magnetic transitions in the $Cu(Cr_{2-x}Sn_x)S_2Se_2$ ($0.2 \leq x \leq 1.0$) solid solutions and experimentally corroborate the appropriate magnetic structure for these systems. Thermodiffraction experiments were carried out at the powder high intensity diffractometer D1B located at the Institut Laue-Langevin, Grenoble, France. We used a wavelength of 1.28 Å and 2.52 Å to study the range 2θ = 2°–130° at temperatures ranging from 1.8 to 300 K. The Rietveld analysis of the diffraction data was performed by using the FULLPROF suite. These measurements allowed to establish that for samples with $x \leq 0.4$ there is a ferromagnetic long-range order transition, while for $x > 0.4$ no magnetic signal is observed, indicating the spin-glass regime.

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Abstract ID: 439

ABSENCE OF ANY FERROMAGNETIC LONG-RANGE ORDER IN HOLMIUM AT 8 GPa: A NEUTRON DIFFRACTION STUDY

M. Pardo-Sainz[1,2], F. Cova[1,3], J.A. Rodríguez-Velamazán[3], I. Puente-Orench[1,3], Y. Kousaka[2], M. Mito[4], J. Campo[1]

[1]*Instituto de Nanociencia y Materiales de Aragón (INMA), CSIC - Universidad de Zaragoza, 50009, Zaragoza, SPAIN*
[2]*Osaka Metropolitan University, 599-8231, Sakai, JAPAN*
[3]*Institut Laue-Langevin, 38042, Grenoble, FRANCE*
[4]*Kyushu Institute of Technology, 804-8550, Kitakyushu, JAPAN*
E-mail: miguel.pardo@csic.es

Ferromagnetic metals have played an important role in condensed matter physics from the viewpoint of its magnetism originated from itinerant electrons [1]. In the 4*f*-electron lanthanide metals, the oscillatory nature of the Ruderman-Kasuya-Kittle-Yosida (RKKY) interaction often results in an incommensurate helimagnetic structure (HM). At low temperatures, this HM structure is destabilized, leading to a FM ground state. Additionally, all 4f-lanthanide FM metals exhibit the structural series of transformations in the sequence *hcp* → Sm-type → double-*hcp* (*dhcp*) → *fcc* → trigonal under increasing pressure. Therefore, much attention has been focused on the relationship between the magnetic properties and structural transformations in 4*f*-lanthanide metals.

Recently, a.c. magnetization measurements in Ho showed that the HM transition was observed at pressures up to 12 GPa, while the FM transition seems to be unstable around 8 GPa [2]. However, previous neutron diffraction experiments reported that the FM ordering survives until at least 20 GPa [3] (see left of Fig.1). To solve this controversy, low-T neutron diffraction experiments have been conducted to investigate the magnetic structures of metallic Holmium at high pressures. We find that at P = 8 GPa and T = 5 K, no nuclear symmetry change is observed, keeping therefore the *hcp* symmetry at high pressure. We also confirm that the FM order does not exist, but the HM one survives down to 5 K (right side of Fig.1).

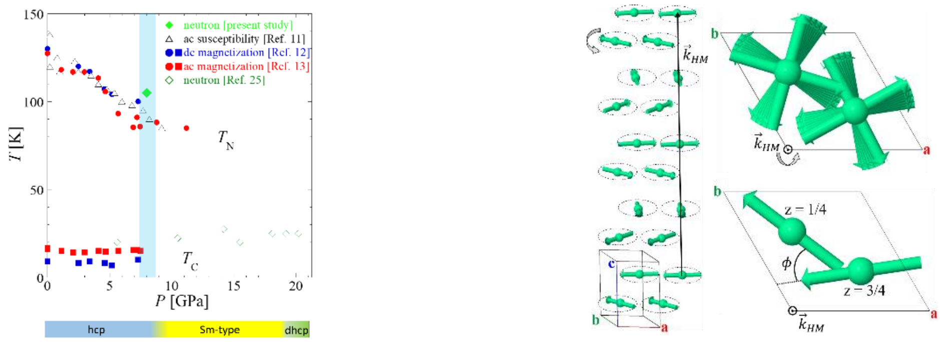

Fig. 1: *Left: Pressure dependence of T_C and T_N. Right: Magnetic structure at 8 GPa and 5 K.*

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Abstract ID: 455

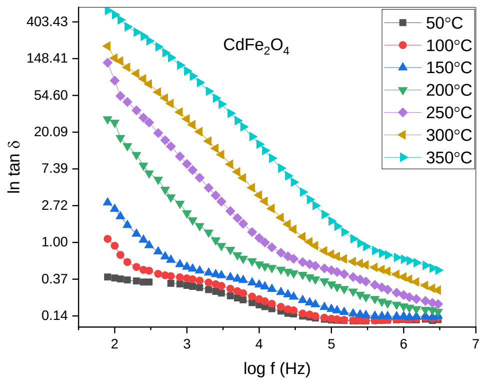
STUDY OF TEMPERATURE AND FREQUENCY DEPENDENT ELECTRICAL PROPERTIES OF MAGNESIUM DOPED CADMIUM FERRITE FOR MEMORY APPLICATIONS

Sania Atique, M. Anis-ur-Rehman

Applied Thermal Physics Laboratory (ATPL), Department of Physics, COMSATS University, Islamabad, PAKISTAN

E-mail: marehman@comsats.edu.pk

Spinel Ferrites have attracted a lot of attention in the research community because of their fascinating magnetic and electrical properties, such as high saturation magnetization, high crystalline anisotropy, low coercivity, and high electric resistivity. Cadmium ferrites have attracted much attention in recent years because of their said properties. Electric properties of cadmium ferrite are rarely reported. We have investigated their electrical response for their potential use in memory applications. Magnesium doped cadmium ferrite with the general formula $Cd_{1-x}Mg_xFe_2O_4$ (x= 0.0,0.1,0.2) were synthesized by using the Sol-gel method. These samples in the form of pellets were sintered at 400 ˚C for 3 hours. X-ray diffraction (XRD) technique was used to study the structural properties of the samples. The temperature dependent electrical, dielectric properties of magnesium-doped cadmium ferrite were studied. AC properties which include dielectric tangent loss (tanδ), dielectric constant (έ), AC conductivity (Ϭ), and impedance (Z) were studied as a function of frequency (20 Hz-3MHz).



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Abstract ID: 456

STRUCTURAL AND ABSORPTION STUDY OF CNTs DISPERSED CHROMIUM ZINC DOPED STRONTIUM HEXAFERRITES

Naima Firdous, M. Anis-ur-Rehman

Applied Thermal Physics Laboratory (ATPL), Department of Physics, COMSATS University, Islamabad, PAKISTAN

E-mail: marehman@comsats.edu.pk

Ferrites have attracted a lot of attention because of high absorption intensity, thin thickness and wide absorption bandwidth in absorption applications. As CNTs possess the advantage of wide frequency bandwidth and high electrical conductivity so the composites of ferrites and CNTs are suitable for the next generation wave absorbing applications. The absorption and structural properties of CNTs dispersed strontium hexaferrites are rarely reported. Chromium zinc doped strontium hexaferrites with the general formula $SrFe_{12-2x}Cr_xZn_xO_{19}$(x=1.0) were synthesized by using the co-precipitation method. 10 and 20 wt% already prepared CNTs were added in composition x=1.0 to enhance the losses. The structural study of ferrites sample was done by X-ray diffraction (XRD). AC properties which include dielectric tangent loss (tanδ), dielectric constant ($\dot{\varepsilon}$), AC conductivity (σ), and impedance (Z) were studied as a function of frequency (20 Hz-3MHz). DC electrical properties which include conductivity and activation energy were measured by using two probe methods as a function of temperature. All these properties of ferrites make them a potential candidate for many applications such as in microwave absorption.

