Spin Waves 2009

International Symposium

Program Abstracts

Saint Petersburg, Russia, June 7-12, 2009

Ioffe Physical- Technical Institute

International Symposium

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Symposium Program
Abstracts

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Symposium Program

Monday June 8

10.00 Opening address L.A. Prozorova, A.I. Smirnov, R.V. Pisarev

Session 1. Ultrafast magnetic dynamics I

10.10-10.45	A. V. Kimel (invited)	*Femtosecond opto-magnetism: a key to novel mechanisms of spin reorientation*
10.45-11.20	U. Nowak (invited)	*Thermally assisted magnetization switching*
11.20-11.50	**Coffee break**	

Session 2. Ultrafast magnetic dynamics I (continued)

11.50-12.25	A. Melnikov (invited)	*On the nature of ultrafast demagnetization in Gd*
12.25-12.40	G. V. Astakhov	*Non-thermal photocoercivity effect in a low-doped (Ga,Mn)As ferromagnetic semiconductor*
12.50-14.20	**Lunch**	

Session 3. Spintronics and nanostructures I

14.20-14.55	A. N. Slavin (invited)	*Dynamics of a nonlinear spin-torque nano-oscillator under the influence of deterministic and stochastic signals*
14.55-15.10	N. I. Polushkin	*Effect of standing microwave fields in ferromagnet-semiconductor hybrids for quantum information processing*
15.10-15.25	P. E. Zilberman	*Exchange low threshold switching at room temperature for ferromagnetic nano-junctions*
15.25-15.40	A. A. Bukharaev	*Volt-Ampere characteristics of magnetic nickel nano-contacts under high-density currents*
15.40-16.10	**Coffee-break**	

Session 4. Nonlinear spin dynamics and magnetic films

16.10-16.25	Yu. A. Filimonov	*Low-frequency auto-oscillations under MSW parametric instability in YIG films*
16.25-16.40	A. A. Galishnikov	*Magnetostatic waves soliton in tangentially magnetized ferrite structures*
16.40-16.55	A. V. Kondrashov	*Investigation of stationary and chaotic auto-generation regimes of ferromagnetic-film-based active rings*
16.55-17.10	Yu. K. Fetisov	*Spin-wave envelope solitons in a medium with strong nonlinear damping*
17.10-17.25	E. G. Ekomasov	*The study of the nonlinear solitary bending waves stimulation in driving domain walls and the origin of the magnetic inhomogenities of pulson type in magnetics with defect*
17.25-17.40	A. B. Borisov	*Dynamical solitons with non-zero Hopf invariant in a uniaxial ferromagnet*
17.40-17.55	M. V. Logunov	*2D magnetic domain structures in garnet films*
18.00-19.30	**Get-together party**	

Tuesday June 9

Session 5. Multiferroics and nonlinear optics I

9.00-9.35	M. Mostovoy (invited)	*Dynamic magnetoelectric coupling in non-collinear magnets*
9.35-9.50	B. Kaminski	*Spin-induced second harmonic generation in europium chalcogenides*
9.50-10.05	M. S. Ivanov	*Multiferroic effects in perovskite manganites/ ferroelectric heterostructures studied by optical second harmonic generation*
10.05-10.20	T. V. Murzina	*Strain-induced effects in nonlinear optical properties of thin bismuth ferrite films*
10.30-11.00	**Coffee-break**	

Session 6. Quantum and frustrated magnets I

11.00-11.35	M. Hagiwara (invited)	*Exotic phases in quantum and frustrated spin systems*
11.35-12.10	I. A. Zaliznyak (invited)	*Covalent bonding and magnetism in cuprates*
12.10-12.25	G. B. Teitelbaum	*Quantum critical dynamics of $S = 1/2$ antiferromagnetic Heisenberg chains studied in CuPzN by ESR*
12.25-12.40	K. Yu. Povarov	*Spin resonance modes in the spin - liquid and ordered phases of a triangular lattice antiferromagnet Cs_2CuCl_4: spin gap above the Néel point*
12.40-12.55	C. W. Sandweg	*Pump-free evolution of a parametrically pumped magnon gas*
13.00-14.30	**Lunch**	

Session 7. Quantum and frustrated magnets I (continued)

14.30-15.05	A. K. Kolezhuk (invited)	*Unconventional order in low-dimensional magnets*
15.05-15.20	V. N. Glazkov	*Electron-spin-resonance study of alternating $S = 1$ antiferromagnetic spin-chains*
15.20-15.35	V. V. Valkov	*On instability of the Neel phase of the anisotropic non-Heisenberg Hamiltonian with antiferromagnetic coupling on a square lattice*
15.35-15.50	P. N. Bibikov	*Magnons in rung-dimerized spin ladders*
15.50-16.05	V. Tugarinov	*Antiferromagnetic resonance and phase diagram of $HoFe_3(BO_3)_4$*
16.05-16.30	**Coffee break**	

Session 8. Spintronics and nanostructures II

16.30-16.45	S. V. Gerus	*Surface magnetostatic waves in Brillouin zone of artificial magnetic crystal*
16.45-17.00	L. V. Lutsev	*Giant magnetoresistance in semiconductor/granular film heterostructures with cobalt nanoparticles*
17.00-17.15	A. A. Stashkevich	*Brillouin light scattering studies of spin wave modes in nickel nanowires*
17.15-17.30	Y. V. Khivintsev	*FMR study in permalloy films on patterned silicon substrates*
17.30-17.45	A. A. Zyuzin	*Spin waves in the spin injected disordered paramagnetic metals*
17.45-19.45	**Poster session** (with refreshments)	

Wednesday June 10

Session 9. Ultrafast magnetic dynamics II

09.00-09.35	M. Fiebig (invited)	*Thermal and nonthermal magnetization dynamics of antiferromagnetic compounds*
09.35-9.50	A. M. Kalashnikova	*Dynamics of an ultrafast all-optical magnetization reversal by 60 fs laser pulses in GdFeCo films*
9.50-10.05	R. V. Pisarev	*Transient inverse Faraday effect and ultrafast optical switching of magnetization*
10.05-10.20	A. Melnikov	*Ultrafast transport of spin polarized carriers induced by femtosecond laser pulses in Au/Fe/MgO(001)*
10.20-10.35	N. B. Orlova	*Spin switching in the spin-orbital field of optically recovered orbital angular momentum*
10.35-11.05	**Coffee break**	

Session 10. Complex magnetic structures and magneto-optics

11.05-11.40	A. Rogalev (invited)	*X-ray detection of magnetic resonance*
11.40-11.55	S. V. Maleyev	*Spin wave interaction and magnetic-field behavior of cubic helimagnets*
11.55-12.10	A. V. Boris	*Spin correlation effects in optical properties of iron pnictides*
12.10-12.25	A. V. Syromyatnikov	*Instability of the collinear phase in two-dimensional ferromagnet in strong in-plane magnetic field*
12.25-12.40	N. Perkins	*Magnetic excitations in* AV_2O_4 *compounds*
12.40-12.55	E. A. Ganshina	*Magneto-optical spectroscopy of diluted oxides* $TiO_{2-\delta}Co$
13.00-14.30	**Lunch**	

Session 11. Magneto-photonics and heterostructures

14.30-15.05	M. Inoue (invited)	*Propagation properties of magnetostatic surface waves in magnetic garnet films with periodic metal stripes*
15.05-15.20	S. L. Vysotsky	*2D magnonic crystal spin wave excitation spectra: experimental and numerical calculations*
15.20-15.35	N. I. Polushkin	*Collective effects on the precessional dynamics in lateral ferromagnetic structures*
15.35-15.50	I. A. Kolmychek	*Magnetic hyper-Rayleigh scattering in core (shell) nanoparticles*
15.50- 16.10	**Coffee break**	

Session 12. Magneto-photonics and heterostructures (continued)

16.10-16.25	V. I. Belotelov	*Electromagnetic field enhancement in magnetic plasmonic heterostructures*
16.25-16.40	T. V. Dolgova	*Enhancement of magneto-optical Kerr effect in magneto-plasmonic photonic crystals*
16.40-16.55	G. S. Patrin	*Magnetic resonance investigations of interlayer coupling in Co/Ge/Co trilayer films*
16.55-17.10	D. I. Kholin	*Temperature dependence of interlayer exchange coupling in Fe/Si/Fe trilayers*
17.10-17.25	A. B. Drovosekov	*Magnetic resonance in cluster-glass type Fe/Cr layered systems*
17.25-17.40	M. A. Bakulin	*Calcalation of the spectra of SWR in two-layer exchange-related structure*
18.00-21.00	**Conference dinner**	

Thursday June 11

Session 13. Low-dimensional and frustrated magnets II

09.00-09.15	L. E. Svistov	*On the magnetic structure of frustrated quasi-one-dimensional antiferromagnets* $LiCu_2O_2$ *and* $NaCu_2O_2$.
09.15-09.30	Y. Matiks	*Excitonic states in quasi-1D Mott-Hubbard insulator* $LiCuVO_4$
09.30-9.45	S. S. Sosin	*Excitation spectrum of XY-pyrochlore antiferromagnet* $Er_2Ti_2O_7$
9.45-10.00	A. V. Semeno	*Electron spin resonance and magnetic polarons in* EuB_6
10.00-10.15	S. Dickmann	*Spin waves in quantum Hall ferromagnets: spectra and relaxation times*
10.15-10.40	**Coffee break**	

Session 14. Multiferroics and nonlinear optics II

10.40-11.15	A. Pyatakov (invited)	*Inhomogeneous magnetoelectric interaction and novel related physical phenomena*
11.15-11.30	E. I. Golovenchits	*Magnetic susceptibility and magnetoresistance oscillations in the semiconductor-multiferroic* $Eu_{0.8}Ce_{0.2}Mn_2O_5$
11.30-11.45	V. V. Menshenin	*Phase transitions, soliton lattices and electric polarization in* RMn_2O_5 *oxides*
11.45-12.00	I. E. Chupis	*Excitation of electromagnons by alternating electric field in* $TbMnO_3$
12.00-12.15	M. Fiebig	*Giant second harmonic generation in multiferroic* $TbMn_2O_5$
12.15-12.30	**Closing remarks**	L.A. Prozorova, A.I. Smirnov, R.V. Pisarev
12.30-14.00	**Lunch**	
14.00-18.00	**Excursions**	

Poster session

Tuesday June 9
17.45 - 19.45

PS1. E. N. Beginin, M. A. Morozova
Magnetostatic waves in bounded quasi-periodic ferrite structures

PS2. E. N. Beginin, S. V. Grishin, and Yu. P. Sharaevsky
Generation of chaotic soliton-like microwave pulses in ring systems with ferromagnetic thin films

PS3. E. N. Beginin, S. V. Grishin, M. A. Morozova, and Yu. P. Sharaevsky
Generation of wideband chaotic microwave signal in ring system with nonlinear delay line on the basis of coupled ferromagnetic thin films

PS4. A. I. Smirnov, L. E. Svistov, L. A. Prozorova, A. Zheludev, M. D. Lumsden, E. Ressouche, O. A. Petrenko, M. Hagiwara, S. Kimura, K. Nishikawa, K. Kindo, A. Ya. Shapiro, L. N. Demianets
Coexistance of spiral and commensurate structures in a triangular antiferromagnet $KFe(MoO_4)_2$

PS5. V. V. Val'kov, A. A. Shklyaev, A. F. Barabanov
The spin-liquid correlations in the problem of a superconducting phase of spin polarons on a 2D Kondo lattice

PS6. L. M. Volkova
Role of crystal chemistry factors in emerging of magnetoelectric properties in multiferroic $BiFeO_3$

PS7. Y. Khivintsev, L. Reisman, R. Adam, C. M. Schneider, R. E. Camley, and Z. J. Celinski
Standing spin-wave mode excitation in Permalloy films using coplanar waveguides

PS8. N. V. Ostrovskaya
On some new branches of exact solutions for the non-dissipative Landau-Lifshitz equation

PS9. O. Bolsunovskaya, G. Petrakovskii, and M. Popov
On the third instability point in a two-subsystem magnetic crystal

PS10. V. V. Radajkin, S. N. Sabaev, D. A. Zyuzin
Transformation of the SWR spectra in the field of layer's temperature phase transition

PS11. A. P. Kuz'menko, E. A. Zhukov, and Yu. I. Shcherbakov
Surface magnetoelastic waves in yttrium orthoferrites

PS12. Y. A. Ignatov, V. I. Scheglov, and S. A. Nikitov
Propagation of magnetostatic surface waves in ferrite garnet films with variable cross-section

PS13. D. V. Perov, A. B. Rinkevich, and V. O. Vaskovsky
The peculiarities of spin-wave resonance in electromagnetic wave penetration through thin magnetic films

PS14. D. V. Kulagin, V. A. Kotov, A. S. Savchenko, V. G. Shavrov, and S. V. Tarasenko
Spin-wave electrodynamics peculiarities of a bounded weak ferromagnet in an external DC electric field

PS15. Yu. A. Filimonov, S. L. Vysotsky
Orientational dependence of magnetostatic surface wave Bragg diffraction in 1D magnonic crystal

PS16. E. M. Epshtein, P.E. Zilberman
High-frequency current induced instability under high spin injection

PS17. N. Grigoryeva
Dipole-exchange spin waves in periodic dipole-coupled multilayers

PS18. E. Lock and A. Vashkovsky
The laws of geometrical optics in anisotropic geometries

PS19. V. V. Shagaev
Ferrite garnet films with increased thermal stability of surface magnetostatic wave spectrum

PS20. A. S. Moskvin, A. M. Kalashnikova, R. V. Pisarev, and Th. Rasing
Charge transfer transitions in the multiferroic $BiFeO_3$ and related ferrite insulators with high Curie and Néel temperatures

PS21. A. M. Kuzmenko, A. A. Mukhin, V. Yu. Ivanov, A. S. Prokhorov, A. M. Kadomtseva, and L. N. Bezmaternikh
Magnetic excitations in $RFe_3(BO_3)_4$ multiferroics at submillimeter wavelengths

PS22. A. S. Dzhumaliev, Y. V. Nikulin, V. K. Sakharov, Y. A. Filimonov
FMR spectra of Ag/Fe(8nm)/Ag(0 ÷12nm)/Fe(8 nm)/Si(111) structures.

PS23. A. S. Dzhumaliev, Y. V. Nikulin, Y. A. Filimonov
Thickness dependence of FMR linewidth of thin Fe films

PS24. A. V. Skorobogatova, Y. V. Nikulin, Y. A. Filimonov
Micromagnetic modeling of magnetization process of magnetic microparticles with defects

PS25. T. G. Chamor, L. Chevnyuk, V. I. Kostenko, A. M. Sorochak
Influence of magnetostriction onto the crystallographic anisotropy field in the barium hexaferrite

PS26. V. V. Pavlov, P. A. Usachev, R. V. Pisarev, D. A. Kurdyukov, S. F. Kaplan, A. V. Kimel, A. Kirilyuk, and Th. Rasing
Magneto-optical study of opal-Fe_3O_4 *photonic structures*

PS27. M. Lafrentz, B. Kaminski, I. Sänger, D. R. Yakovlev, M. Bayer, V. V. Pavlov, A. M. Kalashnikova, and R. V. Pisarev
Magnetic-field-induced second harmonic generation in diluted magnetic semiconductors (Cd,Mn)Te

PS28. P. A. Usachev, R. V. Pisarev, A. M. Balbashov, A. V. Kimel, A. Kirilyuk, and Th. Rasing
Optical and magneto-optical properties and orientation phase transitions in rare-earth orthoferrites

PS29. E. Z. Meilikhov, R. M. Farzetdinova
Ferromagnetism in the quasi-two-dimensional semiconductor heterostructures

PS30. G. M. Dudko
MSW automodulation in ring resonator under external force

PS31. A. N. Ignatenko V.Yu. Irkhin and A.A. Katanin
Spin-wave and vortex excitations in the stacked triangular-lattice antiferromagnet with a weak interlayer coupling

PS32. A. Scaramucci and M. Mostovoy
Multiferroic and magnetoelectric behaviour of conical spirals

Abstracts

FEMTOSECOND OPTO-MAGNETISM: A KEY TO NOVEL MECHANISMS OF SPIN REORIENTATION

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The demand for the ever-increasing speed of information storage and manipulation has triggered an intense search for ways to control the magnetization of a medium by means other than magnetic fields. The control of magnetism by light is one of the promising approaches to this problem, because such methods may access timescales of a picosecond or less [1].

Can light directly and nonthermally magnetize a medium? A circularly polarized photon carries angular momentum. If it would be possible, using this angular momentum, to affect spins of electrons directly, this would result in ultrafast laser control of magnetism, since right- and left-handed circularly polarized light-waves should affect spins as magnetic fields of opposite sign. Therefore, in contrast to the well-known magneto-optical Faraday effect, where the polarization of light is affected by magnetism, one may expect an inverse, *opto-magnetic* phenomenon: polarized light affects magnetism via the inverse Faraday effect.

In my lecture I will demonstrate the feasibility of the inverse Faraday effect in magnetic materials [2]. It will be shown that the effect of this ultrashort optical pulse on a magnetic system was found to be equivalent to the effect of an equally short magnetic field pulse with strengths up to few Tesla [2-4]. Using such a short pulses of effective magnetic field we were able to discover novel mechanisms of spin-reorientation [5-7].

[1] A. V. Kimel et al, *Nature* **429** 850 (2004).
[2] A. V. Kimel et al., *Nature* **435** 655 (2005).
[3] F. Hansteen et al, *Phys. Rev. Lett*. **95** 047402 (2005).
[4] A. V. Kimel et al., *Laser & Photonics Rev.* **1** 275 (2007).
[5] A. V. Kimel et al, (*submitted*).
[6] C. D. Stanciu et al, *Phys. Rev Lett.* **99** 047601 (2007); Patent PCT/NL2006/000264.
[7] K. Vahaplar et al, (*submitted*).

THERMALLY ASSISTED MAGNETIZATION SWITCHING

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Laser induced magnetic writing processes have been extensively studied recently as a possibility to improve the storage density as well as the writing speed in magnetic data storage. Writing information on time scales below conventional or even precessional magnetisation reversal schemes appears to be within reach. Of fundamental interest is the understanding of de- and remagnetisation processes based on physical mechanisms involved in the coupling between spin, charge, and lattice. In this digest, we focus on magnetisation reversal processes during laser heating in the presence of an applied magnetic field. This is important for the understanding of the dynamics of writing processes in the pico-second time scale and in relation to Heat Assisted Magnetic Recording (HAMR).

In [1] the response of a magnetic system to pulsed laser heating in a zero-field on times scales in the picosecond regime was investigated. It was found that the time for recovery of the magnetisation after a heat pulse can vary by orders of magnitude depending on the magnetic state after heating. Though these simulations were done in zero-field they raise the question of the time scale at a field supported writing procedure. In the present work, we focus on the response to a laser pulse in the presence of an applied magnetic field.