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Abstract ID: 472

RESONANCE PHENOMENA AND KAPITZA PENDULUM EFFECTS IN A NANOMAGNET COUPLED TO A JOSEPHSON JUNCTION AND UNDER EXTERNAL RADIATION

K.V. Kulikov[1,2], D.V. Anghel[1,3], M. Dolineanu[3,4], A.T. Preda[3,4], M. Nashaat[1,5], M. Sameh[5], Yu. M. Shukrinov[1,2,6]

[1]*BLTP, JINR, Dubna, Moscow Region 141980, RUSSIA*
[2]*Dubna State University, Dubna, RUSSIA*
[3]*IFIN-HH, 077125 Magurele, ROMANIA*
[4]*University of Bucharest, Faculty of Physics, 077125 Magurele, ROMANIA*
[5]*Department of Physics, Faculty of Science, Cairo University, 12613 Giza, EGYPT*
[6]*Moscow Institute of Physics and Technology, Dolgoprudny 141700, RUSSIA*
E-mail: dragos64@gmail.com

We investigated the resonances phenomena that appear in the oscillations of a nanomagnet coupled to a Josephson junction (JJ) and under external periodic drive (Fig. 1). The schematic diagram of the system is presented in Fig. 1. The dynamics of the magnetic moment of the nanomagnet is described by the Landau-Lifshitz-Gilbert (LLG) equation. We integrate these equations numerically to find the time evolution and the oscillations of the nanomagnet. We denote by Ω_F, Ω_J, and Ω the frequency of the ferromagnetic resonance, the Josephson frequency, and the frequency of the external radiation, respectively, and we observe several resonance phenomena—we call *resonances* very narrow (finite) peaks of the oscillation amplitude, when plotted vs. a frequency. In the absence of external radiation (i.e., $A = 0$, where A is the amplitude of the external radiation), we observe the ferromagnetic resonance at $\Omega_F \approx \Omega_J$. When the external radiation is turned on (i.e., $A \neq 0$), it interferes with the JJ's oscillations, producing a series of peaks in the oscillation amplitude of the nanomagnet, at $\Omega_J + m\Omega \approx \Omega_F$ (where m is an integer). We analyze the system also analytically in the linear regime (small oscillations amplitudes), we explain the resonance phenomena and we obtain a very good agreement with the numerical data.

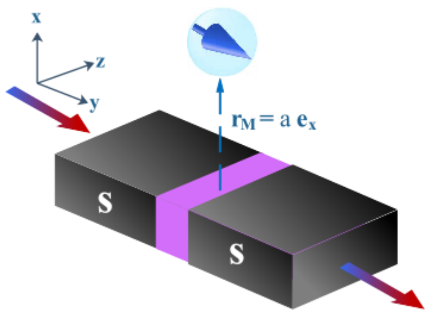

Fig. 1: *The nanomagnet (blue arrow) coupled to external radiation and a short Josephson junction.*

When Ω_J and Ω are much higher than Ω_F, a qualitatively different situation arises. In such a case, the nanomagnet behaves like a Kapitza pendulum subjected to vibrations on two (very) different scales of frequencies. We again investigate the system by both, numerical and analytical methods, and obtain a very good agreement. Using the Kapitza pendulum effect, the nanomagnet is reoriented by the remote combined action of the JJ and external radiation [1].

The effects studied here provide a method to remotely control the oscillations and equilibrium position of a nanomagnet. For example, by only changing the frequency and the amplitude of the external radiation one can control the equilibrium position as well as the amplitude of the oscillations of the nanomagnet, by tuning the interference effects.

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Abstract ID: 473

NONLINEAR EFFECTS IN A PT-SYMMETRIC SYSTEM OF PLANAR COUPLED MAGNONIC WAVEGUIDES

O. Temnaya[1], A. Safin[1,2], S. Nikitov[1,3,4]

[1] *Kotel'nikov Institute of Radioengineering and Electronics, RAS, 125009, Moscow, RUSSIA*
[2] *National Research University "MPEI", 111250, Moscow, RUSSIA*
[3] *Moscow Institute of Physics and Technology, 141701, Dolgoprudny, RUSSIA*
[4] *Saratov State University, 410071, Saratov, Russia*
E-mail: arnellemorte@gmail.com

PT-symmetry is an interesting phenomenon in modern physics that is widely studied in science and technology [1-3]. Recent studies show that the use of PT-symmetric systems in electronics also turns out to be helpful because this makes it possible to reduce the linewidth and noise. These exciting effects manifest themselves at exceptional points where the normal modes of the system degenerate. We study the behavior of PT-symmetric magnon systems in a nonlinear regime. The system consists of two identical ferromagnetic-normal metal structures connected by magnetic dipole interaction. A direct current is applied to the normal metal layers to amplify and attenuate the spin waves. We analyze the dynamics of the exceptional point as a function of additional attenuation, dc, and coupling strength. Such a study is necessary to understand how the system's characteristics will change in large fields; it deepens knowledge of the nature of exceptional points, in general.

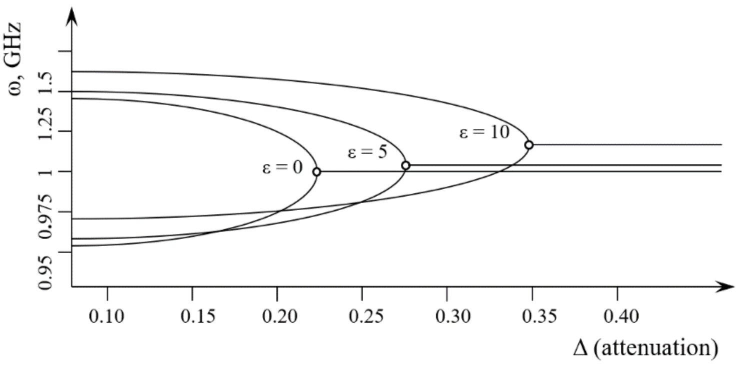

Fig. 1: *Dependence of the exceptional point's position depending on attenuation of spin waves and the parameter of nonlinearity* ε

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Abstract ID: 482

MICROSTRUCTURE AND STRUCTURAL PROPERTIES OF SUPERCONDUCTING CERAMICS $Bi_2Sr_2CaCu_2Fe_xO_{8-\delta}$

Fatima Harma, Karima Belakroum

Ksdi Marbah University, Dept. of Physics, Laboratory for the development of new and renewable energies in arid and Saharan zones, Ouargla, ALGERIA

E-mail: harmaf996@gmail.com

In our work, we studied the nature of superconducting materials, which are characterized by the importance of high technology and continuous development, where we approached the study of doping with iron on Bi-Sr-Ca-Cu -O ceramic compounds, its prepare by solid-state reaction. which is one of the compounds of the Bi-2212 phase using X-ray powder diffraction to follow the formation of the Bi-2212 phase and other phases, an electron microscope scanning was used in order to obtain an image of the microstructure of the grains of the samples studied and the degree of cohesion and condensation of the grains of all the phases obtained.

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Abstract ID: 511

NEW CHALCOGENIDE PHOTOVOLTAIC DEVICES FOR ARCHITECTURAL INTEGRATION

S. Porcar, A. Lahilahi, D. Fraga, J.G. Cuadra, R. Cadena, H. Samtos, J.B. Carda

Universitat Jaume I de Castellón. Inorganic and Organic Chemistry Dept. Avguda Sos Baynat s/n 12071 Castellón, SPAIN

E-mail: samuel.porcar@gmail.com

The development of wide bandgap, stable and low temperature processing materials will allow the extension of PV device concepts to new kinds of lightweight and/or mechanically flexible and/or semitransparent solar modules. This will enable novel applications for which traditional PV modules are incompatible, and address the needs for efficient, flexible and lightweight modules better adapted for advanced PV applications [1,2]. Sb2(S,Se)3, offer huge potential for advanced PV concepts such as tandem and semi-transparent devices, thanks to the unique combination of optical, electrical and structural properties of these materials. Figure 1 shown a typical Sb2(S,Se)3 device, that consist on: the absorber, a Sb2Se3 layer that is a p-type semiconductor, the buffer, a thin film done by CdS (an n-type semiconductor) and two conductive layers that help to close the circuit. The work is focused on the development of new Sb2Se3 solar cell device. The above mentioned material have been prepared by solution-based chemical route: electroplated. Further, low-temperature annealing process will be applied to enhance material crystallinity and substrate adhesion. This method of preparation is easy to be applied at large scale production and could be very attractive for industrial application. Special attention was pressed on crystal structure and morphological characterization, thin film deposition and final product performances to develop high-performance photovoltaic devices based on antimony selenium based absorber compound. For this purpose, the obtained films were characterized by X-Ray diffraction (XRD), scanning electron microscope (SEM) and Raman spectroscopy. Also optoelectronic analysis was done to obtain the dispositive efficiency.

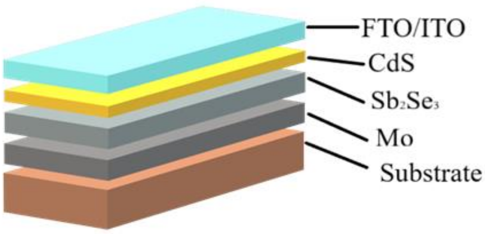

Fig. 1: *Scheme of Sb2(S,Se)3 device.*

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Abstract ID: 519

INFLUENCE OF Nd-SUBSTITUTION ON THE STRUCTURAL & DIELECTRIC PROPERTIES OF (Ca-Bi) COBALTITES SYNTHESIZED BY SOL-GEL METHOD

Haris Farooq Kiani[1,2], M. Anis ur Rehman[1]

[1] *Applied Thermal Physics Laboratory (ATPL), Department of Physics, COMSATS University Islamabad, Islamabad 45550, PAKISTAN*

[2] *Advanced Material & Intelligent Manufacturing Laboratory, Shanghai Jiao Tong University, Minhang, Shanghai 200240, CHINA*

E-mail: harisfarooqkiani@gmail.com & marehman@comsats.edu.pk

Renewable energy resources are becoming more popular around the world as a nonpolluting energy generation choice with a substantial impact on the green economy. For long-term energy production, thermoelectricity is the best technology for converting waste heat into electrical energy. Calcium Bismuth Cobaltites $Ca_{2.7}Bi_{0.3}Co_4O_{9+\delta}$ were synthesized using WOWS (Without water & surfactants) Sol-gel technique with concentration of (x=0.0,0.20) doped with Neodymium (Nd). For further characterizations, pellets of various compositions were formed and sintered. The Monoclinic structure of all the prepared samples was validated using the XRD (X-ray diffraction) technique. The Average crystallite size of the sample was determined to be between 17nm and 25nm. The properties of calcined samples were further investigated using Fourier transform infrared spectroscopy (FTIR). The Transport properties AC conductivity (σ_{ac}) and Dielectric properties include dielectric constant (ε') dielectric loss (ε''), Tangent loss (tanδ), Impedance real (Z') & imaginary parts (Z'') were measured at various frequencies and in the variable range (100Hz– 3MHz). The composition $Ca_{2.7}Bi_{0.10}Nd_{0.20}Co_4O_{9+\delta}$ achieved higher dielectric constant and lower dielectric loss than other compositions. $Ca_{2.7}Bi_{0.10}Nd_{0.20}Co_4O_{9+\delta}$ showed the highest value of AC conductivity. $Ca_{2.7}Bi_{0.10}Nd_{0.20}Co_4O_{9+\delta}$ showed that the most auspicious material for energy storage applications.

Abstract ID: 523

MAGNETIZATION AND HYSTERESIS LOSSES OF MgB_2 ROUND COMPOSITES AT DIFFERENT ORIENTATION OF APPLIED MAGNETIC FIELD

I. Rudnev[1,2], S. Hohorin[2], S. Pokrovskii[1,2], S. Veselova[1,2], D. Uvin[2], R. Batulin[2]

[1] *National Research Nuclear University MEPhI, 115409, Moscow, RUSSIA*
[2] *Kazan Federal University, 420008, Kazan, RUSSIA*
E-mail: iarudnev@mephi.ru

High-temperature superconductor (HTSC) MgB_2 attract much attention due to its low cost, relatively high T_c [1], relatively high operating current [2] and no need of liquid helium for cooling. It is well known that the anisotropy ratio $H_{c2||}/H_{c2}$ is about 2.7 for the bulk crystals and about 1.6-2.0 for thin films and aligned crystallites. However, there is lack of data in the literature for anisotropy of MgB_2 industrial round wires. The anisotropy effect plays an important role for the critical current, magnetization, and hysteresis losses and important for practical applications.

In this work, the magnetization of the MgB_2 industrial round wire (Columbus Superconductors) was measured by vibrational magnetometry at various temperatures in the range of 5 K–45 K and magnetic fields up to 5 T. The orientation of an applied magnetic field was varied from 0 to 90 degree with respect to the wire axis and corresponding hysteresis loops were measured. The ferromagnetic contribution of Fe and Ni (Nickel-alloy sheath) was subtracted and isolated magnetization loops due to the diamagnetic contribution of the MgB_2 superconducting phase were obtained. The dependences $J_c(H)$ as well as values of hysteresis losses were calculated from hysteresis curves for different temperatures. Obtained data are discussed in terms of anisotropy of MgB_2 superconducting properties and the influence of geometrical demagnetizing factor on magnetization value.

The study was supported by the Russian Science Foundation grant No. 22-72-10088.

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Abstract ID: 535

SPIN INJECTION INTO GRAPHENE THROUGH hBN TUNNEL BARRIERS

Shuo-Ying Yang[1], Juan F. Sierra[1], Sergio O. Valenzuela[1,2]

[1] *Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and The Barcelona Institute of Science and Technology (BIST), Barcelona, SPAIN*
[2] *Institució Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, SPAIN*
E-mail: shuoying.yang@icn2.cat

Two-dimensional materials, such as graphene and hBN, are emergent material systems for spintronics applications. Graphene is a good candidate for spin transport, owing to its long spin propagation distance and long spin lifetime. hBN can also be exfoliated to atomic layer thickness, which can be used as tunnel barrier with atomically sharp interface. We study the spin transport in fully hBN encapsulated monolayer graphene fabricated into spin valve devices. Using top layer of mono/bilayer hBN as tunnel barrier, spin injection is realized through ferromagnetic Co electrodes. Spin transport, precession and detection are studied through non-local spin valve and Hanle precession measurements.

Abstract ID: 538

ENHANCEMENT OF CRITICAL CURRENT FOR MgB_2 SUPERCONDUCTING WIRE BY AN ADVANCED IMD PROCESS

D.G. Lee[1], J.H. Choi[1], S.J. Lee[1], G.Y. Yoon[1], S.Y. Park[1], M. Maeda[2], S. Choi[2], J.H. Kim[3]

[1]Sam Dong Co., Ltd., 34027, Daejeon, KOREA
[2]Kangwon National University, 25913, Gangwon, KOREA
[3]University of Wollongong, NSW 2500, North Wollongong, AUSTRALIA
E-mail: dglee@samdong.com

To overcome the poor deformation and brittle nature of magnesium (Mg) and boron (B) mixtures, various metallic tubes are utilized to enable the production of >km-length MgB_2 wire through the power-in-tube (PIT) process. During sintering process, however, the volatile nature of Mg causes ~50% porosity inside the MgB_2 core filament, which negatively impacts its electrical properties. To address this issue, an internal Mg diffusion (IMD) process was developed, but fabrication of long-length remains challenging. In this study, Sam Dong employed an 'Advanced IMD' process that combined the long-length wire manufacture of the PIT process with high-density core of the IMD process. We used large-size Mg powder (> 200 μm) instead of conventionally available Mg powder (approximately 10 μm), which explore the possibility of elongation and dispersion inside the metallic tube as a feature of bundle during drawing process. As a result, we successfully produced flaw-free wire with a length of >1 km and high transport current, due to the fibrous structure of processed Mg that controls the shape and direction of MgB_2 grains.