As a first step, we investigate thermally assisted switching analytically for one macro-spin within the framework of the Landau-Lifshitz-Bloch (LLB) equation recently derived by Garanin [2]. It is found that close to the Curie temperature two different reversal modes appear: elliptical as well as linear reversal [3]. The latter one plays a crucial role for the dynamics of the magnetisation reversal close to and, especially, above the Curie temperature. We calculate the coercive fields and the energy barriers for the elliptical and linear reversal mode as well as the minimal switching time and field needed for thermally assisted switching below and above the Curie temperature. Furthermore, we investigate the case of ultra-short, combined field and temperature pulses as they occur in opto-magnetic writing procedures [4], demonstrating the possiblity of writing on time scales of less than 10 ps.

Since the single macro-spin approach is not capable of reproducing domain structures, in a second step we extended our approach to LLB-based multi macro-spin simulations [5,6]. We simulate extended systems where the exchange coupling is also taken into account in order to investigate the domain structure during the recovery phase following a rapid heat pulse.

[1] N. Kazantseva et al, Euro. Phys. Lett. **81**, 27004 (2008).
[2] D. A. Garanin, Phys. Rev. B **55**, 3050 (1997).
[3] N. Kazantseva et al, Europhys. Lett., in press.
[4] C. D. Stanciu et al., Phys. Rev. Lett. **99**, 047601 (2007).
[5] N. Kazantseva et al., Phys. Rev. B **77**, 184428 (2008).
[6] U. Atxitia et al., Appl. Phys. Lett. **91.** 232507 (2007).

ON THE NATURE OF ULTRAFAST DEMAGNETIZATION IN Gd

A. Melnikov[1], M. Wietstruk[2], C. Stamm[2], T. Kachel[2], N. Pontius[2], C. Gahl[3], M. Sultan[1], W. Eberhardt[2], T.O. Wehling[4], A.I. Lichtenstein[4], M.I. Katsnelson[5], M. Weinelt[1,3], H.A. Dürr[2], and U. Bovensiepen[1]

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Magnetization dynamics driven by femtosecond (fs) laser pulses has for more than a decade challenged our understanding of magnetism. In materials such as Fe, Co and Ni demagnetization times of a few 100 fs have been realized, which is clearly shorter than conventional (quasi-equilibrium) spin angular momentum transfer to the lattice. In 3d ferromagnets the optically excited valence electrons carry the magnetic moment and the complex interplay between itinerant electron behavior and magnetic interactions remains an unresolved problem. To further the understanding of femtomagnetism, it is necessary to separate optical excitation from spin dynamics. Therefore we focus on the rare earth ferromagnet Gd, whose magnetic moment mainly originates from the 4*f* electrons localized at the ionic core. The ferromagnetic order is mediated by indirect exchange interaction via the 5*d*6*s* conduction band.

In this contribution we present results of IR-laser pump x-ray probe experiments, where we optically excite only the 5*d*6*s* valence electrons with an 800 nm 100 fs laser pulses, while probing with 1182 eV x-ray pulses using the x-ray circular dichroism (XMCD) which measures the magnetization of the localized 4*f* electrons. Time-resolved studies have been carried out with a temporal resolution of 12 ps in the low-α operation mode of BESSY. The transient XMCD signal, which is a measure for the 4*f* magnetic moment, shows a decrease of the magnetization with a time constant of 40±10 ps. This can be described by quasi-equilibrium spin-lattice relaxation following the increase of the lattice temperature and is in accordance with theory and earlier results. However, in addition to that, the XMCD signal possesses a fast drop within the time resolution. This faster demagnetization process is resolved with 120 fs x-ray probe pulses generated by the femtosecond slicing technique: recording the transient XMCD, we found a characteristic timescale of $\tau = 1.0 \pm 0.2$ ps for the demagnetization of μ_{4f}. Time-resolved MOKE studies figure out a concomitant reduction of magneto-optical signal reflecting the spin polarization of valence electrons, on the same 1 ps time scale. Therefore, a redistribution of the angular momentum between localized and itinerant spin subsystems can not describe alone the observed behavior.

We establish that an entangled 4*f*-5*d* spin state is responsible for excess energy transfer from the valence band to the 4*f* system. Calculations show that magnon emission, representing the single particle excitation, occurs for hot valence electrons on a 10 fs time scale. Ultrafast demagnetization, i.e. the ensemble response, results from accumulation of emitted magnons, if (i) valence electrons are hot and (ii) the angular momentum is transferred to the lattice during the decay of these hot electrons. Since demagnetization proceeds during the first picosecond, we conclude, that the available lattice excitations, which ensure transfer of the momentum change to the lattice, determine the demagnetization time scale. Hence, our results provide evidence, that ultrafast demagnetization is governed by non-equilibrium spin-lattice coupling and demagnetization proceeds by angular momentum transfer to the lattice.

NON-THERMAL PHOTOCOERCIVITY EFFECT IN A LOW-DOPED (Ga,Mn)As FERROMAGNETIC SEMICONDUCTOR

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Magneto-optical (MO) recording techniques currently attract much interest due to the non-volatility, low cost, and removability of media they offer. Traditionally, the light in such devices is used to modify the strength of magnetic interaction. Because a very large number of magnetic ions is essential to achieve ferromagnetism, the intensity of the light needed is rather high. This results in heating of the recording media, regardless whether or not the thermomagnetic effect is the exploited physical mechanism.

We find a photoinduced change of the coercive field, i.e., a photocoercivity effect (PCE), under very low intensity illumination of a low-doped (Ga,Mn)As ferromagnetic semiconductor [1]. We observe a strong correlation between the PCE and the sample resistivity. Spatially resolved dynamics of the magnetization reversal rule out any role of thermal heating in the origin of this PCE. The PCE is local and reversible, allowing writing and erasing of magnetic images using light. This proof of concept demonstration for low power MO recording is based on focussing the action of the light on modifying the pinning centers which control domain wall movement.

We propose the following mechanism for the PCE. Low doping of (Ga,Mn)As with manganese results in their inhomogeneous distribution, leading to a rather irregular potential landscape which causes partial hole localization and non-metallic behavior. As the magnetic interaction in (Ga,Mn)As is mediated by holes, this irregular potential landscape results in fluctuations of the domain wall energy and the coercivity is high. Under illumination, the photogenerated holes and electrons will tend to separate, moving towards local maxima and minima of the potential landscape. This causes a spatial redistribution of holes, leading to a smoothing of the landscape as a result of Coulomb screening. The fluctuations of the domain wall energy decreases and the coercivity is lowered. Further supporting evidence for this picture comes from the absence of the effect in the metallic control sample. In a metallic sample the Fermi level lies deep in the valence band and the intrinsic holes can thus freely move, leading to a smoothened potential landscape even without illumination.

[1] G. V. Astakhov, H. Hoffmann, V. L. Korenev, T. Kiessling, J. Schwittek, G. M. Schott, C. Gould, W. Ossau, K. Brunner, and L. W. Molenkamp, arXiv:0810.4027.

DYNAMICS OF A NONLINEAR SPIN-TORQUE NANO-OSCILLATOR UNDER THE INFLUENCE OF DETERMINISTIC AND STOCHASTIC SIGNALS

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A theory of non-autonomous dynamics of a strongly nonlinear spin-torque nano-oscillator in the presence of external periodic and/or chaotic (e.g. thermal noise) signals is developed. This theory is based on the nonlinear oscillator equation for the complex amplitude $c(t)$ of a spin wave excited by spin-polarized current [1]

$$dc/dt + i\omega(|c|^2)c + [\Gamma_+(|c|^2) - \Gamma_-(|c|^2)]c = f(t)\,, \qquad (1)$$

where $\omega(|c|^2)$ is the nonlinear frequency of the excited spin wave mode [1], $\Gamma_+(|c|^2)$ is the positive nonlinear damping [2], $\Gamma_-(I,|c|^2)$ is the negative nonlinear damping induced by thevcurrent I [2], and $f(t)$ describes either the action of the external deterministic periodic signal [3] or the influence of thermal noise [4-7].

In the case when $f(t)$ describes a periodic external signal the problem (1) is reduced to the problem of injection-locking of a nonlinear auto-oscillator [3]. In the case of the action of thermal noise the function $f(t)$ is a stochastic Gaussian process with the correlator $< f(t) f^*(t') > = 2\,\Gamma_0\, n_T\, \delta(t - t')$, where $n_T = < |c|^2 >_{I=0}$ is the spin wave power in the state of thermal equilibrium (i.e., at $I = 0$) [4-7].

In a substantially supercritical regime ($\zeta = I/I_c > 1.2$, where I_c is the critical bias current at which the auto-oscillations begin) the main contribution to the linewidth comes from the phase fluctuations of the spin wave amplitude $c(t)$. Analyzing Eq. (1) in this regime, we derived the expression for the linewidth of the spin-torque-induced auto-oscillations:

$$\Delta\omega = \Gamma_0\left(\frac{n_T}{n_0}\right)(1+\nu^2)\,, \qquad (2)$$

where Γ_0 is the equilibrium relaxation rate of the excited mode, $n_0 = |c_0|^2$ is the mean dimensionless power of the excited mode determined from the condition $\Gamma_+(|c_0|^2) = \Gamma_-(|c_0|^2)$, and $\nu = \dfrac{d\omega/d(|c|^2)}{d(\Gamma_+ - \Gamma_-)/d(|c|^2)}$ is the dimensionless measure of the auto-oscillator nonlinearity. Equation (2) clearly shows that the equilibrium relaxation rate of the excited mode Γ_0 determines the overall scale of the possible linewidth variations. Then, it demonstrates that the linewidth $\Delta\omega$ is proportional to the noise level n_T/n_0, which is determined by the ratio of the population of thermal spin waves n_T to the population of driven spin waves n_0. Finally, Eq.(2) shows that the parameter $\nu >> 1$ gives a measure of the contribution of the amplitude fluctuations to the phase noise far above the threshold.

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EFFECT OF STANDING MICROWAVE FIELDS IN FERROMAGNET-SEMICONDUCTOR HYBRIDS FOR QUANTUM INFORMATION PROCESSING

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Surface magnetostatic waves is well known to generate the microwave fields whose intensity away from the surface as $\propto\exp(-kz)$, where k is the wave number. These waves propagating in a lateral ferromagnetic periodic structure form a standing microwave field (SMW) whose periodicity is defined by the structure period [1]. I find that the SMW mediates intense spin-flip cyclotron resonance transitions (the combined resonance [2]) in a two-dimensional electron gas (2DEG), which is brought into close proximity with the lateral ferromagnetic structure. Using a simple formalism, I demonstrate that the electron is able to experience the combined resonance via the Zeeman interaction with the SMW generated by an array of Fe nanostripes. Such an external potential $h(r, t)$ having a spatial period Λ and angular frequency Ω can be considered as a perturbation of the wave function ψ_l of an electron moving along an l-th Landau orbit in a static magnetic field. As the matrix elements of the perturbation operator $\exp[i(\omega_{l,\downarrow;n,\uparrow}-\Omega)t]\int\psi_n^*(r)h(r)\psi_l(r)\mathrm{d}r$ for a transition $l\rightarrow n$ are nonvanishing at $n\neq l$, the coordinate-dependent function $h(r)$ allows for a nonzero rate of the transitions between the l-th and n-th Landau levels with spin rotation at the resonance that occurs when $\Omega=\omega_{l,\downarrow;n,\uparrow}$. To demonstrate the feasibility of the combined transitions, I consider a realistic situation where the electron is confined in a 2DEG from InGaAs. I show that a novel commensurability effect arises in such a hybrid when the cyclotron diameter $2R_c$ is equal to the stripe width. Moreover, my analysis reveals that, in contrast to conventional electron spin resonance, the CR excited in an engineered system such as the $In_{0.53}Ga_{0.47}As$ enables a sizeable change in R_c. This finding enables exciting possibilities in spintronics, for spin-to-charge conversion in quantum computing devices [3]. Another feature is that the stray fields of the patterned elements quickly decay out of them in lateral direction. Localizing the resonant transitions via strong and localized ac fields would be a necessary step for single-electron spin manipulation in quantum information processing.

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EXCHANGE LOW THRESHOLD SWITCHING AT ROOM TEMPERATURE FOR FERROMAGNETIC NANO-JUNCTIONS

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Effect of the exchange magnetization switching was predicted in the papers [1, 2]. Only one channel of the effect was then taken into account – the so called "spin transfer torque". However, the other channel exists also. It was discussed in the papers [3, 4]. This additional channel of switching arises due to spin injection by the current. Injected carriers populate spin subbands in the junction and vary their energy. To minimize the energy it may be necessary to switch the magnetization.

The exchange switching was revealed experimentally in a number of papers. Initially, very high threshold currents were observed, e.g. $j_{th} \approx 3\cdot 10^{7}$ A/cm^2 at RT. Recently, a few orders of magnitude lower threshold was found, that is $j_{th} = 2.0\cdot 10^{4}$ A/cm^2, but only for 15 K^0 and for magnetic semiconductor having low magnetization M [6]. Our aim now is to present the estimations of the threshold calculations for both channels: spin transfer and spin injection. We show the threshold may be lowed down to $j_{th} \le 10^{2}$ A/cm^2 or even more at RT. The calculation based on the theory [7] leads to the expressions for the threshold currents. First:

$$\left|\frac{j_{th}}{e}\right| = \frac{2\pi\gamma M^{2}L\kappa}{\mu_{B}Q}\cdot\left(1+\frac{1}{\nu^{*}}\right), \qquad (1)$$

where on the left hand side here we have current for the spin transfer channel, e - electron charge, M - magnetization, L - thickness of the switched ferromagnetic layer, Q - degree of current polarization, κ - Gilbert dissipation constant, μ_B - Bohr magneton and $\nu^*>0$ is the dimensionless characteristic of the magnetic parameters of the layer. The next expression is:

$$\left|\frac{j_{th}}{e}\right| = \frac{lH_{a}}{\alpha\tau\mu_{B}Q}\cdot\left(\lambda+\frac{Z_{2}}{Z_{3}}\right)\cdot\left(1+\frac{H}{H_{a}}\right), \qquad (2)$$

where the following new values appear: H_a - anisotropy field, H - external magnetic field, l - diffusion length (~20 nm in metals), α - exchange parameter (~2.10^4), $\tau \approx 3\cdot 10^{-13}\,s$ - spin relaxation time, $\lambda = L/l << 1$, Z_2, Z_3 - spin resistances of the layers. After substituting the numerical meanings, we get the following estimations: $\left|j_{th}\right|_p \approx 2\cdot 10^{7}$ A/cm^2 for the case of spin transfer channel and $\left|j_{th}\right|_p \approx 2\cdot 10^{5}$ A/cm^2 for the case of spin injection channel. It is necessary to note, if field H is near the phase transition point, that is $\left(1+H/H_a\right)\to +0$, the threshold may be lowed additionally.

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VOLT-AMPERE CHARACTERISTICS OF MAGNETIC NICKEL NANO-CONTACTS UNDER HIGH-DENSITY CURRENTS

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The magnetization switching of the nanostructures by the spin-polarized current is of great interest from theoretical and applied points of view [1, 2]. The spin transfer torque (STT), the transfer of the spin angular momentum from the spin-polarized current to the magnetic moments of the free magnetic layer, underlies this phenomenon. For the magnetization switching of the free layer the current density (critical current) has to be in the range of 10^6–10^8 A/cm^2. Such high densities can be achieved by passing currents from several to tens milliamperes through the nanopillar or nanocontact with the cross section diameter of the order of 100 nm. The critical current can be decreased by reducing the transverse dimensions of the free layer.

To fabricate nanostructures suitable for the STT to occur, it is necessary to take into account that such high current densities could result in the modification nanostructures due to the electromigration of atoms or a destructive overheating.

In this work *I(V)* and *R(I)* characteristics of Ni nanocontacts electrochemically prepared in solution were studied. The method to prepare such contacts is described in [3]. The goal of this work was to study the mechanisms of the high-density current passage through the nanocontacts of different sizes. Our estimates showed that the electrochemical method allowed us to fabricate nanocontacts with the diameter from 1 to 100 nm. The conductance quantization was recorded for the nanocontacts with minimal dimensions that proved the ballistic transport mechanism. Our homebuild experimental setup allowed us to perform the passage of the current pulses with the duration from 1 ms to several seconds and densities up to 10^{10} A/cm^2 through the nanocontacts. Under such high current densities the irreversible modification of nanocontacts was observed: the contact break or the transition from metallic to tunnel conductivity. For the current densities less than 10^8 A/cm^2 the deviation from the linear dependence of *I(V)* was recorded. The temperature increase and the features of the electron density of the state distribution for Ni near the Fermi level were considered in order to explain the observed nonlinearities in *I(V)*. The contributions of different mechanisms of conductivity to the experimental *I(V)* were estimated numerically.

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LOW-FREQUENCY AUTO-OSCILLATIONS UNDER MSW PARAMETRIC INSTABILITY IN YIG FILMS

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Low-frequency oscillations ($F_s \approx 0{,}01 \ldots 1$ *MHz*) can be excited under parametric excitation of spin waves by perpendicular or parallel pumping in yttrium iron garnet (YIG) films [1,2] and spheres [3]. In this work experimental results on the observation of low-frequency satellites in the spectra of magnetostatic waves (MSW) transmitted through the YIG films are presented, under three-magnon (3M) parametric instabilities.

Experiments were performed on a delay line device with tangentially magnetized YIG films *5…100μm* thick in both backward volume (BVMSW) and surface (MSSW) configurations. MSW were excited and detected by microstrip transducers of different lengths $l=1 \ldots 5$ *mm* and widths $w=30..50$ *μm*. The distance between transducers can be changed from *3* to *10 mm*. Two-pumping method, modified for MSW delay configuration by placing an additional (the third) moveable transducer [3], was used for measurements both MSW parametric instability threshold P and lateral dimensions L_{nl} of the “non-equilibrium” part of the YIG film.

In the case of MSW 3M instability satellites with $F_s \approx 10..20$ *kHz* were observed at MSW overcriticality $C=10\log(P/P_{th})$ levels $C \approx 1..2$ *dB* above the MSW power threshold P_{th}, which was found very close to predicted from Suhll theory,Fig1. As a peculiar finding, with increasing C satellites higher frequencies F_s appear in the output spectra. For MSW powers in the order of $C \approx 7 \ldots 10$ *dB* above the threshold, satellites disappear and they are transformed into noise-like spectra localised near the MSW frequency. Simultaneously well known [5,6] satellites with frequencies $f_s \approx 5 \ldots 100$ *MHz* were observed, see Fig.1.

In contrast with respect to low-frequency oscillations under parallel pumping conditions [2] we have not found any relation between the YIG film lateral dimensions, thickness and the length of nonlinear part of the film L_{nl}, from one side and the frequency F_s from the other .The satellites frequency were independent from length or width of microstrip. From Fig.2 one can see hysterezis in dependencies $F_s=F_s(C)$ and some decreasing F_s with increasing C.