Acknowledgement

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Abstract ID: 545

THE EFFECT OF Ti ON $Ni_{55}Fe_{18}Ga_{27}$ ALLOYS

M. Ozer, H. Gungunes

Hitit University, Department of Physics, 19030, Corum, TURKEY
E-mail: hgungunes@gmail.com

In this study, the effect of Ti element on the morphological, thermal mechanical and magnetic properties of Ni-37.79Ga-14.46Fe alloys was investigated. For the physical characterization of alloys; Scanning electron microscopy (SEM), Vickers micro hardness, differintial scanning calorimetry (DSC), vibrating sample magnetometer (VSM) and mösbauer spectrometry were used. According to DSC results, no phase transition was observed in the 0-600 ^{o}C range. It was determined that the vickers hardness decreased with the increase of Ti amount. The Mössbauer spectra of the alloys composed of 2 doublet and 1 sextet. Acording to Mössbauer results, it was determined that the isomer shift values did not change with the increase of Ti amount, however, the cubic symetry of the nucleus is disordered and amount of paramagnetic phase increased with increased Ti amount. It was determined by compression tests that the mechanical properties decreased with the increase of Ti. The alloy with the greatest ductility was determined as Ni-15.29Fe-37.26Ga-0.53Ti. It was determined by magnetization curves obtained at room temperature that the M_s, M_r and H_c values decreased with the increase of Ti amount in the alloys.

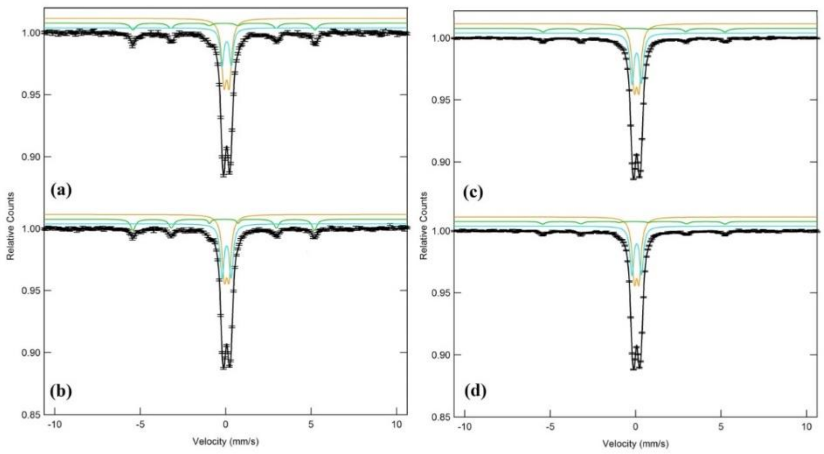

Fig. 1: *Room Temperature Mössbauer Spectra of (a) Ni-37.79Ga-14.46Fe (b) Ni-15.55Fe-36.93Ga-0.12Ti (c) Ni-15.29Fe-37.26Ga-0.53Ti (d) Ni-15.1Fe-37.45Ga-0.65Ti Alloys.*

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Abstract ID: 551

MAGNETIC AND MAGNETOCALORIC PROPERTIES OF THE $LaFe_{11.1-x}Mn_xCo_{0.7}Si_{1.1}$ (x=0.1, 0.2, 0.3) ALLOYS

N.Z. Abdulkadirova[1], A.G. Gamzatov[1], K.I. Kamilov[1,2], A.M. Aliev[1], P. Gebara[3]

[1]*Amirkhanov Institute of Physics, DFRC, Makhachkala, RUSSIAN FEDERATION*
[2]*Department of Physics, M.V. Lomonosov Moscow State University, Moscow, 119991, RUSSIAN FEDERATION*
[3]*Institute of Physics, Częstochowa University of Technology, Częstochowa, 42-200,*
E-mail: nnurizhat@mail.ru

From the point of view of the use of materials in magnetic cooling technology, materials with phase transitions (PT) of the second kind are of greater interest. An excellent example of such materials is compounds based on the La-Fe-Co-Si system with a second-order phase transition [1], although the initial La-Fe-Si compositions exhibit a first-order phase transition [2].

In La-Fe-Si alloys, large values of the change in magnetic entropy are a consequence of giant magneto-volume effects (where the change in the lattice volume can reach ~ 1%). One of the first to pay attention to this was the authors of [2], where it was shown that a large negative expansion of the lattice is the main reason for the giant values of the MCE. However, the presence of giant magnetovolume effects makes experiments on magnetostriction in pulsed magnetic fields very difficult, since the sample is prone to cracking (and sometimes the sample is completely destroyed) even after the initial magnetization. This can be explained not only by the change in volume itself, but also by the high rate of field sweep in the sources of pulsed magnetic fields, which increases the mechanical stress in the sample.

This paper presents the results of a study of the magnetization, magnetostriction and magnetocaloric effect of $LaFe_{11.1-x}Mn_xCo_{0.7}Si_{1.1}$ alloys (x=0.1, 0.2, 0.3) in the temperature range of 80-300 K in pulsed magnetic fields up to 180 kOe. Partial substitution of Fe by Mn leads to a slight decrease in T_c (T_c=247, 222, 202 K for x=0.1, 0.2, and 0.3, respectively). Direct and indirect methods were used to estimate the magnetocaloric properties. Magnetostriction measurements were carried out in a longitudinal configuration, i.e. with a field parallel to the change in length ($\Delta l/l$).

The dependence of ΔS_M on the magnetic field near the T_C for all samples is described by the power law $\Delta S_M \sim H^{2/3}$ without signs of saturation up to 180 kOe, which is typical of second-order phase transitions. The maximum values of ΔS_M for $LaFe_{11.1-x}Mn_xCo_{0.7}Si_{1.1}$ alloy in a field of 180 kOe are 38, 30, and 32 J/kg K, respectively, for x=0.1, 0.2, 0.3. Those partial substitution of Fe for Mn makes it possible to control the T_c, while the value of the MCE changes insignificantly. The results of the study of magnetostriction show that for all samples the field dependences of magnetostriction tend to saturation at H~120 kOe. A further increase in the magnetic field from 120 kOe to 180 kOe leads to an increase in magnetostriction by approximately ~6%. This behavior is a consequence of the fact that in strong magnetic fields for $LaFe_{11.1-x}Mn_xCo_{0.7}Si_{1.1}$ (x=0.1, 0.2, 0.3) alloys with a phase transition close to a second-order transition, the magnetic contribution to the MCE dominates over the lattice contribution [3].

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Abstract ID: 552

THE ROLE OF MICROSTRUCTURE IN THE STRONG FREQUENCY DEPENDENCE OF THE MAGNETOCALORIC EFFECT IN THE $Pr_{0.7}Sr_{0.2}Ca_{0.1}MnO_3$ MANGANITE: DIRECT MEASUREMENT

A.G. Gamzatov, A.T. Kadirbardeev, N.Z. Abdulkadirova, A.M. Aliev

Amirkhanov Institute of Physics, DFRC, RAS, 367003, Makhachkala, RUSSIA
E-mail: nnurizhat@mail.ru

Manganites are prominent representatives of materials with giant values of the magnetocaloric effect [1]. The study of the influence of grain size on physical properties including the magnetocaloric effect of manganites has been studied in detail. This paper presents the results of a study of the influence of the size of granules (microstructure) on the value and frequency stability of the magnetocaloric effect of $Pr_{0.7}Sr_{0.2}Ca_{0.1}MnO_3$ manganite in a cyclic magnetic field of 1.2 T. These samples were prepared by a combination of the solid-state reaction and the mechanical ball milling methods. Ceramics with different sizes of granules were obtained (see Fig.1 (a-c)). The magnetocaloric effect was studied by the direct method of magnetic field modulation.

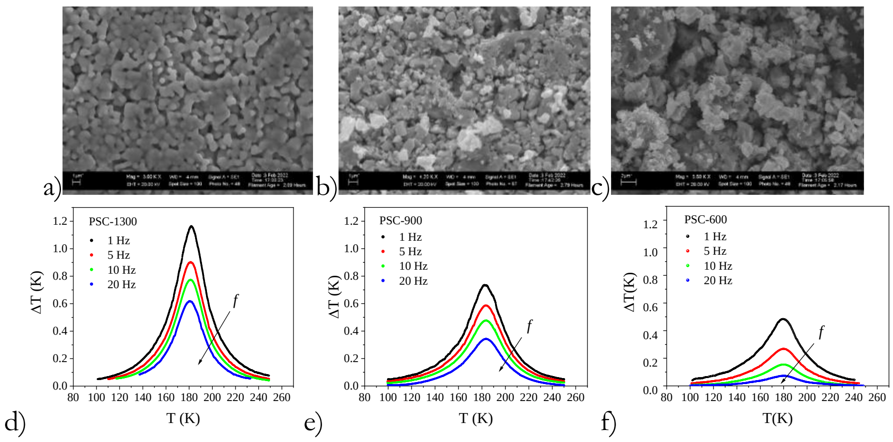

Fig. 1: *(a-c)-SEM for PSC-1300, 900, 600. (d-e)- Temperature dependences of ΔT for PSC-1300(d), 900(e), 600(f) samples in a field H=1.2 T with frequencies of 1, 5, 10, and 20 Hz.*

Figure 1(d-f) shows the temperature dependences of the MCE at different magnetic field frequencies for samples PSC-1300, 900, 600 (d, e, f). As can be seen, for all samples, a decrease in the MCE is observed over the entire temperature range with increasing frequency. The decrease in the effect with increasing frequency from 1 to 20 Hz is approximately 47%, 54% and 81%, respectively, for PSC-1300, 900, 600. A decrease in the grain size in $Pr_{0.7}Sr_{0.2}Ca_{0.1}MnO_3$ manganite leads both to a decrease in the MCE and to a stronger frequency dependence of ΔT. The decrease in the MCE depending on the size of the granules is presumably associated with a decrease in the magnetization, which is associated with a change in the ratio of the core and the near-surface layer of the granule. The strong frequency dependence of the MCE has a more complex origin and may be a combination of several frequency-dependent mechanisms that require more detailed studies.

The study was supported by the Russian Science Foundation grant No. 22-19-00610.

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Abstract ID: 570

EFFECT OF TRANSITION METAL SUBSTITUTION TO Ni-Mn-Sb HEUSLER ALLOY ON MAGNETIC PROPERTIES

M. Ayyildız[1], G. Kirat[2], M.A. Aksan[1]

[1] *Inonu Universitesi, Fen Edebiyat Fakultesi, Fizik Bolumu, 44100 Malatya, TURKEY*
[2] *Inonu Universitesi, Scientific and Technological Research Center, 44100 Malatya, TURKEY*
E-mail: ayyildizmurat44@gmail.com

In this study, the effect of the substitution of Mo, which is one of transition metals, on the magnetic properties of Ni-Mn-Sb Heusler alloy was investigated in detail. In this purpose, $Ni_{50-x}Mo_xMn_{37}Sb_{13}$+$B_2$ (x=0, 1, 3, 5 and 7) were prepared by the arc-melting technique. The martensite phase transition (MT) temperatures shifted to low temperatures as the Mo-content increased. As the temperature was decreased from high temperatures, the samples showed a two-step transition, which is attributed to a premartensitic transformation. It was found that the premartensitic transformation interval decreased with the increase of Mo content in the system. It was observed that the blocking temperature (T_B) was affected by the Mo-substitution. Exchange bias effect was observed in the samples as seen in figure 1. It was seen that The Mo-substitution gradually decreased the shift from the origin in the FC M-H curves. H_E and H_c decreased with increasing the Mo-content in the system. M-H measurements showed that samples x=1, 3 and 5 have double shifted hysteresis loops. From Arrott-Plot curves it was observed that there is a first-order phase transition behavior in phase transition region at low magnetic fields, however, second order phase transition behavior with increasing the magnetic field.

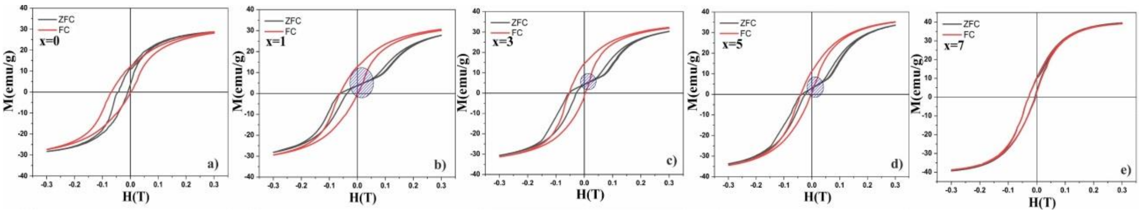

Fig. 1: *ZFC and FC M-H curve of $Ni_{50-x}Mo_xMn_{37}Sb_{13}$+$B_2$ (x=0, 1, 3, 5 and 7) alloys.*

Acknowledgements

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Abstract ID: 572

MAGNETIC FIELD INDUCED SHAPE MEMORY PROPERTIES IN $Ni_{50-y}Cr_yMn_{37}Sb_{13}+B_2$ HEUSLER ALLOY

M. Ayyildiz[1], G. Kirat[2], M.A. Aksan[1]

[1] *Inonu Universitesi, Fen Edebiyat Fakultesi, Fizik Bolumu, 44100 Malatya, TURKEY*
[2] *Inonu Universitesi, Scientific and Technological Research Center, 44100 Malatya, TURKEY*
E-mail: ayyildizmurat44@gmail.com

In this study, effect of the Cr substitution into $Ni_{50-y}Cr_yMn_{37}Sb_{13}+B_2$ (y=0, 3, 5 and 7) Heusler system prepared by arc melting method on electrical, magnetic properties were investigated. It was found that the samples with the low Cr-content are in the martensite phase at the room temperature, but ones with low Cr-content are in austenite phase at the room temperature. The Cr-substitution into $Ni_{50}Mn_{37}Sb_{13}+B_2$ Heusler system caused a decrease in the martensite phase transition. A magnetic field-induced phase transformation occurred from ferromagnetic austenite phase to weak magnetic martensite phase with decreasing the temperature under magnetic field. The hysteresis obtained in *M-H* loops confirmed a magnetic field-induced transformation in the samples. It was seen that FC *M-H* hysteresis loops shifted to the negative field axis of *M-H* plot, indicating exchange bias effect (EB). The dependence of the magnetic entropy change on the field and temperature reveals that there is a first-order magnetic phase transition in the samples. The magnetocaloric effect properties were investigated by applying the Maxwell's equations to isothermal magnetization data.

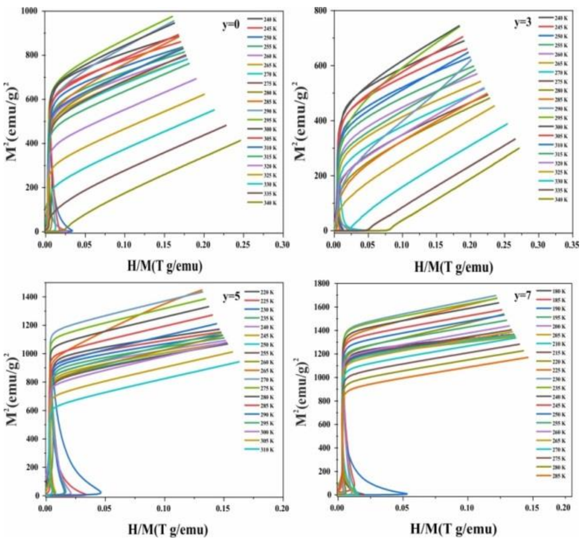

Fig. 1: $M^2-(H/M)$ *(Arrott-Plot) plots of* $Ni_{50-y}Cr_yMn_{37}Sb_{13}+B_2$ *(y=0, 3, 5 and 7) samples at different temperatures.*

Acknowledgements

This work was supported by the Research Fund of Inonu University, Turkey under Grant Contract No. FDK-2022-2892.