As an interpretation, the satellites can be considered like secondary MSWs formed by a thresholdless confluent process of parametric magnons [6]. In fact, a threshold of $C \approx 1..2$ *dB* is needed for achieving satellites with frequency $F_s \approx 10..20$ *kHz* in suggestion that in confluent process parametric magnons from one dispersion surface of spin waves spectra with frequencies $f \approx (f_p - F_s)/2$ are involved.

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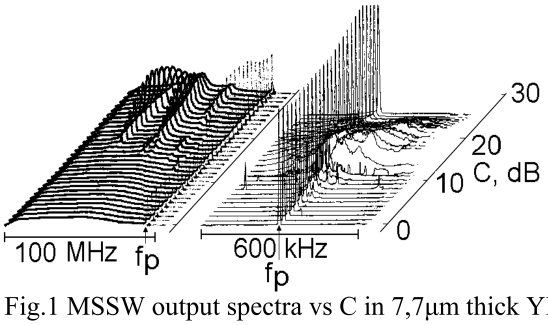
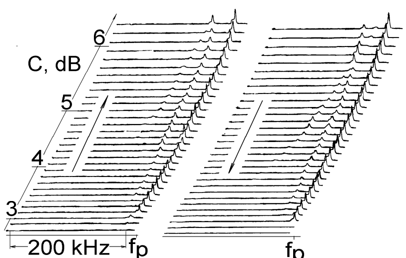


Fig.1 MSSW output spectra vs C in 7,7μm thick YIG film f_p=3455 MHz. H=515Oe



Figs. 2. Low-frequency satellites in MSSW output spectra as a function of *C* in *7,7 μ* thick YIG film, *H=489 Oe*, f_p*=3250 MHz*

MAGNETOSTATIC WAVES SOLITON IN TANGENTIALLY-MAGNETIZED FERRITE STRUCTURES

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MSSW bright soliton formation have been investigated in ferrite-dielectric-metal (FDM) structure based on a $14\mu m$-thick yttrium iron garnet film separated with metal by an air gap with thickness $h_1 \approx 100\mu m$ or $h_2 \approx 200\mu m$. It was found experimentally for MSSW with wavelength $\lambda \approx h$ that modulation instability leads to soliton formation for rectangular input pulses with duration T_0 less when character transient time t^* needed for starting parametric instability, while pulses with $T_0 \geq t^*$ strongly subjected by parametric instability. The thresholds for parametric and modulation instabilities were measured and are in agreements with theoretical predictions. An influence of additional pumping in the form of both continuous and pulse signals on soliton formation was studied. It was shown that additional pumping signal with duration $T \geq t^*$ and amplitude above the threshold of the parametric instability suppressed MSSW soliton. Numerical modelling of the pulse width dependence on the microwave power under propagation in the FDM structure are in agreement with experimental observations.

Soliton formation process was numerically investigated. As it was shown, peak amplitude A and half-height width W of linear rectangular input MSW pulse evaluate non-monotonous and reach their maximum $A = 1.33A_0$ and minimum $W = 0.67 \cdot T_0$ at the distance $L_C = 0.44L_D$, where A_0, T_0 – input pulse amplitude and duration, L_D – dispersion length. Such "compression" caused by induced phase modulation of the input pulse. It was shown that soliton formation length is various from $2L_C$ near one-soliton threshold to L_C near two-soliton threshold. Compression effect was observed experimentally so for MSBVW as for MSSW, for both cases compression was easy to observe and compression length L_C, measured experimentally was in a good agreement with theoretical value.

An influence of the non-solitary (dispersive wave) part of the MSW pulse on soliton propagation was numerically investigated, it was shown, that such wave can leads to leveling off or some peak in MSW pulse output vs input power dependence $P_{out}(P_{in})$.

MSBVW soliton was experimentally observed in the terms of transient processes: main attention was paid to pulse input and soliton formation that differ this work from well-known [1,2]. $P_{out}(P_{in})$ dependences was analyzed for different T_0, it was shown that soliton formation is occur for pulse durations $T_0 \approx T_C$, where T_C is a pulse duration, for which L_C is equal propagation length that is in good agreement with our theory. For $T_0 \geq t^*$ soliton formation was observed as it described in [3].

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INVESTIGATION OF STATIONARY AND CHAOTIC AUTO-GENERATION REGIMES OF FERROMAGNETIC-FILM-BASED ACTIVE RINGS

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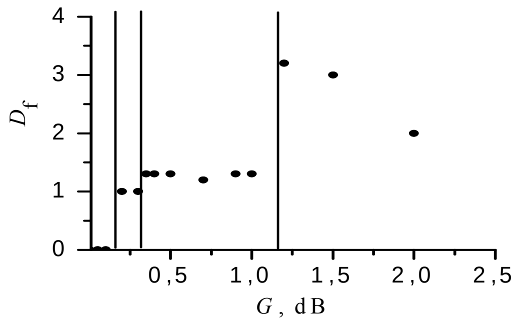
The aim of the present work is to study stationary and chaotic auto-generation regimes of spin-wave active rings when nonlinear effects are governed by four-wave interaction processes. The experimental feedback device structure consisted of ferromagnetic-film microwave delay line, microwave amplifier, adjustable attenuator, and directional coupler. The delay line was used as nonlinear element. The amplifier was used to compensate for losses in the feedback ring. The attenuator controlled the ring gain level *G*. The directional coupler was used to detect microwave signal circulating in the ring. The delay line was fabricated using a YIG film sample which was placed on microstrip antennae. The microstrip antennae were of 50 *м*m thick and 2 mm long. The YIG sample was a 6.9 mm thick strip cut from a larger film grown by liquid phase epitaxy. The saturation magnetization was equal 1750 Gs. A static magnetic field of 1300 Oe was applied in the film plane and parallel to the spin-wave propagation direction.

For investigation of the auto-generated signal parameters we measured power spectra and time profiles for different gain levels *G*. With gradual increasing the ring gain level, first a auto-generation of cw signal was started in the active ring. Following to [1], this gain level was conditionally used as zero level signal *G*=0. Further increasing in the gain level led to appearance of the additional harmonics and to enrichment and broadening of the signal power spectrum. As a result, we obtained three different types of auto-generation regime, namely, a continuous wave, a bright soliton train, a stationary periodical waveform, and a chaotic signal generation regime.

For description of the nonlinear system behavior as well as for characterization of the parameters of the auto-generated signals their phase portraits were reconstructed using the time-delay method. From the reconstructed phase portraits a connection between fractal dimension and ring gain value was obtained (Fig. 1). We found that fractal dimension D_f increases when gain *G* value increases. In particular, fractal dimension was equal 1 in the solitonic regime and it was equal 1.2 in the stationary periodical waveform auto-generation regime. Maximum magnitude of the fractal dimension for the chaotic signal generation regime turned out to be 3.2 for *G* = 1.2 dB. The obtained data proved the deterministic origin of the observed dynamic behavior of the ferromagnetic-film-based spin-wave active rings.



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SPIN-WAVE ENVELOPE SOLITONS IN A MEDIUM WITH STRONG NONLINEAR DAMPING

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Envelope solitons are wave packets, which keep their shape during propagation in a nonlinear dispersive medium. They are excited with short pulses and formed during propagation in the medium due to compensation of dispersion spreading and nonlinear compression. From theoretical point of view, the solitons formation is possible in a dissipationless medium only, where its shape is established at infinite distance from excitation point. In experiments formation of solitons was observed at finite distances only in media with weak dissipation.

In this paper we demonstrated experimentally, on example of backward volume spin-waves (SW) propagating in thin yttrium-iron garnet (YIG) ferrite films, that envelope solitons can also be formed at finite distances in medium with strong nonlinear damping as well.

The SW solitons were excited with microstrip transducers by 0.7 ms long microwave pulses with 4.77 GHz carrier frequency in a rectangular YIG film sample of 5.1 μm thick, 2 mm wide, and 25 mm long. The film was placed in dc magnetic field H =1 kOe parallel to the long sample side. Distance between exciting and receiving transducers was varied from 1.5 to 12 mm. Excitation power P_{in} was up to 500 mW and output pulse power P_{out} was measured.

Fig.1 shows typical envelops of output SW pulses excited by 0.7μs input pulses with low (a) and high (b) powers. One can see narrow (~ 10 ns) spike in the beginning of the pulse in Fig 1b, which is a SW envelope soliton formed from a long excitation pulse. The threshold for the soliton formation is $P_{in}^{sol} = 30$ mW, it has flat phase-time response, and its peak power decays double in comparison with linear continuous wave damping in YIG films.

The SW soliton formation was possible due to joint action of nonlinear damping and modulation instability for backward volume SW (see Fig.2). Measured threshold power of 4 mW for nonlinear damping was found to be much lower than threshold power level of 30 mW for modulation instability. Nevertheless, characteristic time of 8 ns for the modulation instability turned out much shorter, than minimum characteristic time of 50 ns for the four-wave nonlinear damping.

The research was supported by grants from Russian Foundation for Basic Research and Ministry of High Education and Science of Russia.

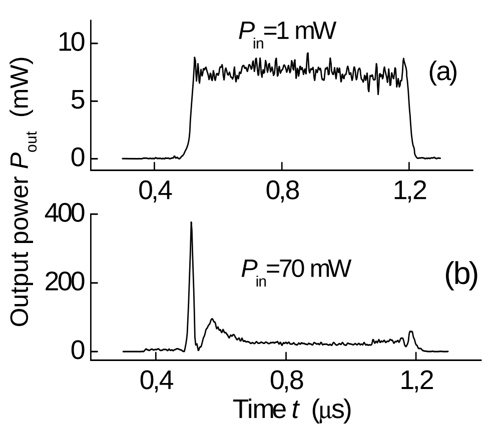

Fig.1. Envelopes of SW pulses excited by low (a) and high (b) power input.

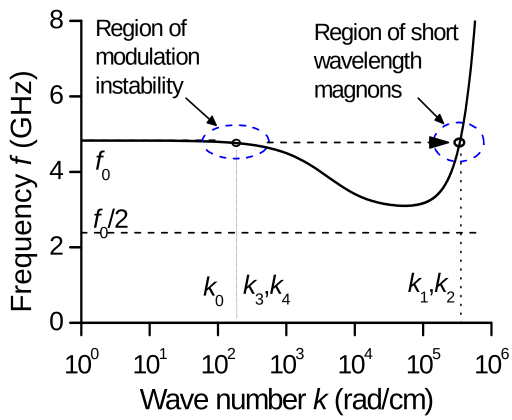

Fig.2. Dispersion curve for the backward volume SW in 5.1 μm thick YIG film.

THE STUDY OF THE NONLINEAR SOLITARY BENDING WAVES STIMULATION IN DRIVING DOMAIN WALLS AND THE ORIGIN OF THE MAGNETIC INHOMOGENITIES OF PULSON TYPE IN MAGNETICS WITH DEFECT

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It is known that in real magnetics the appearance of magnetic parameters local changes happens due to structural and chemical non-homogeneities and local influence (mechanical, thermal or solar). As it is usually difficult to make a precise (microscopic) calculation, one is to model the functions, which describe the parameters of a non-homogeneous material [1, 2]. The case is especially interesting, when the size of a magnetic non-homogeneity and the size, describing non-homogeneity of parameters of the stuff, are of the same order. It results in considerable complication of Landau-Lifshitz equation for the magnetization. Although the task of excitation and distribution of the magnetization waves, under certain conditions, is reduced to the studies of the modified sine-Gordon equation with floating factor [3]. The investigation of big perturbations influence on the solution of modified sine-Gordon equation in general case can be investigated only with the help of numerical methods. In dynamic, when in the area of such non-homogeneities (or defects) a temporally or spatial non-homogeneous perturbation acts, under certain conditions, a strongly non-linear waves of magnetic character can be aroused. Such waves are weakly investigated.

In the research a non-linear dynamic of domain walls (DW) (sine-Gordon equation kinks) for the case of 2D non-homogeneity of the material parameters (for example, magnetic anisotropy constant and exchange constant) were investigated with the help of numerical methods. We have investigated the dynamic of solitary bending waves, which appear on the DW crossing of defect region, and the origin and evolution of the magnetic non-homogeneities of pulson type, localized in this region. It is shown that the solitary bending waves appear “kink on kink”. Dependences of maximum amplitude solitary bending waves on DW speed and on non-homogeneities region characteristics in case of DW inertial motion and DW motion in an external magnetic fields was found. Analytic form of amplitude solitary bending waves, that gives qualitative description to our results, was found. Dependences of maximum deflection magnetization in magnetic non-homogeneities of pulson type on time, non-homogeneities region characteristics and DW speed were received.

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DYNAMICAL SOLITONS WITH NONZERO HOPF INVARIANT IN A UNIAXIAL FERROMAGNET

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Stable three-dimensional solitons in uniaxial ferromagnet with nonzero Hopf invariant have been discussed 30 years ago [1]. Simple reasoning based on the Derrick theorem indicates the absence of nontrivial static three dimensional solitons with finite energy in the aforementioned media. However, dynamical structures of this kind, which are stabilized by the precession of the magnetization vector **M**, can exist [2]. Constant-velocity precession solitons with Hopf index H=1 were numerically found in the Heisenberg model for an isotropic ferromagnet [3]. In this work, we numerically find stationary [4] and uniformly moving precession three-dimensional toroidal solitons with nonzero Hopf indices, in a uniaxial ferromagnet. Figure 1 shows the magnetization distribution of stationary (V=0) and moving (V>0) along the anisotropy axis soliton with the same precession frequency, in polar coordinate system (r,ѓУ,z).

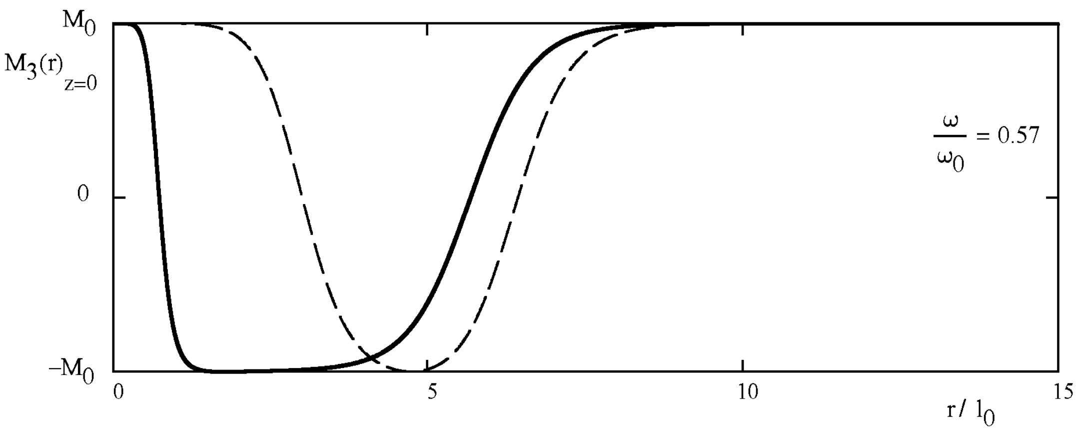

Figure 1. Shape of stationary (solid line) and moving (dashed line) soliton with speed V=0.15 $l_0\,\omega_0$, for H=3; here ω_0 is the FMR frequency, l_0 - characteristic domain wall width.

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2D MAGNETIC DOMAIN STRUCTURES IN GARNET FILMS

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In garnet films the big assortment of spatially-ordered domain structures forming 2D - lattices of domains is revealed [1-3]. The lattices belonging to various spatial groups of symmetry, consist from topologically modified bubble domains. Their formation occurs in pulse or harmonic magnetic fields, and ordering conditions are kept at switching-off of pulse or harmonic fields as much as long. Such structures can be a basis for operated magneto-photonic crystals [4]. Studying of formation processes of the spatially-ordered domain structures in homogeneous magnetic fields, that is actually self-organizing of structures from initial disorder (labyrinth) structures can be of interest and as analogue of process of self-assembly nanostructures [5].

In labyrinth structure there is no distant order in an arrangement of domains. In the present work the basic attention is given to studying of dynamic processes of movement and transformation of domains during formation of 2D - lattices of domains. We used magneto-optic setup and high-speed photography for dynamic domain registrations. The programmed digital generator of signals was used for receiving of the set number of the periods of harmonic magnetic field. The generated single radio-frequency pulse after amplification submitted on remagnetization device. Dynamic domain structures corresponding to different phases of the field periods were registered.

During action of the radio-frequency field pulse there is a formation of domain structure which elements in the shape of distorted bubble domains is formed (as a first approximation) hexagonal most dense packing. It is necessary condition for formation of the 2D - lattices of domains after the end of radio-frequency field pulse. Various sites of the same domains make movement with different velocity about what their geometry wrong form speaks. Only magneto-static interaction with the neighbour domains leads to alignment of domain walls and formation of bubbles, dumpbell-shaped, or elliptic domains as the elements of 2D - lattices of domains.

The final form of symmetry of 2D - lattices of domains (*Cmm*2, *Cmm*6, *P*2, *Pab*2, *Pmm*2, *P*6) is determined by magneto-static interaction of domains in the lattice, constant bias field, relaxation processes after the ending of the radio-frequency pulse of magnetic field, and the frequency, amplitude, number of the periods (10^3-10^6) of harmonic magnetic field in radio-frequency pulse.

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DYNAMIC MAGNETOELECTRIC COUPLING IN NON-COLLINEAR MAGNETS

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Two different microscopic mechanisms, inducing an electric polarization in multiferroic materials, are by now well understood. The first mechanism is of relativistic origin. It involves the antisymmetric Dzaloshinskii-Moriya interaction, works in many spiral magnets, but results in rather low electric polarizations. An electric polarization can also result from the magnetostriction driven by the symmetric Heisenberg exchange. The second mechanism gives relatively large electric polarization, but requires commensurate spin orders that break inversion symmetry.

In orthorhombic rare earth manganites, $RMnO_3$ and RMn_2O_5, ferroelectric incommensurate spiral states compete with ferroelectric commensurate spin states. This competition has important implications for the dynamic magnetoelectric coupling between spin waves and polar phonons, resulting in mixed electromagnon excitations. I will present theory of single-magnon and bi-magnon excitation by an electric field of light, which explains electromagnon peaks recently observed in orthorhombic manganites. I will discuss applications of this theory to magnetoelectric Kagome systems, carrying monopole and toroidal magnetic moments, and to other non-collinear magnets. I will show that optical studies can provide useful information about competing multiferroic states in frustrated magnetic materials.