Abstract ID: 579

MAGNETIC PROPERTIES OF LUDWIGITES $Mn_{1.17}Co_{1.83}BO_5$ AND $Mn_{1.39}Co_{1.61}BO_5$

D.V. Popov[1], T.P. Gavrilova[1], M.A. Cherosov[2], V.A. Shustov[1], E.M. Moshkina[3], I.I. Fazlizhanov[1], R.M. Eremina[1]

[1]*Zavoisky Physical-Technical Institute, FRC KSC of RAS, 420029 Kazan, RUSSIA*
[2]*Kazan (Volga Region) Federal University, Kremlevskaya st., 18, 420008 Kazan, RUSSIA*
[3]*Kirensky Institute of Physics, FRC KSC SB RAS, 660036 Krasnoyarsk, RUSSIA*
E-mail: reremina@yandex.ru

Oxiborates with ludwigite type structures (structural formula $M_2M'BO_5$, where M and M' are metallic ions with valence 2+ and 3+ respectively) bears some extremely unusual magnetic properties, such as random magnetic ions distribution, mixed valence, strong electronic correlations, uncommon charge ordering, etc [1]. These properties are caused by zigzag walls in their crystal structure formed by the metal ions of different valence.

$Mn_{1.17}Co_{1.83}BO_5$ and $Mn_{1.39}Co_{1.61}BO_5$ ludwigites were synthetized by the flux technique and investigated by means of X-ray diffraction, X-ray fluorescence analyses, static and AC magnetic susceptibility and specific heat methods. The crystal structure of both ludwigites belongs to the Pbam space group with a = 9.25Å, b = 12.41Å and c = 3.05Å for $Mn_{1.17}Co_{1.83}BO_5$ and a = 9.27Å, b = 12.45Å and c = 3.05Å for $Mn_{1.39}Co_{1.61}BO_5$. The simultaneously observed negative values of the Curie-Weiss temperatures and ferromagnetic-like hysteresis loops allow us to assume that the ferrimagnetic ordering is realized in $Mn_{1.39}Co_{1.61}BO_5$ at T_{PhT} = 60.8K, while in $Mn_{1.17}Co_{1.83}BO_5$ the in addition to the above the frequency dependence of the real and imaginary parts of the magnetization was observed assuming the presence of the canonical spin-glass state below $T_{PhT} \approx$ 42.3K. An exchange bias of high values was observed for $Mn_{1.17}Co_{1.83}BO_5$ (see Fig1). The effective magnetic moments per unit cell are $\mu_{eff}=8.06\mu_B$ for $Mn_{1.17}Co_{1.83}BO_5$ and $\mu_{eff}=9.03\mu_B$ for $Mn_{1.39}Co_{1.61}BO_5$.

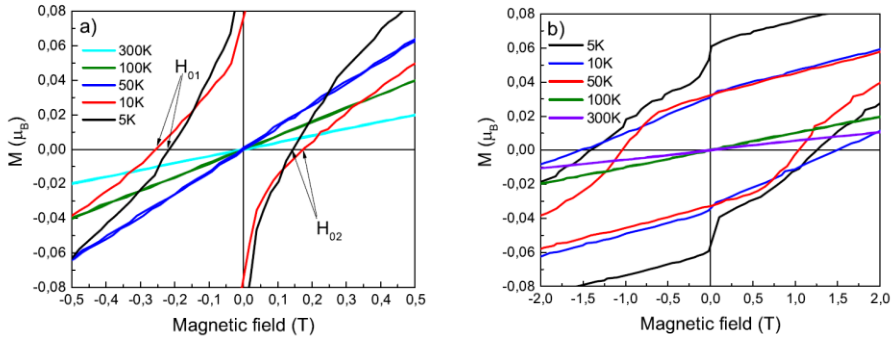

Fig. 1: *Isotherm magnetization in a) $Mn_{1.17}Co_{1.83}BO_5$ and $Mn_{1.39}Co_{1.61}BO_5$ ludwigites.*

The work was performed with the financial support from the RSF 23-72-00047.

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Abstract ID: 585

MAGNETIC OXIDE CERAMICS FOR SPINTRONIC APPLICATIONS

Cristina Bartha[1], Andrei Alexandru-Dinu[1,2], Mihai Grigoroscuta[1], Cezar Comanescu[1,2], Nicu Iacob[1], Claudiu Locovei[1], Aurel Leca[1], Petre Badica[1]

[1] *National Institute of Materials Physics, Atomistilor str. 405A, Bucharest-Magurele, ROMANIA*
[2] *Faculty of Physics, University of Bucharest, Street Atomistilor 405, 077125 Magurele, ROMANIA*
E-mail: cristina.bartha@infim.ro

Electric-field control of magnetism has remained a major challenge which would greatly impact especially data storage technology, but also other types of logic and electromagnetically controlled devices. Control of magnetic properties by an electric field would enable new data storage technologies operating at low electrical power. Although the electric field could be used to manipulate a wide range of magnetic properties, e.g. Curie temperature, magnetic moment, coercivity, and magnetic anisotropy, the realization of 180° magnetization switching could only be obtained in few systems [1-3]. This work is centered on the design, fabrication and properties characterization of an innovative material (garnet) with the $Gd_3Fe_5O_{12}$ structure with suitable magnetic properties for high performance spintronic applications such as magnetic memories or devices based on logic operations, electromagnetically controlled. The proposed material was obtained by our original technological route that combines a cheap and facile surfactant assisted hydrothermal method to prepare mesoporous $RE_3Fe_5O_{12}$ powders followed by sintering. Garnet materials have been characterized by structural, microstructural, hyperfine (Mossbauer spectroscopy) and magnetic properties seeking technology-properties relationships and control.

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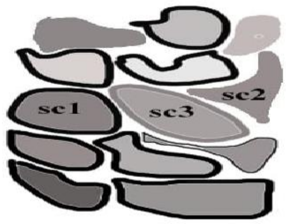
Abstract ID: 594

MODELING OF GRANULAR SUPERCONDUCTOR USING LONG JOSEPHSON JUNCTION APPROACH

I.N. Askerzade[1], D. Matrasulov[2], R.T. Askerbeyli[3], M. Salati[1]

[1] *Department of Computer Engineering, Ankara University, 06100, Ankara, TURKEY*
[2] *Turin Polytechnic University in Tashkent, 17 Niyazov Str., 100095, Tashkent, UZBEKISTAN*
[3] *Karabuk University, Numerical metods of Business Administration Dept, Karabuk, TURKEY*
E-mail: raskerbeyli@karabuk.edu.tr

The model for granular superconductor on Josephson junctions (Fig.1) will be discussed. Long Josephson junction on the basis of granular superconductors will be used. It is well known that the increasing of critical current density of granular compounds is important from the point of high-scale applications [1-3]. The influence of the result in long Josephson junction with alternating critical current density will be considered. Possible effects of external magnetic field and pinning effects on averaged current-voltage characteristics of granular medium will be discussed. Detalization of results can be obtained by using the sine-Gordon soliton solutions in branched Josephson junctions created by granular superconductors.