SPIN-INDUCED SECOND HARMONIC GENERATION IN EUROPIUM CHALCOGENIDES

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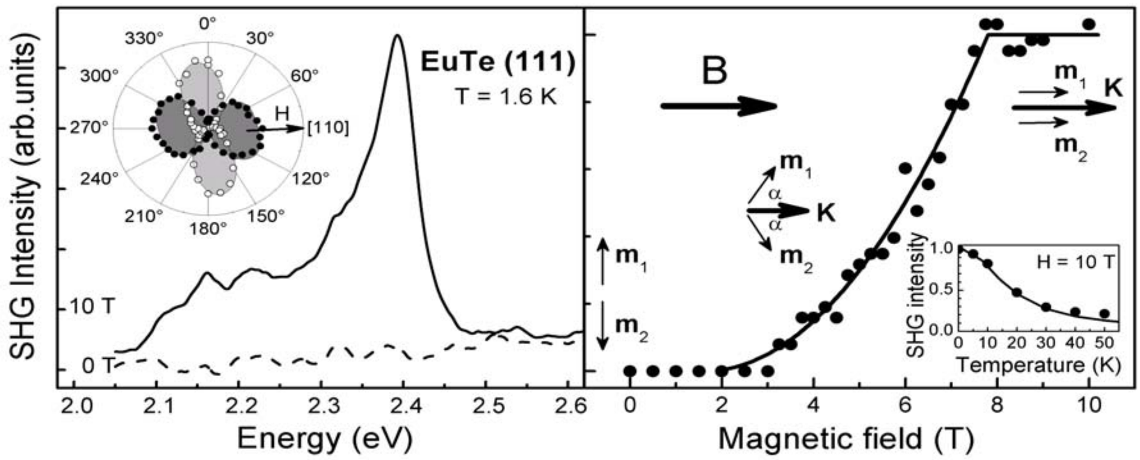
Europium chalcogenides Eu*X* (*X*=O, S, Se, and Te) are centrosymmetric magnetic semiconductors displaying interesting strong magnetic and magneto-optical properties. Current interest to these materials is raised by their potential applications in spintronics [1]. The magnetic properties result from the strongly localized electrons of the half-filled $4f^7$ levels of Eu^{2+} ions with spin *S*=7/2 and a competition between the nearest and the next nearest neighbour interaction. Consequently the magnetic phases can include ferro-, ferri- and antiferromagnetic ordering as well as a paramagnetic phase at higher temperatures.



The second harmonic generation (SHG) in these materials is fordbidden in the electric dipole and the electric quadrupole approximations due to the centrosymmetricity of the crystal lattice and the electronic band structure [2] with an odd parity 4*f*-5*d* band gap transition.

Nevertheless SHG signals in the vicinity of the band gap of 2.2-2.4eV of was found in EuTe and EuSe. (For EuTe see Figure, left panel; inset shows the SHG anisotropy.) Further magnetic field and temperature investigations (see Figure, right panel) revealed that this contribution is induced by a ferromagnetic spin component, which strongly enhances the magnetic-dipole transition. This new type of spin induced susceptibility opens access to various classes of centrosymmetric magnetic materials by second harmonic generation spectroscopy.

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MULTIFERROIC EFFECTS IN PEROVSKITE MANGANITES/FERROELECTRIC HETEROSTRUCTURES STUDIED BY OPTICAL SECOND HARMONIC GENERATION

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The growing interest in multiferroic materials, displaying simultaneous ferromagnetism and ferroelectricity, arises due to their promising applications for "ferroelectromagnets" and spintronic devices, in which magnetism can be tuned with voltage and vise versa, and therefore a single material may serve two functions. Two types of multiferroic materials are currently investigated and designed: single phase intrinsic multiferroics such as Cr_2O_3, $BiFeO_3$, which properties can be improved by-doping, and artificial double phase column-like and multilayered nanostructures possessing record values of magnetoelectric coefficients.

The nonlinear optical technique of second harmonic generation (SHG) has been proven to be a powerful tool to study local magnetic and ferroelectric properties of thin films and nanostructures. The magnetoelectric coupling can be studied very efficiently by the SHG technique as well [1,2]. We report here ferroelectric, magnetic and coupled magnetoelectric properties of multilayered $LaCaMnO_3/BaTiO_3$ (LCMO/BTO) structures studied by SHG.

Multilayered epitaxial $LaCaMnO_3/BaTiO_3$ (LCMO/BTO) structures were fabricated by a metalorganic aerosol deposition technique on MgO(100) substrates. Each sample consisted of N double LMO/BTO layers (N=2-25) with LMO bottom and BTO top layers. The thickness of LMO and BTO layers was 25 unit cells and 20 unit cells, respectively. A planar electrode system was used for in-plane electric field application. The SHG response was studied using a standard Ti:Sapphire laser system and photon counting technique.

All the structures revealed separately electric-field-induced $I_{2\omega}(U)$ and magnetization-induced $I_{2\omega}(H)$ SHG with hysteresis-type behavior, which can be considered as a measure of ferroelectric polarization and magnetization hystereses, respectively. However, a direct influence of a magnetic field on the polarization hysteresis loop or an influence of an electric field on the magnetization hysteresis loop were not observed. Instead we found indirect evidence of a magnetoelectric interaction which is the appearance of a ferroelectric polarization loop measured as $I_{2\omega}(U)$ at temperatures below the magnetic Curie temperature.

Parts of this work were supported by the Russian Foundation for Basic Research, the Ministry of Science and Education of Russia, and The Netherlands Organization for Scientific Research (NWO).

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STRAINED-INDUCED EFFECTS IN NONLINEAR-OPTICAL PROPERTIES OF THIN BISMUTH FERRITE FILMS

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Materials which demonstrate the coupling between electric, magnetic and structural order parameters, are known as multiferroics. Among this class of materials, much attention is attracted to magnetoelectric materials that possess simultaneously ferroelectric and ferromagnetic (or antiferromagnetic) ordering. Their unique properties and in particular the possibility to influence the magnetic state of the medium through variation of its ferroelectric state and vise versa, opens unique perspectives for their application in information storage devices, sensors etc. Among magnetoelectric materials, special attention is attracted to bismuth ferrite, $BiFeO_3$, which possess simultaneously high values of both Neel and ferroelectric Curie temperatures, T_C=1103 K and T_N=643 K, as well as large values of magnetoelectric effect. It was expected that the mechanical strain can influence both the ferroelectric and magnetic properties of $BiFeO_3$.

Optical second harmonic generation (SHG) provides unique possibilities for the characterization of magnetoelectrics because of its intrinsic sensitivity to the ferroelectric and magnetic state of a material. In particular, approximation of the linear decrease of the SHG intensity to zero with increasing temperature allows for the estimation of the ferroelectric Curie temperature. In the present work, the SHG probe is applied to study the strain-induced features in structural and multiferroic properties of thin epitaxial films of bismuth ferrite.

$BiFeO_3$ thin films with the thickness 150÷400 nm grown on (001) $SrTiO_3$ substrate by single source MOCVD at the temperature of 700°C using $Fe(thd)_3$ and $Bi(C_6H_5)_3$ as volatile precursors. The XRD φ-scans and rocking curves prove a good epitaxial quality of the films. The samples with the epitaxial stress in the interval σ=0.27÷1.64 GPa were studied. The SHG experiments were performed using the output of a Q-switched Nd^{3+}:YAG laser at 1064 nm wavelength and pulse duration of 15 ns as the temperature of the samples was varied in the temperature interval 25÷750°C.

Crystallographic structure of the films was characterized by measuring the azimuthal dependences of the SHG intensity for various combinations of the input and output polarizations. The anisotropy correlates with the monoclinic symmetry of the $BiFeO_3$ films, which differs from the rhombohedral structure of single crystal and is attributed to the influence of the epitaxial strain.

A continuous decrease of the SHG intensity on temperature is observed for all the samples under study and in the whole temperature range. For $BiFeO_3$ films with σ=0.27÷0.6 GPa, two temperature regions can be distinguished: approximately 25÷350°C and T>450°C. In the first interval, a sharp increase of the SHG intensity with decreasing T is observed, which demonstrates a rise of spontaneous polarization of the $BiFeO_3$ films when the antiferromagnetic state is established. The films with larger σ values do not reveal such a behavior.

In the second temperature range, all the samples demonstrate a continuous decrease of the SHG intensity that is close to a linear function of the temperature. Such a behavior is typical for ferroelectric materials in the vicinity of the ferroelectric phase transition [1]. The ferroelectric T_C values are estimated, which show that the T_C (σ) dependence is close to inverse exponential one, the lowest $T_C \approx$ 500°C being attained for the film with maximal strain, σ=1.64 GPa.

EXOTIC PHASES IN QUANTUM AND FRUSTRATED SPIN SYSTEMS

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I will talk about two topics on a quantum spin system regarded as a quasi one-dimensional (1D) spin (*S*) 1/2 Ising-like antiferromagnet and an *S*=1 geometrically frustrated spin system.

For the former topic, I will show the results and interpretations of high field ESR[1], specific heat[2] and neutron scattering[3] experiments on $BaCo_2V_2O_8$ which shows an interesting field-induced order-disorder transition[4] around H_c=4 T along the chain direction. At sufficiently low temperatures down to 200 mK above H_c, we observed a new ordered phase by specific heat[2] and found a peculiar incommensurate ordering, namely a longitudinal SDW-like ordering, in this ordered phase by the neutron scattering experiment[3], which reflects a quantum critical nature of the *S*=1/2 1D Ising-like antiferromagnet.

For the latter topic, it will be shown the results of high field ESR experiments on $NiGa_2S_4$[5] that is a quasi two-dimensional (2D) triangular lattice antiferromagnet with *S*=1 indicating no long-range order down to 0.08 K. The absorption line width of ESR spectra increases as the temperature is lowered from about 80 K to 8.5 K and shows an anomaly at an intermediate temperature about 23 K. We have successfully explained that the line broadening is caused by a 2D short range order above 23 K and by the dissociation of Z_2 vortex pairs[3] between 23 and 8.5 K. One of the conventional spiral resonance modes explains well the frequency dependence of the ESR resonance fields far below 8.5 K. This means that spin wave excitations are realized in this compound without long range order, meeting Z_2 vortex scenario[6]. Accordingly, all the experimental results suggest the occurrence of a Z_2 vortex-induced topological transition at 8.5 K[7].

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COVALENT BONDING AND MAGNETISM IN CUPRATES

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We have investigated spectra of spin excitations in chain cuprates Sr_2CuO_3 and $SrCuO_2$ by time-of-flight inelastic neutron scattering. We find good agreement of their energy-momentum structure with the exact results for one-dimensional (1D) spin-1/2 Heisenberg Hamiltonian, which were calculated using recently developed techniques based on quantum field theory methods [1]. Hence, we find no evidence for spectral effects resulting from electron itinerancy [2]. However, we have observed that total scattering intensity is a factor 2 or more lower than that calculated for scattering by chain of spins carried by the electrons localized on Cu^{2+} $d(x^2\text{-}y^2)$ orbitals [3]. Very similar observations of missing intensity were reported in doped and undoped varieties of the related planar cuprate La_2CuO_4, which is a parent material of high-temperature superconductors [4]. Comparison with exact results available for 1D spin-1/2 Hamiltonian allows us to exclude exotic explanations proposed for 2D materials. We have performed an ab initio calculation of the Wannie wave function of magnetic electron and found that the most plausible reason for missing spectral weight is covalency (charge transfer), i. e. the hybridization of Cu 3d-orbitals with oxygen p-orbitals [5] , which results in the significant suppression of Cu^{2+} magnetic form factor and, consequently, of magnetic neutron scattering intensity.

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QUANTUM CRITICAL DYNAMICS OF S = 1/2 ANTIFERROMAGNETIC HEISENBERG CHAINS STUDIED IN CuPzN BY ESR

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The systematic ESR investigations of S = 1/2 quantum antiferromagnetic chain compound copper pyrazine dinitrate ($Cu(C_4H_4N_2)(NO_3)_2$ or CuPzN) are reported. This quasi one dimensional material is regarded [1] as an excellent example of the isotropic Heisenberg system, which remains disordered down to ~ 100 mK.

In a wide temperature range the measurements of Cu ESR carried out at 9.4 GHz revealed a single Lorentzian line with *g*-factor and linewidth having the same orthorhombic symmetry respect to the magnetic field *H* orientation. But at temperatures $T \leq J/k_B$, drastic symmetry changes in the linewidth ΔH angular dependence upon *H* rotating in the ***bc*** crystal plane have been found (J = 10.7 K is the intrachain exchange coupling). The most impressive among them is that the characteristic temperature dependence of the linewidth ΔH becomes extremely sensitive to the magnetic field orientation: for *H* along the ***b*** or ***c*** axis it decreases upon cooling proportional to *T*, whereas for the direction making an angle 45° with these axes it diverges as $\Delta H \sim 1/T^2$. For understanding of such nontrivial behaviour it is crucial, that the CuPzN unit cell contains two linear chains - each of them formed by spins from the slightly inequivalent Cu sites, which are coupled by the weak exchange. As a result the linewidth complex angular dependence reflects the subtle interplay of two different perturbations of the isotropic Heisenberg model: *i*) the exchange anisotropy and *ii*) the staggered magnetic field induced by alternating *g*-factors of nonequivalent Cu sites (the effect of Dzyaloshinskii-Moriya interaction is negligible for CuPzN). The experimental data enable us to estimate the magnitude of these perturbations, which drive the system from the ideal Tomonaga-Luttinger-Liquid state to the state with the field-induced gapped spin excitation spectrum [2].

We show that the effective spin model describing CuPzN system corresponds to zigzag spin ladder which may be converted to the linear Heisenberg spin chain with interaction of the nearest and next nearest neighbours. This observation is important for understanding of the phase diagram of CuPzN and of its antiferromagnetic ordering observed [3] at 100 mK.

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SPIN RESONANCE MODES IN THE SPIN - LIQUID AND ORDERED PHASES OF A TRIANGULAR LATTICE ANTIFERROMAGNET Cs_2CuCl_4: SPIN GAP ABOVE THE NEEL POINT

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Cs_2CuCl_4 is a quasi two-dimensional S=1/2 antiferromagnet with a distorted triangular lattice. It remains in a disordered short-range correlated state at cooling far below Curie-Weiss temperature $\Theta \approx 4$ K, and then demonstrates a spiral ordering at T_N=0.62 K [1, 2].

We present a study of the electron spin resonance in the frequency range 9-100 GHz, at the temperatures both above and below T_N. At T > 10 K there is a conventional paramagnetic resonance with g-factor values g_a=2.2, g_b=2.08, g_c=2.3. At cooling through 4 K the absorption spectrum becomes strongly anisotropic, with three resonant modes instead of one at higher temperatures. Two of these three modes are gapped, the gaps arise at the temperature about 5 K and strongly increase with cooling. Below T_N only gapped modes are present, while the gapless mode is absent. Gap values are 23 and 30 GHz at T=0.45 K. Two-gap spectrum corresponds well to a spiral antiferromagnet with two-axis anisotropy. At T = T_N we observe a change of the slope of the temperature dependence of the gap, the gap values being nonzero (15 and 20 GHz) at this point. The described temperature evolution of the spin resonance spectrum differs strongly from a classical antiferromagnet, which has a gap, appearing exactly at T_N and growing proportionally to the order parameter.

Similar energy gaps, which open above T_N, were found recently in a strongly frustrated pyrochlore antiferromagnet $Gd_2Ti_2O_7$[3] and S=1 antiferromagnet with a triangular lattice $NiGa_2S_4$[4].

To explain the energy gap in the magnetic resonance spectrum above T_N we assume that the characteristic fluctuations of the order parameter in the correlated state are slow compared to the period of spin oscillations in observed resonance modes.

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PUMP-FREE EVOLUTION OF A PARAMETRICALLY PUMPED MAGNON GAS

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A magnon gas is a promising model system for the investigation of interacting bosonic particles and thus for correlated systems in general. Its potential is due to the wide controllability of the magnon-magnon interaction by change both of spectral properties and magnon density. The most effective technique to control the magnon gas density is parametric pumping using microwaves. The pumping role is versatile: it serves both as an energy source and as a strong disturbing factor in the spin-wave system. This defines the important problem of pumping-free evolution of a non-equilibrium magnon gas.

Here we present two distinct effects observed on parametrically pumped magnon gas in an in-plane magnetized Yttrium-Iron-Garnet film. Both of them are focused on the behavior of a parametrically driven magnetic medium after the pumping source is switched off.

The first effect involves the magnons directly influenced by an external parallel electromagnetic pumping. During this pumping process pairs of photon-coupled exchange magnons are created at half of the pumping frequency. The microwave magnetic field induced by these pairs is shifted in phase compared to the external pumping. This leads to an effective reduction of the net pumping in a stationary state. Thus, switching the external pumping off is accompanied by an increase of the net magnetic field at the pumping frequency and as expected should lead to the strong interaction of the initially excited magnons with other magnon groups. A microstrip transducer was used both to supply the microwave pumping pulse and receive the signal irradiated by the sample at half of the pumping frequency. A sharp peak at the end of this signal was detected immediately after the pumping pulse was switched off. The appearance of this peak is interpreted as a result of the parametric amplification of long-wavelength spin waves by the non-compensated internal field.

The second effect we present is the free evolution of a Bose-Einstein condensate of parametrically injected magnons after shutdown of a pumping microwave field. This evolution was studied by means of time-resolved Brillouin light scattering spectroscopy. The light scattered by the directly injected magnons, which were parametrically excited near the frequency of ferromagnetic resonance, as well as by the Bose-Einstein condensate (BEC) formed by thermalized magnons at the bottom of spin-wave spectrum was detected and analyzed. A pronounced and sharp (60 ns) intensity jump of the BEC of magnons above its equilibrium level has been observed just after switching off the external pumping source. Accompanied with this we detected the decay of the directly injected magnon group with a relaxation time around 60 ns. The subsequent decay of the BEC of magnons is much slower and is characterized by the relaxation time of 800 ns. The discovered surge can be interpreted as an increase in scattering efficiency of the parametrically injected magnons to the Bose-Einstein condensate in absence of pumping.

UNCONVENTIONAL ORDERS IN LOW-DIMENSIONAL MAGNETS

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In usual magnets, spin degrees of freedom order ferro- or antiferromagnetically, while those two basic orders may be viewed as special cases of a general spin density wave order parameter characterized by a certain wave vector. It had been known for a long time [1-3] that other "exotic" spin orderings with a vanishing spin density are theoretically possible, but only recently such orders have been observed in numerical studies of realistic models [4-7]. For low-dimensional magnets, unconventional order parameters may become dominating, since quantum fluctuations have a tendency to destroy the usual magnetic order. I will give an overview of our recent studies concerning the vector chiral order (known also as the spin current, or *p*-type spin nematic order) in isotropic frustrated spin-*S* chains subject to an external magnetic field. Fig. 1 illustrates a typical behavior of the chiral order parameter in chains with *S r*anging from ½ to 2.

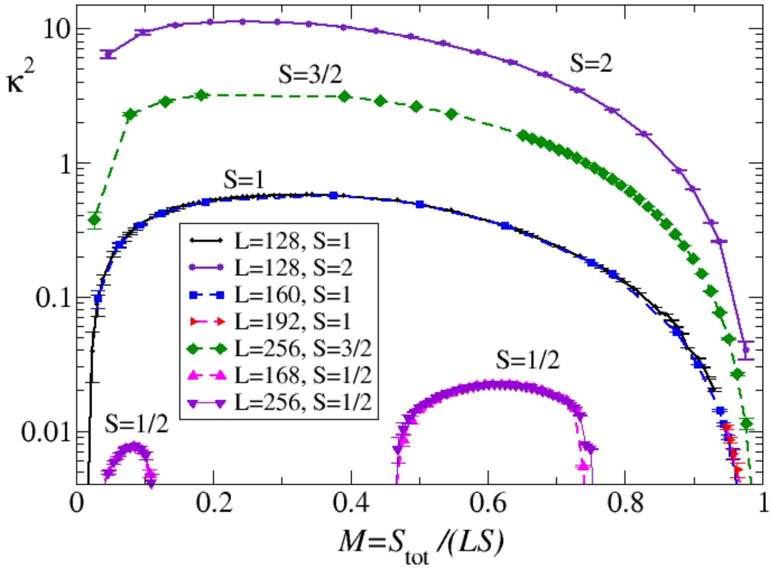

Fig. 1 The chiral order parameter $\kappa^2 = \lim_{n\to\infty}\langle \vec{\kappa}_0 \cdot \vec{\kappa}_n \rangle$ (where the chirality operator $\vec{\kappa}_n = (\vec{S}_n \times \vec{S}_{n+1})$ is defined as a vector product of two adjacent spins along the chain as a function of the magnetization M for isotropic antiferromagnetic frustrated spin-S chains with the next-nearest neighbor to nearest neighbor exchange ratio $\alpha = 1$.

I will also discuss the relation between the emergence of the vector chiral order and instabilities in multicomponent Bose gases.

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ELECTRON-SPIN-RESONANCE STUDY OF ALTERNATING S=1 ANTIFERROMAGNETIC SPIN-CHAINS

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Metallo-organic compound NTENP (which is abbreviation for $Ni(C_4H_{24}N_4)NO_2(ClO_4))$ is a recently found example of the S=1 quasi one-dimensional antiferromagnet with strongly alternated exchange interaction [1]. Due to the alternation (dimerization) of the exchange bonds the ground state differs strongly from the well known Haldane state which realizes for uniform S=1 spin chains. The energy gap of exchange origin separates singlet ground state from the excited triplets. Energy levels of triplet excitations are additionally strongly split by the effective crystal field [2]. The values of the triplet sublevels' energies as determined by neutron scattering [2] are 0.97, 1.13 and 2.0 meV. Magnetic field of about 10 T closes the energy gap, which results in the formation of the field-induced 3D antiferromagnetic order at the temperature below 0.6 K [2].

We have performed an electron-spin-resonance (ESR) study in the frequency range 20-150 GHz, both below and above the critical field at the temperatures down to 0.4 K. Three types of resonance absorption were found:

I. Thermally activated triplet excitations. The frequency-field dependences for this resonance mode, in particular, the shift from g=2.0 resonance field, frequencies of "two-quantum" transitions, indicate the splitting of the triplet sublevels by the effective crystal field and allows one to refine parameters of effective crystal field in addition to known neutron scattering data.

II. Singlet-triplet over gap transitions. The frequency-field dependence of this resonance signal is close to zero at the critical field.

III. Antiferromagnetic resonance above the critical field in the field-induced antiferromagnetic phase. This signal is found to broaden rapidly with the increasing frequency, which is unlike to the behavior of the antiferromagnetic resonance in the field-induced antiferromagnetic phases in other quantum spin-gap systems [3]. This broadening may be indicative of the decay of the antiferromagnetic magnons into the continuum, as suggested in [2].

The work is supported by the Russian Foundation for Basic Research grant 09-02-00736-a and by the Presidential grant for young scientists MK-4569.2008.2.

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ON INSTABILITY OF THE NEEL PHASE OF THE ANISOTROPIC NON-HEISENBERG HAMILTONIAN WITH ANTIFERROMAGNETIC COUPLING ON A SQUARE LATTICE

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One of the most important problems related to the theoretical consideration of the properties of two-dimensional antiferromagnets (2D-AFM) on a square lattice is the role of quantum fluctuations in the stability of the Neel phase. In the simplest case of an isotropic Heisenberg 2D-AFM with the interaction between the nearest neighbors, the effect of the quantum fluctuations at T=0 appears insignificant even at the minimum spin value S=1/2 and expansion in the parameter (1/2S) is justified.

For the Hamiltonian possessing of cubic symmetry in the spin space, the invariants that describe the first-order interaction degenerate into the isotropic forms $I_{fm}\left(\vec{S}_f\vec{S}_m\right)$. Such interactions do not violate invariance of the Hamiltonian relative to the SU(2) group of arbitrary rotations in the spin space. In this case, for the Neel phase the spontaneous symmetry break occurs and, according to the Goldstone theorem, the excitation spectrum is gapless: $\Delta = \omega(q=0) = 0$. Here the question about renormalization of the gap due to the quantum fluctuations does not arise.

The situation qualitatively differs as soon as the Hamiltonian takes into account the four-order invariants describing the cubic anisotropy of the exchange interactions. In this case, the total Hamiltonian does not posses of a continuous symmetry group and for the Neel phase the spontaneous symmetry break occurs only relative to the discrete group. Therefore, the gap in the excitation spectrum is nonzero and the quantum fluctuations will lead to renormalization of "seed" gap Δ. This means that, in the anisotropic case, the Neel phase boundaries can shift. The special attention should be paid on the stability of the Neel phase under the condition of anisotropy of the four-spin interaction.

In this study, the effect of the anisotropic four-spin exchange interaction on the spectral properties of the non-Heisenberg 2D-AFM on a cubic lattice is considered. The cubic anisotropy is taken into account by three four-spin invariants. For different ratios of the system parameters, the nonlinear theory of the spectral properties has been developed and the stability regions of three symmetrically allowable phases have been found. The effect of the cubic anisotropy and frustrated interactions on the stability region of the Neel phases has been studied. Spin-wave rigidity and the gap have been renormalized in the elementary excitation spectrum.

This study was supported by the Program "Quantum Physics of Condensed Matter" of the Presidium of the Russian Academy of Sciences, the Russian Foundation for Basic Research (project no. 07-02-00226), and the Siberian Branch of the Russian Academy of Sciences (integration project no.53).

MAGNONS IN RUNG-DIMERIZED SPIN LADDERS

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We treat within the Bethe ansatze spectral problem for one- two- and three-magnon sectors of exactly rung-dimerized spin ladders. Explicit formulas are presented for wave functions and dispersion of one- two-magnon and bound three-magnon states. The three-magnon sector is studied at all values of total spin S=0,1,2. The S=0 spectral problem is always solvable however for S=1 and S=2 ones complete solvability takes place only in five integrable cases. Nevertheless even in general non integrable case there is a special partial solution in the S=1 sector. Relevance of the obtained spectrum with neutron and Raman scattering is discussed.

ANTIFERROMAGNETIC RESONANCE AND PHASE DIAGRAM OF $HoFe_3(BO_3)_4$

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Rare-earth iron borates with *huntite* structure $RFe_3(BO_3)_4$ has attracted considerable interest to their magnetoelectric, optical and magnetic properties. Lasts are determined by interaction between subsystems of iron and rare-earth ions. For Gd ions the spin-reorientation transitions between the low-temperature easy axis (EA) and high-temperature easy plane (EP) states induced both by the temperature and magnetic field are observed[1, 2].

The nature of the spin-reorientation transition in gadolinium ferroborate is a competition between the contributions of Fe^{3+} and Gd^{3+} subsystems to total magnetic anisotropy of the crystal [2], these contributions have opposite signs and are close in absolute values. Magnetic structure of $HoFe_3(BO_3)_4$ was determined in [4] using neutron diffraction investigations. The easy plane (EP) state below the Néel temperature 37.4 K and the spontaneous reorientation to easy axis (EA) one at $T_{SR}≈5$ K were found. In the present work we study the magnetic resonance and low-temperature magnetic diagram of holmium ferroborate. The magnetic properties of $HoFe_3(BO_3)_4$ are studied in the temperature range 2-300 K in magnetic field up to 9 T. According to the magnetic and calorimetric measurements the phase boundaries of EA and EP states were obtained for H||c and H⊥c (Fig.1). The nature of the spin reorientations in $HoFe_3(BO_3)_4$ and $GdFe_3(BO_3)_4$ are similar.

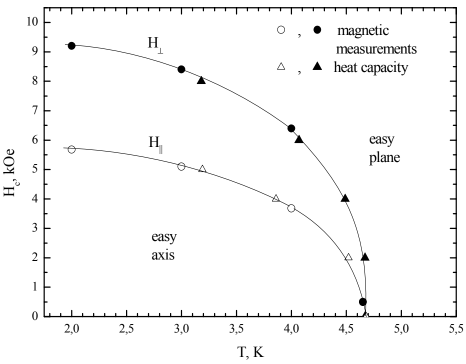

Fig. 1. Magnetic phase diagrams of $HoFe_3(BO_3)_4$ in H||c and H⊥c.

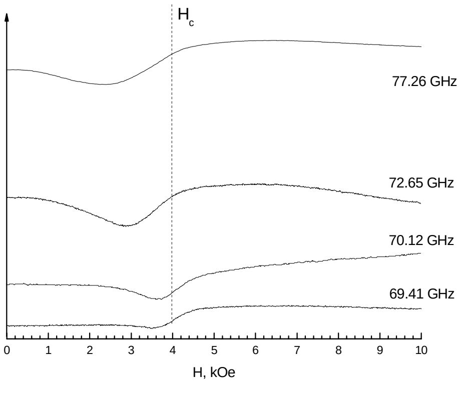

Fig. 2. Magnetic resonance spectra of $HoFe_3(BO_3)_4$ in H||c at 4.2 K.

AFMR investigations of $HoFe_3(BO_3)_4$ were performed in the frequency range 25-80 GHz and temperature range 4.2-77 K. For H||c the resonance absorption was found at 4.2 K in the frequency range 70-78 GHz. The resonance line breaks in a field ~4 kOe (Fig. 2) coinciding with the critical field of transition at this temperature. The frequency-field dependence corresponds to EA state and can be described by the energy gap at T=4.2 K $N_c≈80$ ГГц which is considerably higher than the gap $N_c≈30$ GHz in $GdFe_3(BO_3)_4$ [1]. As the gap value is determined by the sum of anisotropy fields of iron and rare earth subsystems this difference can be explained by the anisotropy field of Ho^{3+} exceeding one for Gd^{3+} at T=4.2 K.

Taking into account that T_{SR}=4.7 K in $HoFe_3(BO_3)_4$ is considerably lower than T_{SR}=10 K in $GdFe_3(BO_3)_4$ it can assume the stronger temperature dependence of anisotropy field of Ho^{3+} than for Gd^{3+}.

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SURFACE MAGNETOSTATIC WAVES IN BRILLOUIN ZONE OF ARTIFICIAL MAGNETIC CRYSTAL

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A magnetic crystal is implemented on the basis of an yttrium iron garnet (YIG) film magnetized to saturation in a uniform bias field. Surface magnetostatic waves can propagate through such a film. To form a magnetic crystal, a spatially periodic magnetic structure is imposed on a film. The magnetic field of this structure, penetrating the YIG film, modulates its magnetic permeability, thus forming a magnetic crystal [1]. We used a high-coercivity (H_C = 1000 Oe) magnetic tape with a recorded sinusoidal signal to form a one-dimensional magnetic crystal.

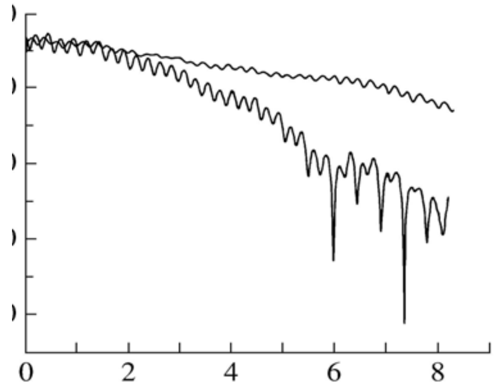

Fig. 1. Dependence of the power of the surface magnetostatic wave on its path length in a magnetic crystal at different frequencies. The lower and upper curves correspond to the central and edge frequencies of the band gap.

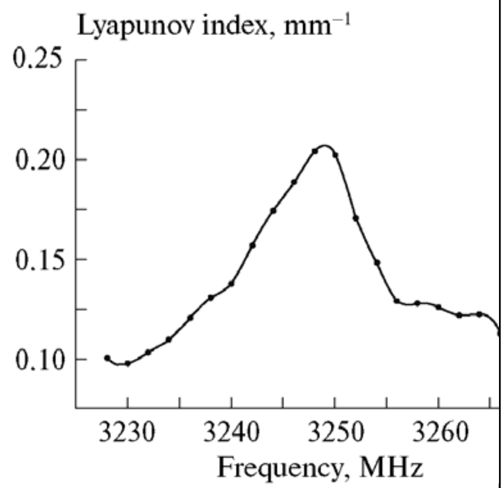

Fig. 2. Lyapunov index for a surface magnetostatic wave of a magnetic crystal in the band gap region.

Waves in a YIG film are excited by a microwave current passing through a thin wire (antenna), which is pressed against the film surface. The transmitted wave is detected by a similar receiving antenna. Wave vector of a surface magnetostatic wave is oriented perpendicularly to the direction of the bias field, which lies in the YIG film plane [1], and the reverse vector of the recorded signal is perpendicular to the bias field.

In the pan mode, a dip is observed in the amplitude–frequency characteristic of the measuring device, which corresponds to the band gap. Obviously, a wave penetrates the magnetic crystal at band gap frequencies; however, its exponential (on average) decay, related to the imaginary part of the Bloch wave vector (Lyapunov index), is observed. In this study, we experimentally measured the frequency dependence of the Lyapunov index. The signal amplitude was measured at a specified frequency, with a displacement of the receiving antenna along the propagation direction of the surface magnetostatic wave. The curves of the change in the signal amplitude with a change in the observation depth are shown in Fig. 1. Frequency dependence of the Lyapunov index for the Brillouin zone is shown on Fig. 2. It can be seen that this dependence has a characteristic bell-shaped form. This work is supported by RFFR pr. №07-02-00233a.

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GIANT MAGNETORESISTANCE IN SEMICONDUCTOR / GRANULAR FILM HETEROSTRUCTURES WITH COBALT NANOPARTICLES

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We have studied the electron transport in SiO_2(Co)/GaAs and SiO_2(Co)/Si heterostructures, where the SiO_2(Co) structure is the granular SiO_2 film with Co nanoparticles. In SiO_2(Co)/GaAs heterostructures the giant magnetoresistance effect (the injection magnetoresistance, IMR) is observed [1-3]. The IMR-effect has positive values, is pronounced, when electrons are injected from the granular film into the GaAs semiconductor, and has the temperature-peak type character (Fig. 1). The temperature location of the effect depends on the Co concentration and can be shifted by the applied electrical field. For the SiO_2(Co)/GaAs heterostructure with 71 at.% Co the magnetoresistance reaches 1000 (10^5 %) at room temperature, which is two-three orders higher than maximum values of the GMR in metal magnetic multilayers and the TMR in magnetic tunnel junction structures. On the contrary, for SiO_2(Co)/Si heterostructures magnetoresistance values are very small (4 %) and for SiO_2(Co) films the magnetoresistance has an opposite value. High values of the IMR-effect in SiO_2(Co)/GaAs heterostructures have been explained by the spin-dependent potential barrier formed in the semiconductor for injected electrons and by the spin-polarized electron tunnelling from the highest sublevel of exchange-splitted localized states near the interface. The barrier and exchange-splitted localized states are due to the exchange interaction between electrons in the accumulation electron layer (quantum well) in the semiconductor and *d*-electrons of Co. The existence of localized electron states in the accumulation layer results in the temperature-peak type character of the effect. Spin injectors and spin-valve structures on the base of ferromagnet / semiconductor heterostructures with quantum wells with spin-polarized localized electrons in the semiconductor at the interface are considered.

This work was supported by the Russian Foundation for Basic Research.

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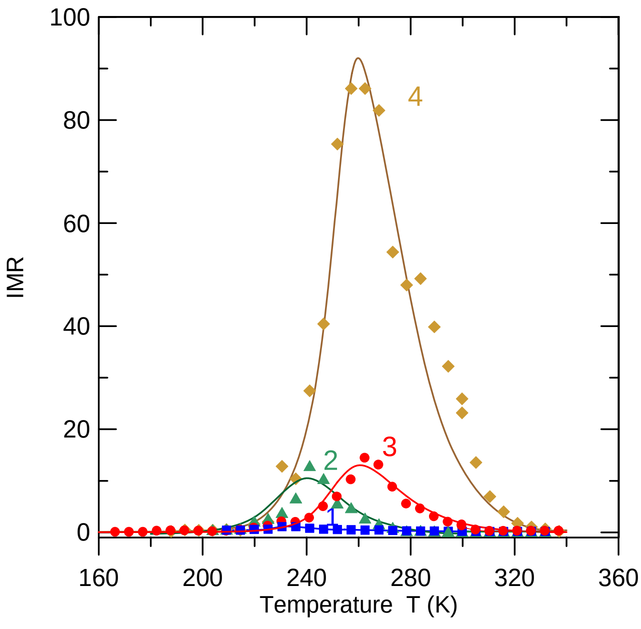

Fig. 1. Temperature dependencies of the injection magnetoresistance, IMR, for the SiO_2(Co)/GaAs structure with 71 at.% Co content in the in-plane magnetic field H = 10 kOe at applied voltages: (1) U = 40 V, (2) 50 V, (3) 60 V, (4) 70 V. Solid lines are theoretical fittings.

BRILLOUIN LIGHT SCATTERING STUDIES OF SPIN WAVE MODES IN NICKEL NANOWIRES

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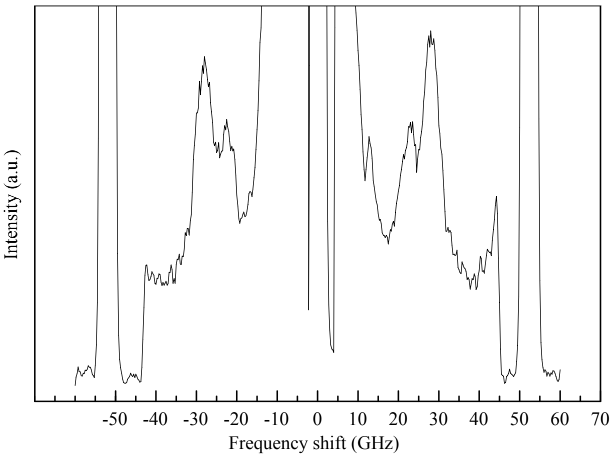
Numerous potential applications of ferromagnetic nano-wires have stimulated extensive research effort aiming at the investigation of the dynamic behavior of such systems. For the case of small precession angles it manifests itself though the presence of dipole exchange modes localized on individual wires coupled via inter-wire dipole-dipole interactions. In this paper we study the dynamic properties of arrays of Ni nanowires with finite aspect ratios, in which case vertical spin-wave resonances (SWR), previously neglected in the studies of nanowires with $R > 50$ [1,2], become extremely important.