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Abstract ID: 595

MAGNETIC PROPERTIES OF RARE EARTH IRON GARNETS PREPARED BY TWO SYNTHESIS ROUTES

Andrei Alexandru-Dinu[1,2], Cristina Bartha[1], Mihai Grigoroscuta[1], Cezar Comanescu[1,2], Nicu Iacob[1], Claudiu Locovei[1], Dana Radu[1], Aurel Leca[1], Victor Kuncser[1], Petre Badica[1]

[1] *National Institute of Materials Physics, Atomistilor str. 405A, Bucharest-Magurele, ROMANIA*
[2] *Faculty of Physics, University of Bucharest, Street Atomistilor 405, 077125 Magurele, ROMANIA*
E-mail: andrei.alexandrudinu@infim.ro

Rare earth (RE) iron garnets $RE_3Fe_5O_{12}$ are fascinating insulators with various magnetic phases and a distribution of properties. Among them, their magnetic properties play an essential role in the design and manufacture of new sensors and advanced spintronic devices that operate at low power.

It is remarkable that the magnetic response of the garnet samples can be controlled by magnetic and electric fields and by temperature variation. Very few materials [1-3] allow full magnetization switching with 180 °C and garnets are among those showing such features. Their specific crystal structure is comprised of two sub lattices of RE and of Fe and their interaction explains rich and complex magnetic properties of these materials. An essential factor in the control of these couplings, respectively, of the properties is represented by the processing methods. At present some aspects are not fully understood and require further research.

In this work we explore comparatively structural, microstructural, and magnetic properties of garnets, where rare earth elements are Dy, Tb, Ho. Samples are prepared by a chemical route, namely by a surfactant assisted hydrothermal method, and by conventional solid state reaction starting from oxide raw materials. We found that it is hard to obtain single phase materials for samples with Ho when using the chemical route. Magnetic assessment of the materials is performed by magnetometry using SQUID and PPMS systems. The relationship between technology and properties considering also the influence of RE is discussed.

Authors acknowledge project PN-III-P2-2.1-PED-2021-2007 (contract no. 676PED/2022) funded by the Romanian Ministry of Research, Innovation, and Digitalization through UEFSCDI

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Abstract ID: 603

MAGNETIC PROPERTIES OF LUDWIGITES $Mn_{1.17}Co_{1.83}BO_5$ AND $Mn_{1.39}Co_{1.61}BO_5$

D.V. Popov[1], T.P. Gavrilova[1], M.A. Cherosov[2], V.A. Shustov[1], E.M. Moshkina[3], I.I. Fazlizhanov[1], R.M. Eremina[1]

[1]Zavoisky Physical-Technical Institute, FRC KSC of RAS, 420029 Kazan, RUSSIA
[2]Kazan (Volga Region) Federal University, Kremlevskaya st., 18, 420008 Kazan, RUSSIA
[3]Kirensky Institute of Physics, FRC KSC SB RAS, 660036 Krasnoyarsk, RUSSIA
E-mail: ilshat2004@yandex.ru

Oxiborates with ludwigite type structures (structural formula $M_2M'BO_5$, where M and M' are metallic ions with valence 2+ and 3+ respectively) bears some extremely unusual magnetic properties, such as random magnetic ions distribution, mixed valence, strong electronic correlations, uncommon charge ordering, etc [1]. These properties are caused by zigzag walls in their crystal structure formed by the metal ions of different valence.

$Mn_{1.17}Co_{1.83}BO_5$ and $Mn_{1.39}Co_{1.61}BO_5$ ludwigites were synthetized by the flux technique and investigated by means of X-ray diffraction, X-ray fluorescence analyses, static and AC magnetic susceptibility and specific heat methods. The crystal structure of both ludwigites belongs to the Pbam space group with a = 9.25Å, b = 12.41Å and c = 3.05Å for $Mn_{1.17}Co_{1.83}BO_5$ and a = 9.27Å, b = 12.45Å and c = 3.05Å for $Mn_{1.39}Co_{1.61}BO_5$. The simultaneously observed negative values of the Curie-Weiss temperatures and ferromagnetic-like hysteresis loops allow us to assume that the ferrimagnetic ordering is realized in $Mn_{1.39}Co_{1.61}BO_5$ at T_{PhT} = 60.8K, while in $Mn_{1.17}Co_{1.83}BO_5$ the in addition to the above the frequency dependence of the real and imaginary parts of the magnetization was observed assuming the presence of the canonical spin-glass state below $T_{PhT} \approx$ 42.3K. An exchange bias of high values was observed for $Mn_{1.17}Co_{1.83}BO_5$ (see Fig1). The effective magnetic moments per unit cell are $\mu_{eff}=8.06\mu_B$ for $Mn_{1.17}Co_{1.83}BO_5$ and $\mu_{eff}=9.03\mu_B$ for $Mn_{1.39}Co_{1.61}BO_5$.

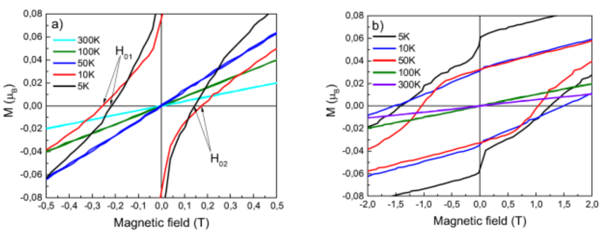

Fig. 1. *Isotherm magnetization in (a) $Mn_{1.17}Co_{1.83}BO_5$ and (b) $Mn_{1.39}Co_{1.61}BO_5$ ludwigites.*

The work was performed with the financial support from the RSF 23-72-00047.

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Abstract ID: 615

NATURAL STRATEGIES FOR CREATING NON-EQUILIBRIUM MORPHOLOGY WITH SELF-REPAIRING CAPABILITY TOWARDS RAPID GROWTH OF YBCO BULKS

Xin Yao

School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai 200240, CHINA
E-mail: xyao@sjtu.edu.cn

The fabrication of sizable $YBa_2Cu_3O_{7-\delta}$ (YBCO) bulks in top-seeded melt-growth can be realized by multiple-seeds and large-sized seed with a rapid coverage on the *a-b* plane. However, in the former one, imprecision in seeding alignment leads to a detrimental impact on grain boundaries. For the latter case, bulbs hardly release from growing samples, resulting in an increased porosity in bulks. Those demerits negatively affect superconducting properties. Here, we developed two novel seeding strategies for creating incomplete crystallographic shapes (i.e., right-angled concave corners) of YBCO superconducting crystals with self-repairing capability. One is in situ self-assembly seeding, by which self-reparability promotes YBCO growth, while the other is vertically-connected seeding, by which self-reparability triggers YBCO nucleation. Consequently, due to the nature of non-equilibrium morphology, rapid surface crystallization originated at concave corners and swiftly generated initial growth morphology approaching equilibrium. Furthermore, these rapid-growth regions including the concave crystal or seed innately functioned as sizable effective seeding regions, enabling the enlargement of *c*-oriented growth sector and the enhancement of properties for YBCO crystals. This nature-inspired self-repairing work offers insights into the design of seeding architecture with non-equilibrium morphology for inducing sizable high-performance crystals in the YBCO family and other functional materials.

Abstract ID: 625

EFFECT OF Zn/Cu SUBSTITUTION ON THE MICROSTRUCTURAL, SUPERCONDUCTING AND MAGNETIC PROPERTIES OF YBCO SUPERCONDUCTORS

S. Safran[1], O. Ozturk[2], G. Guducu[2], S. Kurnaz[2], H. Koralay[3]

[1]*Ankara University, Faculty of Sciences, Department of Physics, 06100, Tandoğan Ankara, TÜRKIYE*
[2]*Kastamonu University, Department of Electrical and Electronics Engineering, 37210 Kastamonu, TÜRKIYE*
[3]*Gazi University, Faculty of Sciences, Department of Physics, Teknikokullar, Ankara, TÜRKIYE*
E-mail: safranserap@gmail.com

The effect of Zn/Cu substitution on the electrical, superconducting, structural, and magnetic properties of Y-123 and Y-358 ceramic materials is examined using powder X-ray diffraction, electrical resistivity, scanning electron microscopy, energy dispersive X-ray spectrometry, and related calculations. $YBa_2Cu_{3-x}Zn_xO_{7-\delta}$ and $Y_3Ba_5Cu_{8-x}Zn_xO_{7-\delta}$ samples are prepared using the sol-gel technique at four different molar percentages ($0.0 \leq x \leq 0.15$). The Bean model and DC magnetization data are used to determine how the critical current densities vary in response to an applied magnetic field. Energy-dispersive X-ray spectrometry measurements indicate that materials are precisely synthesized in the required stoichiometric ratios. Additionally, all of the experimental findings demonstrate that the replacement mechanism causes the fundamental specific features to decline. The substitution mechanism's adverse effects include the beginning of weak-interaction challenges between surrounding superconductive layers, the formation of tiny defects in the structure, and the decoupling of superconducting grains.