More specifically, we used the Brillouin Light Scattering (BLS) technique to investigate spin wave (SW) modes on arrays of Ni nanowires with aspect ratios $R = 9$ and $R = 2.5$. In both samples the Ni nanowires were 175 nm long, while their diameter was equal to 20 nm and 70 nm, respectively. The BLS spectra from nanowires with a low value of the aspect ratio are characterized by two major features, namely, a two-peak structure of BLS lines (see the figure) and a high degree of the Stokes/anti-Stokes (S-AS) asymmetry. The former is explained by the presence of zones with high density of states in the spectrum of the SWRs localized on a nanowire, each producing a separate sub-peak. To estimate the SWR spectra and to identify the modes, we used a purely numerical finite element technique which returns the distribution of the dynamic magnetization. These numerical simulations have revealed non-negligible dipole pinning on the top and on the bottom of a wire. The effect is the most pronounced for the purely dipole Kittel mode. No dispersion of magnetic modes has been detected which is explained, within a simple "mean-field" theory, by too low packing density. The S-AS asymmetry, typically ascribed to collective behavior of the Damon-Eshbach type, here is due to the elliptic character of the polarization of the light interacting with magneto-static waves. Numerical simulations of the light polarization within a nanowire, dependent on near-field interaction between the wires in the array, led to a simple theoretical model providing a qualitative and partially quantitative description of this effect.



A typical two-peak BLS spectrum ($R = 2.5$).

This work was partially supported by the ACI "NANODYNE".

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FMR STUDY IN PERMALLOY FILMS ON PATTERNED SILICON SUBSTRATES

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For the past few decades, magnetic excitations in patterned ferromagnetic structures have been the subject of strong interest stimulated by the desire of a deeper understanding of fundamental physics of magnetism as well as the importance for technical applications [1]. In this work we study magnetic excitations in patterned Permalloy (Py) films obtained by the deposition of continuous films on patterned substrates.

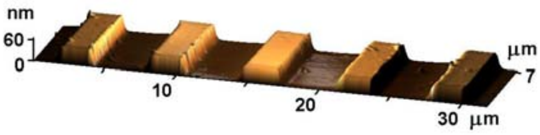

Fig. 1 Atomic force microscopy image of the silicon substrate with 50 nm deep trenches before the Py film deposition.

Films of 50 nm thick Py were deposited by magnetron sputtering on Si substrates which were previously patterned using photolithography and ion etching in the form of a periodical striped structure with the stripe width and the gap between the stripes of order 3 µm – see Fig. 1. Three samples were fabricated: with 25, 50 and 150 nm deep trenches. Ferromagnetic resonance (FMR) was used to examine the magnetic excitations in these samples. The FMR spectrum at different angles between the in-plane magnetic field and the stripes axis was measured at about 9.9 GHz.

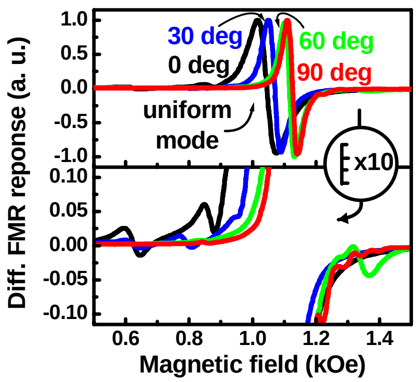

Fig. 2 FMR response for the sample with a 150 nm deep trench at different directions of the in-plane magnetic field relatively to long axis of the stripe. The bottom figure represents the top one with the vertical axis magnified 10 times.

The effect of patterning on the FMR spectrum was observed only in the case of the samples with 50 and 150 nm deep trenches. These samples indicated the presence of shape anisotropy with the easy axis along the stripes resulting in the angular dependence of the FMR field for uniform mode – see Fig. 2 and 3. The effect of the shape anisotropy increased with the profile depth, showing a difference in the FMR fields for the field applied along and perpendicular to the stripe of 45 and 80 Oe for the samples with 50 and 150 nm deep trenches, respectively. Moreover, additional FMR responses were observed for these samples, both below and above the uniform mode response depending on the direction of the applied magnetic field. In general, the observed features are similar to those for uncoupled ferromagnetic stripes [2] except that the effective demagnetizing fields are tunable with the depth of the trenches. As the depth of the trench is increased, the effective shape anisotropy field becomes larger and additional modes are observed in the FMR spectra.

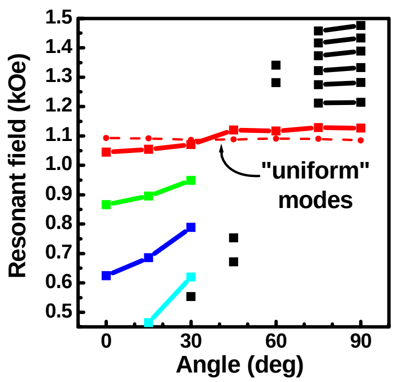

Fig. 3 Fields corresponding to different FMR responses versus angle between the applied magnetic field and stripe axis in the case of the sample with 150 and 25 nm (dash line) deep trenches.

This work was supported by RFBR (grants # 09-07-00186 and # 08-07-00119) and ARO (grant # W911NF-04-1-0247).

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SPIN WAVES IN THE SPIN-INJECTED DISORDERED PARAMAGNETIC METALS

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The spin accumulation in nonmagnetic materials could be produced by spin injection [1-3]. The result of weak exchange interactions in paramagnetic metal with spin imbalance is the long-lived spin waves excitations predicted by Aronov [4]. We study the effect of weak electron-electron exchange interactions on the non-equilibrium spin excitations in the impure paramagnetic metal. We calculate the transverse magnetic susceptibility and the spin waves spectrum in the disordered system at low temperatures.

Spin injection into the paramagnetic metal leads to the non-equilibrium polarization R that is connected with the Fermi energy shift of spin up and spin down electrons $\delta\mu$ through the relation

$$IR = \lambda\nu \frac{\delta\mu + 2\omega_z}{1-\lambda\nu}, \quad (1)$$

where $\nu = mp_F / 2\pi^2$ is the electron density of states per spin direction, ω_z is the Zeeman energy, $\lambda > 0$ is the electron coupling constant and $I = 4\nu\mu\lambda/3$. We suggest the condition $\lambda\nu < 1$, which is opposite to the Stoner condition for the ferromagnetism. The spectrum of spin density excitation is defined by the poles of the transverse dynamical magnetic susceptibility. Taking into account eq. (1), in the limit of very clean sample when $IR\tau >> 1$ we recover the result of Aronov [3] with additional effects of Zeeman oscillations and disorder for $IR >> q\mathrm{v}_F$, Ω:

$$\Omega = 2\omega_z - \left[1 + \frac{i}{\tau IR}\right]\frac{(q\mathrm{v}_F)^2}{3IR}(1-\lambda\nu). \quad (2)$$

It is seen that at small Zeeman frequency $\omega_z << IR$ the real part of spin waves frequency becomes negative [4], such that $\Omega = -(q\mathrm{v}_F)^2/3IR$. The frequency has an opposite sign compared to the case of equilibrium ferromagnetic, while the imaginary part of Ω describes the damping of spin excitations and is much smaller than its real part. However, in the opposite limit when disorder is strong, $1/\tau >> IR >> q\mathrm{v}_F$, the spectrum takes the following form

$$\Omega = 2\omega_z - Dq^2[i + \tau IR](1-\lambda\nu), \quad (3)$$

where $D = v_F^2\tau/3$ is the electron diffusion coefficient. The attenuation of spin wave mode in the diffusive limit is defined by the diffusion coefficient modified by the correction $1-\lambda\nu$. The decay of the spin-wave excitations in the disordered system is much stronger than it is in the pure case. When the Zeeman term in Eq. (3) is small, $\omega_z << q\mathrm{v}_F$, the imaginary part of frequency Ω is much larger than its real part signaling of strong damping of spin wave.

Recently [5], the amplification of an oscillating electric field was demonstrated in the nonmagnetic systems with strong spin-orbit coupling and spin injection. We argue that the account of weak electron-electron exchange interactions in the paramagnetic metals with non-equilibrium spin polarization leads to the effect of amplification of electromagnetic wave propagating through such medium. Depending on signs of Ω and imaginary part of magnetic susceptibility the power is extracted or supplied to the field. In the spin injected system proposed, power supplies to the field with frequency near collective spin excitation where Ω<0.

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THERMAL AND NONTHERMAL MAGNETIZATION DYNAMICS OF ANTIFERROMAGNETIC COMPOUNDS

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In three examples it is shown that the magnetization dynamics of antiferromagnetic compounds differs noticeably from that of ferromagnetic compounds. Optical second harmonic generation and linear reflection were used to monitor the evolution of the antiferromagnetic order parameter subsequent to intense optical excitation with a temporal resolution of better than 1 ps.

Comparison of the dynamical properties of the model antiferromagnet Cr_2O_3 to model ferro- and ferrimagnets reveals that spin-lattice relaxation as temporally limiting thermalization process of the magnetic subsystem is more complex and inherently faster than in compounds displaying a spontaneous magnetization.

The exchange-bias compound NiO exhibits an ultrafast photoinduced antiferromagnetic phase transition in the course of which the antiferromagnetic order parameter is switched controlled and reversibly in three dimensions. Properly timed sequences of pump pulses can reorient the antiferromagnetic order parameter repeatedly within 10 ps, thus demonstrating ultrafast antiferromagnetic switching. It is demonstrated that this is a non-thermal way of magnetic order-parameter control.

In multiferroic $HoMnO_3$ the magnetoelectric interaction of the Mn^{3+} and Ho^{3+} sublattices is investigated. Pump and probe experiments reveal several time scales for the relaxation processes following optical excitation which reveal the Mn-Mn, Ho-Mn, and Ho-Ho coupling.

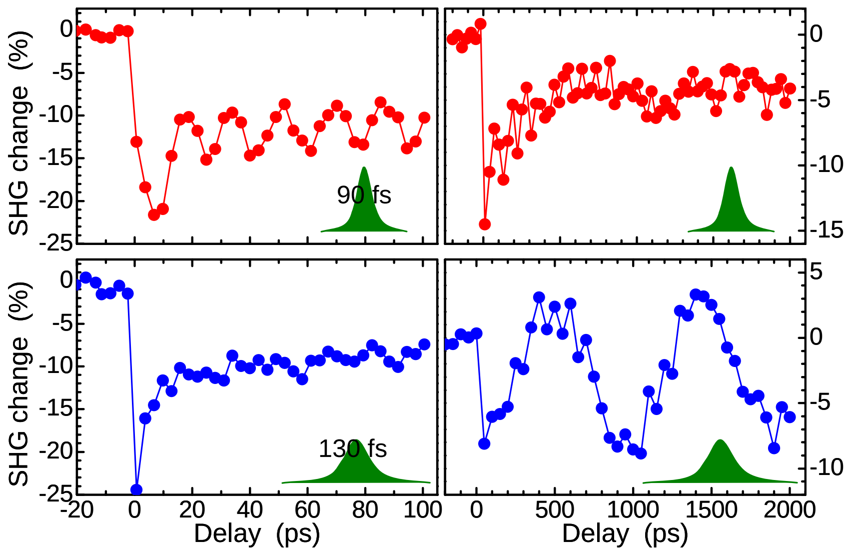

Figure: Change of SHG intensity for antiferromagnetic NiO at 2.00 eV upon irradiation with an intense pump pulse of 100 fs and 1.55 eV. Note that only the temporal width but not the energy of the pump pulse was varied in the experiment.

DYNAMICS OF AN ULTRAFAST ALL-OPTICAL MAGNETIZATION REVERSAL BY 60 fs LASER PULSES IN GdFeCo FILMS

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The feasibility of the all-optical magnetization reversal has been an intriguing issue since first successful experiments on the ultrafast laser-induced spin dynamics [1]. Recently, it was shown experimentally, that 40 fs circularly polarized laser pulses can reverse the magnetization in the thin films of a ferromagnetic alloy GdFeCo [2]. The reversal direction was unambiguously determined by the helicity of the laser pulses. The understanding of a microscopic mechanism and actual time scale of this process emerged as an issue of not only fundamental but also practical importance for a magnetic recording and data proceeding.

Here we present the time-resolved study of the all-optical magnetization reversal in GdFeCo films, described elsewhere [2]. We developed a time-resolved single-shot Faraday microscopy technique, which allows to visualize the magnetic state of a sample at different delay times after an excitation by a *single* right-(σ^+) or left-handed (σ^-) circularly polarized 60 fs laser pulse (pump). The study was carried out for the samples with different compositions and at the temperature range of 10-400 K.

The TRSSM measurements show that for the magnetization reversal process proceeds via a strongly-nonequilibrium demagnetized state formed within ~100 fs after the excitation by a laser pulse. This is followed by either formation of the domain with a reversed magnetization or by the relaxation to a initial state depending on the helicity of the pump pulse. The reversal occurs as a result of an action of a pulse of an light-induced effective magnetic field $\mathbf{H}\sim\mathbf{E}\times\mathbf{E}^*$ [3] upon magnetic system brought into a strongly-nonequilibrium state by an ultrafast laser-induced heating. The following relaxation to a new or initial state involves growth of domains with reversed or conserved magnetization, which speed is determined by the composition of the samples and the temperature, as indeed observed in our experiments.

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TRANSIENT INVERSE FARADAY EFFECT AND ULTRAFAST OPTICAL SWITCHING OF MAGNETIZATION

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Over the last decades the development of femtosecond-pulse lasers has opened new potentials for the studies of ultrafast phenomena in solids, in general, and in magnetically-ordered materials in particular [1]. Recent studies show that circularly polarized laser pulses can be used for ultrafast all-optical switching of spontaneous magnetization [2]. We propose a theoretical model for describing the *non-thermal* switching of the spin magnetization $\mathbf{M}_s$ caused by circularly polarized femtosecond laser pulses [3]. At the initial stage the intense pulse induces in the magnetic medium a non-equilibrium orbital momentum $\mathbf{L}_{neq}$ which in its turn creates a non-equilibrium anisotropy field $\mathbf{H}_{neq}$ potentially capable to reorient $\mathbf{M}_s$. The field $\mathbf{H}_{neq}$ is characterized by a mean value $\langle\mathbf{H}_{neq}\rangle$ and fluctuations $\delta\mathbf{H}_{neq}$ which both can be quite large in the non-equilibrium state. Transverse fluctuations $\delta\mathbf{H}^{\perp}_{neq} \perp \langle\mathbf{H}_{neq}\rangle$ provide a supplementary channel for the coupling of spins with the lattice thus accelerating the spin-lattice relaxation necessary for the reorientation of $\mathbf{M}_s$. In contrast, longitudinal fluctuations $\delta\mathbf{H}^{||}_{neq} \parallel \langle\mathbf{H}_{neq}\rangle$ impede the reorientation of $\mathbf{M}_s$ because they are responsible for the quenching of atomic orbital momenta in the equilibrium state. They lead to strong oscillations of $\mathbf{H}_{neq}$ thus drastically reducing $\langle\mathbf{H}_{neq}\rangle$ down to a value comparable with the equilibrium magnetic anisotropy field. Were that the case the switching of $\mathbf{M}_s$ would be illusive. In order to suppress these objectionable fluctuations of $\delta\mathbf{H}^{||}_{neq}$ we propose a mechanism resulting from the interatomic interaction V_{ll} of orbital momenta. We show that the parameter V_{ll} can be chosen in such a way that, on the one hand, it can not restore the quenched orbital momenta in the equilibrium state, and on the other hand, it can suppress the longitudinal oscillations of $\mathbf{H}_{neq}$ to a sufficiently low level $\delta H^{||}_{neq} / \langle H_{neq}\rangle \approx 0.1$. The switching of $\mathbf{M}_s$ becomes feasible provided the life time τ_q of the non-equilibrium state is longer than the spin-lattice relaxation time time τ_s.

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ULTRAFAST TRANSPORT OF SPIN POLARIZED CARRIERS INDUCED BY FEMTOSECOND LASER PULSES IN Au/Fe/MgO(001)

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The ultrafast magnetization dynamics induced by a transport of spin polarized carriers is a hot topic over last decades. It is motivated by the fundamental interest in magnetic excitations and their coupling to other degrees of freedom, as well as by applications like spintronics and data storage. To achieve a microscopic understanding of the underlying elementary processes, which typically occur on femtosecond time scales, we have developed a time domain approach that probes the ballistic (or diffusive) hot electron-induced spin dynamics in a pump-probe experiment. In this contribution we focus on the photo-excitation of spin-polarized carriers in a ferromagnet and their transport through a paramagnetic metallic layer. This approach allows us to create femtosecond pulses of the spin current running in the absence of a bias, i.e. in the absence of a charge current, which will be the basis for future time-resolved experiments on the spin transfer torque-induced magnetization dynamics.

The experiments were performed in epitaxial Au/Fe/MgO(001) structures, where the Au layer thickness is much larger than the optical penetration depth and comparable to the mean free path of ballistic hot electrons. Hot carriers are excited in the magnetized Fe layer by 800 nm 35 fs pump pulses delivered by a cavity-damped Ti:sapphire oscillator and focused onto the sample from the side of transparent MgO substrate. Owing to the exchange-split Fe band structure, minority and majority carriers are excited at different energies and with different concentrations. These hot, or non-equilibrium, spin-polarized carriers propagate towards the Au surface forming a spin-polarized current. The charge component of this current is screened by a displacement of equilibrium carriers in Au. The transient spin polarization (SP) of the Au surface created by these spin currents is detected by (surface sensitive!) magneto-induced second harmonic generation. We realize a pump-probe scheme with the probe pulse focused onto the same spot at the sample as the pump pulse but from the side of the Au surface.

After a pump-probe delay similar to the thickness of Au layer divided by the Fermi velocity, a detectable magneto-optical signal builds up, changes its sign at a 300 fs time scale and then vanishes at a 1 ps time scale. Increasing Au thickness not only increases the delay of this build-up, but also stretches the time profile indicating considerable diffusive fraction in the hot electron transport. According to *ab initio* band structure calculations, the observed non-monotonicity can be attributed to different life times of hot carriers transporting positive and negative SP. If the negative SP is transported predominantly in the ballistic regime, the transport of positive SP is essentially diffusive and thus has a considerably smaller velocity. Under certain experimental conditions the transport of positive SP can be suppressed almost completely, which results in a single 50-100 fs pulse of spin current. Its polarity is defined by the magnetization of Fe layer and thus can be easily varied in experiments. Estimations give the density of generated spin current corresponding to spin polarized carrier transport on the order of 10^{10} A/cm^2. This opens a way to study spin dynamics of ballistic spin current excited by femtosecond pulses.

SPIN SWITCHING IN THE SPIN-ORBITAL FIELD OF OPTICALLY RECOVERED ORBITAL ANGULAR MOMENTUM

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In 2007 the first announcement of magnetization switching caused by femtosecond laser pulse was published [1]. The results discussed in our report correspond to the model suggested in [2] for describing the ultrafast optical switching of magnetization. The main idea of this model is that the switching process consists of the two stages. At the first stage a non-equilibrium angular momentum is induced by an optical pump (the effect of optical recovery of an orbital angular momentum). The spin magnetization M_S can be switched in the spin-orbital field H_{SO} when

$$M_S \uparrow\downarrow H_{SO}. \qquad (1)$$

The possibility of such switching is obvious if the field H_{SO} does not change for a sufficiently long time period. The conditions of stability H_{SO} were discussed in [2] and we suppose them to be fulfilled. The problem is to select the model for quantitative description of M_S switching by the means of the spin-orbital interaction

$$V_{SO} = -\lambda M_S M_L = -H_{SO} M_S. \qquad (2)$$

The V_{SO} interaction by itself cannot change the relative orientation of M_L and M_S vectors since it conserves the full angular momentum $M_L + M_S$. When considering the M_L relaxation caused by the crystal field, the change of the relative orientation of M_L and M_S vectors becomes possible.

In the report, the results of the analysis of macroscopic equations solutions for M_L and M_S will be discussed. In these equations, the interaction with the crystal field V_{SO} (2) at the initial condition (1) is taken into account. It's shown that the task could be reduced to a nonlinear equation for the component M_S^z $(z \parallel H_{SO})$:

$$\frac{dM_S^z}{dt} = \frac{M_0^2 - (M_S^z)^2}{\tau_S} + \frac{M_0 - M_S^z}{T_S}, \qquad (3)$$

Where M_0 is the value of $M_S^z(t)$ at $t \to \infty$. The parameter τ_S is connected with the M_L relaxation time by a certain equation. We suppose that $T_S >> \tau_S$. The magnetization switching time is defined by the value of τ_S since its dependence on T_S / τ_S appears to be logarithmically-slow.

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X-RAY DETECTION OF MAGNETIC RESONANCE

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X-ray Detected Magnetic Resonance (XDMR) is a new spectroscopy in which X-ray Magnetic Circular Dichroism (XMCD) is used to *probe* the resonant precession of the magnetization when a strong microwave *pump* field $\mathbf{h}_p$ is applied perpendicularly to a static bias field $\mathbf{H}_0$. XDMR is element- and edge-selective and could become a unique tool to resolve the magnetization dynamics of spin and orbital components at various absorbing sites [1-4]. We shall compare different experimental configurations which we used to detect the weak XDMR signals and to access to *element selective* information such as the *opening angle* and the *phase* of precession, as well as the relevant relaxation times, *i.e.* T_1 or T_2.

To illustrate the presentation, we shall produce XDMR measurements carried out essentially at the iron K-edge using ReIG thin films or single crystals. Recall that XDMR spectra recorded at the Fe K-edge reflect the precessional dynamics of pure *orbital* magnetization components. It will be shown that these orbital components can couple to non-exchange (magnetostatic) *spin waves*, whereas a sharp increase of the *apparent* opening angle of precession was observed beyond the 2nd order Suhl's instability threshold [4]. In GdIG, XDMR spectra were shown to be sensitive to the change of chirality of the precession of the Fe orbital components on crossing the compensation temperature. Recently, we could also measure the *ellipticity* of the precession of those Fe orbital components using the generation of 2nd harmonics at microwave frequencies.

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SPIN-WAVE INTERACTION AND MAGNETIC FIELD BEHAVIOR OF CUBIC HELIMAGNETS

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Non-centrosymmetric cubic helimagnets (MnSi, FeGe, FeCoSi etc) demonstrate unusual behavior in magnetic field and at pressure. We point out complex magnetic phase diagram. In zero field the sample consists of magnetic domains with randomly orientated helix wave-vectors $\vec{k}$. Then in small field H_1 the single domain state occurs with $\vec{k}$ along the field $\vec{H}$. Then in narrow field region this wave-vector rotates perpendicular to the field (A phase), and restores its initial direction along $\vec{H}$ at H_{in}. The ferromagnetic transition holds at $H_C = Ak^2$ where A is the spin-wave stiffness at $q >> k$. The quantum phase transition (QPT) to partly disordered magnetic state is puzzling also as the physical reason for the transition was unknown. Conventional linear spin-wave theory cannot explain both phenomena, as it predicts gapless spectrum depending on the field component $H_{\|}$ along $\vec{k}$ only.

Spin-wave interaction gives a key for both problems. It gives rise the square of spin-wave gap $\Delta^2 = \Delta_I^2 + \Delta_{ME}^2$ where the first term is a result of the magnon-magnon interaction. It is positive. The second term appears due to magnon-phonon interaction. It is negative as a second order perturbation. Competition between these terms can lead to QPT, as the helical structure is stable if $\Delta^2 > 0$ only. Perpendicular magnetic field mixes spin deviations with $\vec{q} = 0, \pm\vec{k}, \pm 2\vec{k}...$ and the magnetic energy is given by

$$E_M = E_A - \frac{H^2}{4H_C}\left[2\cos^2\Psi + \frac{\sin^2\Psi}{\cos^2\Psi + (1 - H^2/2\Delta^2)\sin^2\Psi}\right],$$

where E_A is the anisotropy energy and Ψ is an angle between $\vec{H}$ and $\vec{k}$. The first two terms compete at weak field and single domain term with $\vec{k} \| \vec{H}$ occurs. Then when $t = 1 - H^2/2\Delta^2 < 1/2$ the states with $\vec{k} \perp \vec{H}$ become energetically preferable and the first order transition may occur to multi-domain configuration, which has to depend on the field direction, magnetic anisotropy, the sample form and some other tiny factors. For $t < 0$ the $\vec{k} \| \vec{H}$ state restores in agreement with experiment. At positive *t* the second harmonic of the spin rotation was predicted and observed.

Hence H_C and the spin-wave gap Δ are crucial parameters for explanation magnetic properties of the considered materials. The former is determined from magnetization measurements and we have $H_C \approx 0.6T \approx 0.07meV$ for $MnSi$. Usually the spin-wave parameters are measured by inelastic neutron scattering. But in this case Δ is too small. Fortunately small angle neutron scattering allows observe the helix rotation in the A phase and determine $H_{in} = \Delta\sqrt{2}.$ As a result we have $\Delta = 12\mu eV$ for $MnSi$. Similar results were obtained for other compounds with the same structure: $Fe_{1-x}Co_xSi$ and $Mn_{1-x}Fe_xSi$.

SPIN CORRELATION EFFECTS IN OPICAL PROPERTIES OF IRON PNICTIDES

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Interplay between spin fluctuations and superconducting pairing is a challenge to our current understanding of the origin of the remarkably high critical temperature in superconductors near magnetic phases. Recently a new family of layered superconductors containing the 'classical' magnetic element Fe attracted much attention due to a rapid increase of T_c up to 56 K.

We report a comprehensive spectroscopic ellipsometry study on $Ba(Sr)_{1-x}K_x Fe_2As_2$ single crystals over a temperature interval 7 - 300 K and photon energies extending from the far infrared (IR) into the deep ultraviolet (UV), 0.01 - 6.5 eV. We found that the charge carrier response in the normal state of this system is heavily damped. This implies that the electronic states near the Fermi surface are strongly renormalized. For $SrFe_2As_2$, opening of the pseudo-gap at about 0.15 eV was clearly observed upon entering into the spin-density wave state below $T_{SDW} \approx 205$ K. Strong and discontinuous softening and narrowing of the in-plane 256 cm^{-1} phonon mode with predominantly iron character observed at T_{SDW} give evidence for a strong spin-electron-lattice coupling. We also identify a pronounced low-energy collective electronic mode which appears in $SrFe_2As_2$ around 15 meV - 20 meV and exhibits a clear anomaly at T_{SDW}. This observation is suggestive of the dynamic AFM-domain (SDW) or exciton-string (CDW) scenarios as possible quasi-particle renormalization factors in iron pnictides.

Formation of the superconducting energy gap in the far-ifrared optical conductivity spectra, $2\Delta_{SC} \approx 5.5\text{-}6.5\ k_BT_c$, was observed in optimally doped $Ba_{0.6}K_{0.4} Fe_2As_2$ single crystals with $T_c = 38.5$ K. The frequency and temperature dependencies of the SC gap formation allow us to conclude about the ***extended* s-*wave*, $s_\pm$**, pairing symmetry, with strong coupling to the intermediate bosonic state centered at ~25 meV.

INSTABILITY OF THE COLLINEAR PHASE IN TWO-DIMENSIONAL FERROMAGNET IN STRONG IN-PLANE MAGNETIC FIELD

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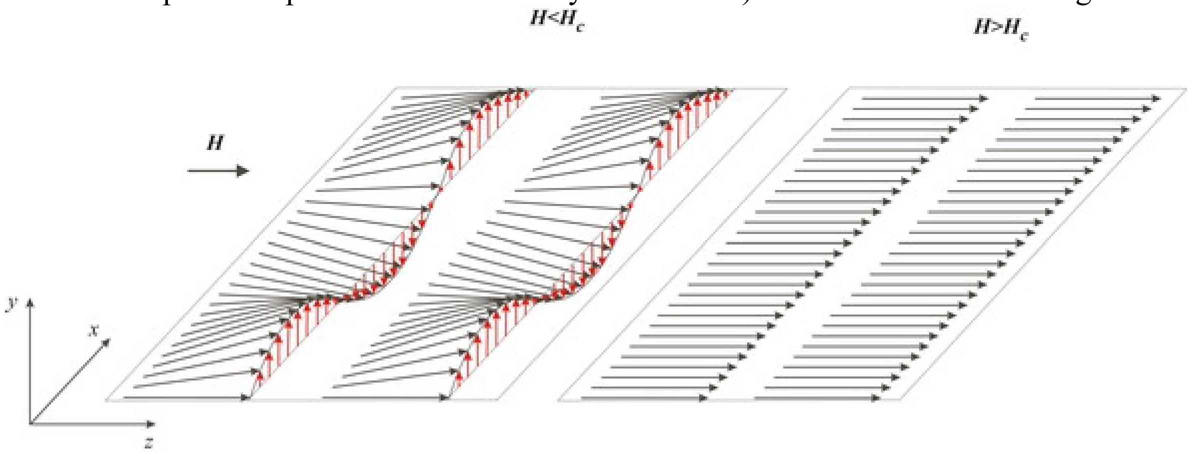
It is well known that in thin ferromagnetic film with a net magnetization perpendicular to the film the collinear arrangement of spins is unstable in an in-plane field H smaller than its saturation value H_c.[1] Existence of a stripe phase was proposed with elongated domains of alternating direction of magnetization component perpendicular to the film (see the figure, in which transverse spins components are shown by red arrows). We consider the strong-field regime



$H < H_c$ and discuss the minimal microscopic model describing this phenomenon, two-dimensional Heisenberg ferromagnet with strong easy-axis anisotropy and dipolar forces. The noncollinear phase is discussed using the technique of the Bose-Einstein condensation of magnons. Some previously unknown results are observed concerning the noncollinear (stripe) phase. First, evolution is established of the spin arrangement in the noncollinear phase upon the field rotation within the plane. Second, we find a rapid decreasing of the period of the stripe structure as the field decreases. Third, we demonstrate that spins components perpendicular to the film form a sinusoid in the noncollinear phase at $H \approx H_c$ that transforms to a step-like profile upon the field decreasing so that the domain wall density decreases from unity to a value much smaller than unity. Fourth, the spin-wave spectrum in the noncollinear phase is derived [2].

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MAGNETIC EXCITATIONS IN AV_2O_4 COMPOUNDS

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Transition metal oxide (TMO) compounds with a general formula AB_2O_4 became at the center of research activities in the last decade due to variety of interesting electronic and magnetic properties. In this talk, I consider vanadium oxides and present a discussion of three interesting examples: ZnV_2O_4, MnV_2O_4 and CaV_2O_4. While the first two compounds, ZnV_2O_4 and MnV_2O_4, as the majority of systems belonging to this class of materials, are spinels, CaV_2O_4 crystallizes at room temperature into a calcium-ferrite-type structure with orthorhombic space group Pnam. In all these compounds, magnetically active V^{3+} ions have two 3*d* electrons in the t_{2g}-manifold, which due to strong Hund's interaction couple S=1 spin. However, while in ZnV_2O_4 and MnV_2O_4 compounds, V ions form a geometrically frustrated pyrochlore lattice, vanadium ions in CaV_2O_4 form quasi-one-dimensional zig-zag chains of slightly distorted edge-sharing VO_6 octahedra. Since threefold t_{2g} orbitals of vanadium cations are occupied partially, these systems provide a particular example to investigate the interplay among spin, orbital and lattice degrees of freedom.

In this talk, I will present a study which is aimed to understand the structural distortion, orbital and magnetic ordering in the grounds state and the nature of excitations. The unquenched orbital fluctuations of V ions bring fourth three main perturbation to V Heisenberg spins: 1) single ion spin-orbit coupling, 2) orbital-population dependent exchange interaction (super-exchange), and 3) orbitally driven Jahn-Teller effect. In vanadium compounds, all these perturbations have the same energy scale, which lead to significant complications of the theoretical analysis. For each of three examples I will present a minimal model. These models, despite the differences on the underlying lattice structure, include three major components: super-exchange, crystal field splitting and spin-orbit interaction. Then I present and compare the ground state properties and the excitation spectrums for ZnV_2O_4, MnV_2O_4 and CaV_2O_4 compounds. I also show that magnetic behavior of these systems interpolates between Heisenberg and Ising models depending on the lattice geometry. Finally, I discuss relevance of our study to various experimental findings.

MAGNETO-OPTICAL SPECTROSCOPY OF DILUTED MAGNETIC OXIDES $TiO_{2-\delta}$:Co

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The search for ferromagnetism above room temperature in diluted magnetic semiconductors and magnetic oxide semiconductors has been intense in recent years. The discovery of high Curie temperature T_C (>800K) in anatase and rutile Co-doped $TiO_{2-\delta}$ and in $TiO_{2-\delta}$ without introduction of magnetic ions has attracted much interest to these magnetic oxides. In spite of intense research activity in this field the main mechanisms of magnetic, magneto-transport and magneto-optical properties of Co-doped $TiO_{2-\delta}$ magnetic oxides are far from being well understood and the origin of ferromagnetic order in such materials is still under debate.

We present recent experimental data on structural, magnetic and magneto-optical properties of $TiO_{2-\delta}$: Co thin films focusing on magneto-optical spectroscopy both in visible and X-ray spectrum range.

The $TiO_{2-\delta}$: Co thin films were deposited on $LaAlO_3$ (001) substrates by magnetron sputtering in the argon–oxygen atmosphere at oxygen partial pressure of 2.10^{-6}-2.10^{-4} Torr. Magneto-optical spectra in the range 0,5 - 4.0 eV were studied in the transverse Kerr effect (TKE) geometry. It was obtained that TKE spectra in ferromagnetic samples are extremely sensitive to the Co volume fraction, the crystalline structure, and technology parameters. The observed well-pronounced peaks in TKE spectra for anatase Co-doped $TiO_{2-\delta}$ films at low Co (<1%) volume fraction are not representative for bulk Co or Co clusters in $TiO_{2-\delta}$ matrix that indicates on intrinsic ferromagnetism in these samples. With increase of Co volume fraction up to 5-8% the fine structure of TKE spectra disappears and the magneto-optical response in reflection mode becomes larger than that for thick Co films. Moreover, the TKE increases further in the case of the films fabricated onto $SrTiO_3$ substrates.

To clarify the valence state of Co ions and the origin of magnetic moments in rutile $TiO_{2-\delta}$: Co at room temperature we applied element selective and sensitive techniques such as X-Ray absorption spectroscopy (XANES) and X-Ray magnetic circular dichroism (XMCD). XANES measurements were performed at the Co and Ti K absorption edges (the hard X-ray energy range), both XANES and XMCD measurements were carried out at the Co $L_{2,3}$ absorption edges (soft X-Ray region). For a 200 nm TiO_2 film doped with 8% Co atoms we observed non-metallic states of doped Co atoms and sizeable *3d* magnetization of cobalt at the Co $L_{2,3}$ absorption edges. Element-selective magnetization curve recorded by XMCD at the Co L_3 absorption edge clearly exhibits a ferromagnetic behavior at room temperature.We discuss possible mechanisms of ferromagnetic order at room temperature in magnetic oxides based on $TiO_{2-\delta}$, as well as perspectives of applications of these novel materials in spintronics and magnetophotonics.

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PROPAGATION PROPERTIES OF MAGNETOSTATIC SURFACE WAVES IN MAGNETIC GARNET FILMS WITH PERIODIC METAL STRIPES

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Magnetostatic surface waves (MSSWs), possessing the wavelength ranging from millimeter to sub millimeter scale in GHz band, are attractive information career for miniaturization and functionalization of devices in GHz band. In this study, fundamental propagation properties of MSSWs were studied experimentally and theoretically so as to examine the possibility of bandgap material structure for controlling the MSSW properties.

Yttrium iron garnet (YIG) single crystal film, which was grown epitaxially on a gadolinium gallium garnet (GGG) substrate, was used as the MSSW propagation medium. For exciting and detecting MSSWs, a pair of Cu microstrip lines was formed on a Teflon substrate by photolithography, on which the YIG film was placed. An external magnetic field was applied in plane perpendicular to the propagation direction of MSSW. Propagation characteristics of MSSW were quantitatively evaluated with a vector network analyzer. Good agreements among the experimental and theoretical MSSW properties were obtained.

For a periodical modulation of MSSW, one-dimensional Cu stripes on the Teflon substrate between the excitation/detection transducer microstrip lines were formed. When the periodicity of Cu stripes was 400 μm, stop band clearly appeared in MSSW transmission spectrum. By placing the Cu stripe line whose width differed to the other Cu stripes resulted in the appearance of localized mode of MSSW within the stop band region. There results suggest that the bandgap material concept is applicable for controlling the propagation properties of MSSW.

At the conference further experimental results will be discussed together with the discussion on application of MSSWs travelling in the bandgap material structures.