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PROXIMITY SUPERCONDUCTIVITY IN ATOM-BY-ATOM CRAFTED QUANTUM DOTS (THEORY): THE MACHIDA-SHIBATA STATE

Lucas Schneider[1], Khai That Ton[1], Ioannis Ioannidis[2,3], Jannis Neuhaus-Steinmetz[1], Thore Posske[2,3], Roland Wiesendanger[1], Jens Wiebe[1]

[1]Department of Physics, University of Hamburg, D-20355 Hamburg, GERMANY
[2]I. Institute for Theoretical Physics, University of Hamburg, D-22607 Hamburg, GERMANY
[3]Centre for Ultrafast Imaging, Luruper Chaussee 149, D-22761 Hamburg, GERMANY
E-mail: ioannis.ioannidis@uni-hamburg.de

Gapless materials in electronic contact with superconductors acquire proximity-induced superconductivity in a region near the interface. Numerous proposals build on this addition of electron pairing to originally non-superconducting systems like ferromagnets and predict intriguing quantum phases of matter, including topological, odd-frequency, or nodal-point superconductivity. However, atomic-scale experimental investigations of the microscopic mechanisms leading to proximity-induced Cooper pairing in surface or interface states are missing. Here, we investigate the most miniature example of the proximity effect on only a single quantum level of a surface state confined in a quantum corral on a superconducting substrate, built atom-by-atom by a scanning tunneling microscope. Whenever an eigenmode of the corral is pitched close to the Fermi energy by adjusting the corral's size, a pair of particle-hole symmetric states enters the superconductor's gap. We identify the in-gap states as spin-degenerate Andreev bound states theoretically predicted 50 years ago by Machida and Shibata, which had so far eluded detection by tunnel spectroscopy. We further find that the observed anticrossings of the in-gap states indicate proximity-induced pairing in the quantum corral's eigenmodes. Our results have direct consequences on the interpretation of impurity-induced in-gap states in unconventional or topological superconductors, corroborate concepts to induce superconductivity into a single quantum level and further pave the way towards superconducting artificial lattices. In this poster presentation, we focus on the theoretical description of the phenomena using a Green's function approach.

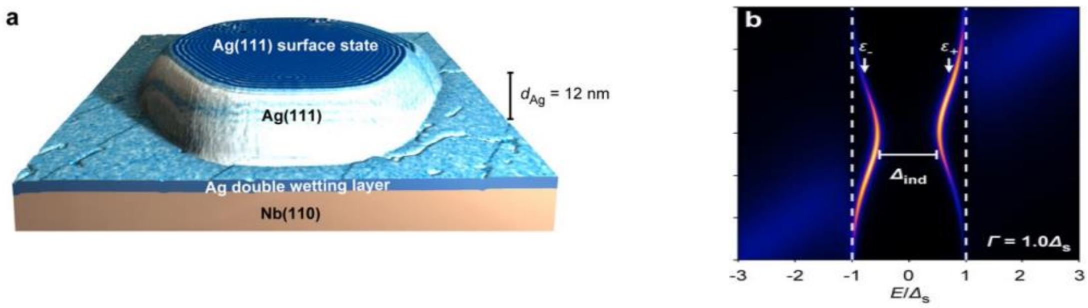

Fig. 1: *(a) Experimental setup showing the emerging surface states at the surface of Ag (111). (b) Density of states of the Machida-Shibata states from resonance scattering at a spin degenerate localized level.*

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THE EFFECT OF PARTICLE SIZE ON STRUCTURAL AND MAGNETIC PROPERTIES OF $Zn_{0.5}Co_{0.5}Fe_2O_4$ PREPARED BY GLYCOL-THERMAL TECHNIQUE

S.J.C. Masuku[1], J.Z. Msomi[1], T. Moyo[2], T.A. Nhlapo[3]

[1]Department of Chemical and Physical Sciences, Walter Sisulu University, P/bag X01, Mthatha, 5117, SOUTH AFRICA
[2]School of Chemistry and Physics, University of KwaZulu-Natal, SOUTH AFRICA
[3]Department of Medical Physics, Sefako Makgatho Health Sciences University, P. O Box 146, Medunsa, 0204, SOUTH AFRICA
E-mail: smasuku@wsu.ac.za

$Zn_{0.5}Co_{0.5}Fe_2O_4$ powders were prepared by the glycol-thermal method and subsequently annealed in air from 400 ^{0}C to 1100 ^{0}C for 4 hours. The general increase crystallite sizes from 8 nm to 22 nm with creasing annealing temperature was observed. The effect of increasing particles was investigated by using Mössbauer spectroscopy, transmission electron microscopy (TEM) and magnetization measurements. The X-ray diffraction (XRD) patterns confirm the formation of a spinel phase structure without any impurity peaks. TEM data revealed agglomerated particles with nearly spherical shapes. The reduction in micro strain with increasing particle size observed can be explained by reducing residual stress in the crystal lattice due to annealing. The Mössbauer spectra could be resolved into three sextets and two quadrupole doublets associated with ordered and paramagnetic ^{57}Fe nuclei at the tetrahedral (A) and octahedral (B) sites. The presence of both magnetic sextets and doublets reveals superparamagnetic relaxation and blocking temperatures higher than the room temperature (~300 K). The ZFC and FC magnetization measurements confirmed blocking temperature above 380 K. An increase in coercive magnetic fields from 0.1 Oe at 300 K to about 30 kOe at 10 K due to spin freezing at lower temperature has been observed.

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Abstract ID: 633

THE EFFECT OF SUBSTITUTION OF Cd^{2+}ION ON THE STRUCTURAL AND MAGNETIC PROPERTIES OF $CoFe_2O_4$ NANOPARTICLES

S.J.C. Masuku[1], J.Z. Msomi[1], T. Moyo[2], T.A. Nhlapo[3]

[1]*Department of Chemical and Physical Sciences, Walter Sisulu University, P/bag X01, Mthatha, 5117, SOUTH AFRICA*
[2]*School of Chemistry and Physics, University of KwaZulu-Natal, SOUTH AFRICA*
[3]*Department of Medical Physics, Sefako Makgatho Health Sciences University, P. O Box 146, Medunsa, 0204, SOUTH AFRICA*
E-mail: smasuku@wsu.ac.za

The glycol thermal method was used to synthesize $Cd_xCo_{1-x}Fe_2O_4$ ($0.0 \leq x \leq 0.4$, $x = 0.6$ and 0.7) nano ferrites. X-ray diffraction (XRD) confirmed the structural formation and nanocrystalline structure of spinel ferrites. Samples possess a cubic spinel lattice structure with crystallite sizes ranging from 6 nm to 15 nm. Transmission electron microscopy (TEM) revealed fine particles which are nearly spherical in shape. The ^{57}Fe Mössbauer spectral studies showed ordered magnetic spin state for $x \leq 0.5$ which transforms to paramagnetic phase for $x \geq 0.6$ due to the weakening of super exchange interactions. The saturation magnetization (M_S) was the highest at $x = 0$ with a value of 73.3 emu/g and fluctuated between 44.3 emu/g and 19.8 emu/g after addition of non-magnetic Cd^{2+} ions. The almost zero coercivity and remanent magnetization data reveal the superparamagnetic nature of the compounds investigated.

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