2D MAGNONIC CRYSTAL SPIN WAVE EXCITATION SPECTRA: EXPERIMENTAL AND NUMERICAL INVESTIGATION

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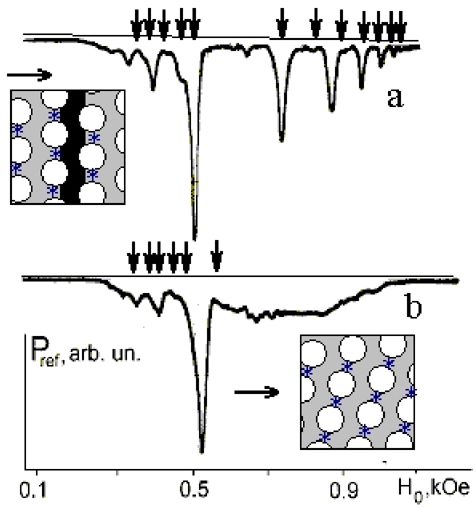
Eigen spin-wave spectrum (SWS) of 2D magnonic crystal (MC) consists of rhombic array of 4-4,5 μm depth chemically etching holes based on 5 μm yttrium iron garnet (YIG) film was experimentally investigated. The spectrum of power P_{ref} reflected from a microstrip transducer placed on MC surface depending on the value and direction of bias tangential magnetic field H_0 was analyzed at f=3,5 GHz. It was found that SWS of MC consists of two sets of absorption peaks in “low-field” and “high-field” regions relating to the H_0 value of uniform resonance in YIG film. “Low-field” peaks could be observed independently of direction of H_0 without significant changes. In contrast "high-field" peaks were distinctly observed in the vicinity of direction of H_0 close to perpendicular to every array axis - see for example curve "a" and upper inset in the Figure, H_0 is directed along the horizontal arrow. Changing of H_0 direction results in transformation to broadband excitation region - see curve "b" and the lower inset.

OOMMF code [1] was used both for simulating of internal magnetic field H_{in} distribution over MC area and for investigation of eigen frequencies of MC using Fourier transform of the temporal evolution of magnetization component depending on value and direction of H_0. It was shown that “low-field” peaks correspond to modes localized between nearest holes (marked asters at the insets). In turn “high-field” peaks can be associated with spin excitation of an effective strip waveguide (marked dark at the upper inset to the Figure) oriented perpendicularly to external magnetic field analogously [2]. The set of magnetic field values corresponding to resonances at 3,5 GHz in Fourier transform (marked by vertical arrows on the Figure) was found in good agreement with experimental data.



Support by RFBR grants No. 08-07-00119-a and 09-07-00186-a is acknowledged.

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COLLECTIVE EFFECTS ON THE PRECESSIONAL DYNAMICS IN LATERAL FERROMAGNETIC STRUCTURES

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Precessional dynamics in (ferro)magnetic nano-objects is well described by the Landau-Lifshits equation for the motion, which can be reduced to that for a simple linear (or even nonlinear) oscillator. What happens in their system if individual magnetic nano-oscillators are brought closely each to other and excited? A common answer here would be that the coupled oscillators should synchronously resonate either in phase (acoustic mode) or anti-phase (optic mode) with respect to each other.

We find a *diversity* of collective oscillation modes in periodic arrays of patterned magnetic stripes with no any separation between adjacent stripes but with different saturation magnetizations in them [1]. In the microwave absorption (MA) spectra of such heterostructures, we observe multiple resonances, whose intensity strongly depends on the ratio of stripe widths and the structure period. Such a behavior contrasts to that typically occurring in thin ferromagnetic films and laterally confined structures where the intensities of resonant modes are insensitive to the structure dimensions [2]. To explain the observed anomaly, a linear response theory has been formulated for stripe structures with arbitrary profile of the saturation magnetization over the period. The developed theory (*i*) supports an existence of dipolar standing-wave resonances in the arrays where stripes are separated from each other; (*ii*) establishes basic differences between the resonant modes occurring in individual stripes and, on the other hand, in our heterosructures; (*iii*) allows us to assign the measured MA resonances to specific oscillation regimes.

Finally, the obtained results indicate the existence of coupled oscillations of a new type. These oscillations are standing-wave-like modes of the dynamic magnetization, which are extended through a whole heterostructure period. In the lowest (acoustic-like) mode, such a standing wave has nonzero minima of the oscillation amplitude instead of the nodes. In the higher (optic-like and hybrid) modes the distances between the nodes are smaller than a half of wavelength of an usual standing wave.

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MAGNETIC HYPER-RAYLEIGH SCATTERING IN CORE (SHELL) NANOPARTICLES

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As is well known, metallic nanostructures can demonstrate plasmon resonance which is highly dependent on their material, size, shape and is localized near the metal surface. Plasmon resonance leads to the amplification of the local field within the structure resulting in the enhancement of nonlinear-optical processes. In the case of magnetic nanostructures one can expect a plasmon-assisted influence on the magneto-optical response. Magneto-optically active nanoparticles are very perspective as they could have applications in the emerging field of nanophotonics, data storage, and sensing.

In this work, magnetization-induced second harmonic generation (SHG) is applied to the studies of the nonlinear properties of magneto-plasmonic core (shell) γ-Fe_2O_3 (Au) nanoparticles.

Core (shell) nanoparticles consist of Fe_2O_3 core 20-25 nm in diameter, and the Au shell of the thickness of about 2-4 nm. Nanoparticles are deposited on glass substrate as a solid film. The absorption spectrum of these films demonstrates a maximum centered at about 550 nm, which is associated with the existence of the localized plasmon resonance.

For the nonlinear-optical experiments, the p-polarized output of a YAG: Nd^{3+} laser at the fundamental wavelength of 1064 nm was used, so that the SHG at the wavelength of 532 nm is within the plasmon resonance spectral line. The second harmonic radiation was generated in reflection at the angle of incidence of 45°.

For the nonlinear magneto-optical studies the geometry of the transversal magneto-optical Kerr effect was used, as the magnetic field of 2 kOe was applied to the samples. The measure of the magnetization-induced effect in SHG is the magnetic contrast of the SHG intensity: $\rho_{2\omega} = \dfrac{I_{2\omega}(\uparrow) - I_{2\omega}(\downarrow)}{I_{2\omega}(\uparrow) + I_{2\omega}(\downarrow)}$, where $I_{2\omega}(\uparrow)$ and $I_{2\omega}(\downarrow)$ are the SHG intensities measured for the opposite directions of the applied magnetic field.

The SHG indicatrix, i.e. the dependence of the SHG intensity on the polar angle of scattering, demonstrates that the SHG is diffuse and scattered in a wide angular range, with no maximum in the direction of the specular reflection. The observed diffuseness and depolarization of the SHG signal are the intrinsic features of the hyper-Rayleigh scattering. This mechanism of the nonlinear-optical response is attributed to incoherent response of core (shell) nanoparticles, the averaged SHG intensity being proportional to the number of the nonlinear scatterers (nanoparticles). At the same time the SHG magnetic contrast is determined by the ratio of the magnetic to nonmagnetic components of the hyperpolarizability of a single nanoparticle $\rho_{2\omega} \approx 2\dfrac{\gamma^{magn}(M)}{\gamma^{cryst}}$ and characterizes its magnetic properties.

The SHG magnetic contrast was measured in a wide range of the scattering angle. The typical value of the magnetic contrast is about 0.2, which allows to estimate the ratio of the magnetic to nonmagnetic components of the hyperpolarizability of a single nanoparticle $\dfrac{\gamma^{magn}(M)}{\gamma^{cryst}} \approx 0.4$. Moreover, it is found that a narrow specular maximum in $\rho_{2\omega}$ indicatrix appear, that can be associated with the magnetization-induced partial coherence of the SHG response in spatially inhomogeneous structure.

MAGNETOOPTICAL EFFECTS AND ELECTROMAGNETIC FIELD ENHANCEMENT IN PLASMONIC HETEROSTRUCTURES

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Optical properties of plasmonic heterostructures, i.e. metal-dielectric periodically nanostructured materials (metallic gratings, perforated films) which can sustain the propagation of the surface plasmon-polariton waves, are shown to have some peculiarities leading to new optical effects like the effect of the extraordinary optical transmission and magnetooptical Faraday effect [1,2]. Moreover, such systems have some other interesting properties.

In this work we consider a bilayer system of the periodically perforated with the holes arrays metallic layer (silver or gold) and a dielectric layer magnetized either in longitudinal or polar configurations (bismuth iron garnet). By varying the thickness of the dielectric layer it is possible to achieve quasi-waveguiding conditions. Magnetooptical effect determined by the relative intensity change while passing between magnetized and demagnetized states of the magnetic layer is found. It is quadratic in magnetization and shown to be related to the quasi-waveguiding in the magnetic layer. This effect can be attributed to the class of so-called orientational magnetooptical effects observed earlier for uniform magnetic films [3]. However, orientational effects in nanostructured media are several times or even an order of magnitude larger then that for the smooth films.

The other very important phenomenon related to the excitation of surface plasmon-polaritons is related to the electromagnetic field enhancement in the vicinity of the metal-dielectric interface. For example, the increase of the field intensity leads to the growth of some nonlinear effects. In this work we investigate another very interesting consequence of the field enhancement. This is the increase of the local stationary magnetic field appearing due to the inverse Faraday effect while the heterostructure is illuminated by the circular polarized light. We show that the stationary magnetic field can be made an order of magnitude lager being compared to the uniform non-plasmonic case. Such increase of the magnetic field implies possibility of much more efficient remagnetization process and consequently writing magnetic bits at record-breaking subpicosecond time scale.

Work is supported by RFBR (07-02-01445, 07-02-91588, 07-02-92183, 08-02-00717).

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ENHANCEMENT OF MAGNETO-OPTICAL KERR EFFECT IN MAGNETOPLASMONIC PHOTONIC CRYSTALS

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Recent achievements in optoelectronics and photonics require development of magnetophotonic microdevices intended for controlling of magneto-optical response at the micro- and submicroscales. These can be used in Faraday microisolators, magneto-optical spatial light modulators, magneto-optical switchers and ultrafast all-optical magnetic memory units. One of the ways for enhancing the magneto-optical response is magnetophotonic crystals (MPCs), which are photonic crystals fabricated from transparent magnetic materials. Being initially realized as one-dimensional (1D) photonic crystals, MPCs are extended now for all dimensionalities utilizing either microcavity-type enhancement of multiple reflectance interference or modification of the light dispersion law at the photonic-band gap edge. In metals, the only possibility to realize the effects analogous to photonic band gap for is the excitation of surface plasmon-polaritons (SPPs) in planar periodically nanostructured metal films which are called as plasmonic or SPP-crystals. Dispersion law of SPPs becomes modified as a function of metal profile perturbation and many effects analogous to electromagnetic waves in photonic crystals can be observed in propagation of SPPs, such guiding, spatial localization and anomalous slowing. In this paper, enhancement of transversal magneto-optical Kerr effect (TKE) is experimentally controlled in one-dimensional magnetoplasmonic crystals made of nickel films perforated in subwavelength diffraction gratings and two-dimensional magnetoplasmonic crystals fabricated by nanosphere lithography technique. A two-times increase of the TKE value is observed in angular-specular interval corresponding to fulfillment of phase-matching conditions for surface plasmon-polaritons. Periodic structure of 1D magnetoplasmonic crystals is formed by periodical nickel grooves made on the nickel surface. The period of the structure is 320 nm and the depth of the grooves is ~50 nm. SPP excitation is experimentally observed as a dip in reflection spectra for p-polarized light, corresponding to energy flux redistribution between reflected light and SPP. Azimuthal dependences of reflection spectra are also measured. The shift of the dip position corresponding to the SPP excitation is shown to be the same as the one predicted by the numerical calculations. MOKE measurements in transversal geometry demonstrate that SPP excitation lead to the TKE enhancement resulting as a sharp peak in TKE spectrum. Two modes of SPP excitation are observed in 2D magnetoplasmonics crystals. First one corresponds to SPP excitation due to phase matching with one vector of reciprocal lattice quiet analogically to 1D samples. The second one appears as a result of superposition of SPP excited by phase matching with two different vectors of reciprocal lattice. Each case is experimentally observed as a dip in reflection spectra. The spectral and angular position of this dip is in good correlation with numerical calculations. TKE measurements demonstrate the enhancement of the effect connected with SPP excitation for both SPP modes observed in the experiment.

MAGNETIC RESONANCE INVESTIGATIONS OF INTERLAYER COUPLING IN Co/Ge/Co TRILAYER FILMS

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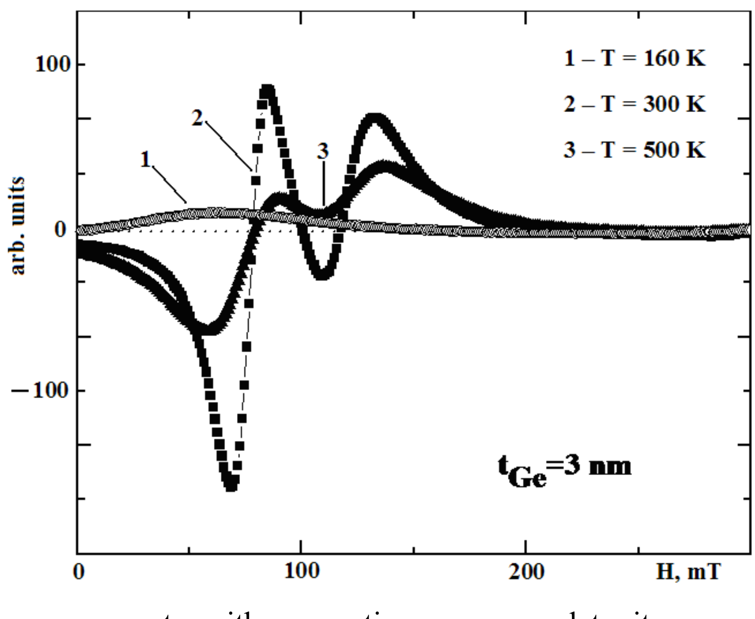
Multilayer magnetic films with a nonmetal spacer, in particular, those belonging to the system *ferromagnetic metal/semiconductor* attract close attention by virtue of a great variety of effects observed in these films. As the electron magnetic resonance (EMR) parameters are sensitive to coupling factors that are responsible for the formation of a magnetic state, this method turns out informative to establish detail information in multilayer films.

In given report we present the results of investigations of interlayer coupling in Co/Ge/Co films obtained by EMR method. The films were prepared by rf-sputtering technique. The glass was used as a substrate material. For all films investigated the cobalt thickness was 13 nm while the germanium thickness was varied. Microwave frequency was f_{MWf} = 9,2 GHz. Experiments were made in temperature range 78 – 500 K in the heating conditions. Before every measurement the film was cooled in zero magnetic fields (ZFC). Magnetic field was in film plane. The resonance spectra received in temperature range 78 – 500 K were constituted a superposition of two lines (see Fig.). On the basis of fitting of experimental results by two Lorentz lines the temperature behavior of parameters of each absorption lines was determined.

To explain temperature dependences of magnetic resonance parameters taking into account of biquadratic (J_2) contribution was necessary. So at room temperature there are received following values of interlayer coupling constants J_2 = -2×10^{-5}, -3×10^{-5}, and -2.2×10^{-5} erg/cm^2, for films with germanium thickness 18, 9 and 3 нм, correspondingly. Non-monotone dependence of J_2 on nonmagnetic spacer thickness is evidence of oscillating character of interlayer interaction which agrees with literature data.



From comparative analysis of static magnetic, magneto-optic, and magneto-resistive measurements with magnetic resonance data it was established that on boundary between different material layers the interface of solid solution Co-Ge is formed. The presence of solid solution influents noticeably on magnetic state both separate cobalt layer and the whole Co/Ge/Co system, as well as character of interlayer coupling.

The present investigations have financial support of Russian Fund of Basic Research (grant № 08-02-00397-a).

TEMPERATURE DEPENDENCE OF INTERLAYER EXCHANGE COUPLING IN Fe/Si/Fe TRI-LAYERS

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The problem of interlayer coupling in Fe/Si/Fe multilayer systems has attracted much attention for more then a decade [1-5] due to a possible use of these systems in high-tech applications. But experimental results in this field are rather contradictory mainly because of an uncontrollable diffusion of iron atoms into the silicon spacer or poor quality of Fe/Si interfaces.

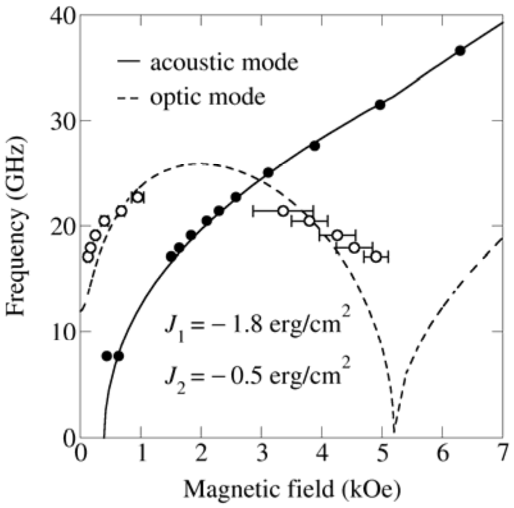

Fig. 1. Dependence of resonance frequency on magnetic field for the AFM sample at room temperature. The field was applied along the hard magnetization axis of iron in the sample plane. Dots are experimental results (● – acoustic mode, ○ – optical mode); lines are results of approximation using the biquadratic coupling model.

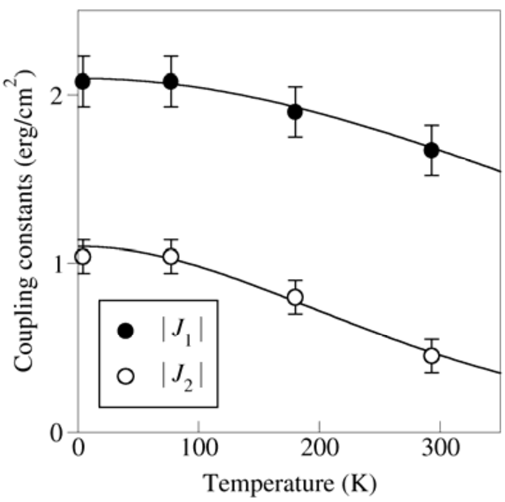

Fig. 2. Temperature dependence of J_1 and J_2 coupling constants for the AFM sample. Dots are experimental results; solid lines are guides to the eye. The coupling parameters are defined via the areal energy density: $E_{ex} = -J_1\cos(\theta) - J_2\cos^2(\theta)$, where θ is the angle between the two layer's magnetizations.

In this work, we report our results on FMR measurement of interlayer coupling in two Fe(70Å)/Si(t_{Si})/Fe(70Å) samples with t_{Si} of about 10Å grown by MBE technique at room temperature. Due to a small deviation of the spacer thickness from the nominal value one of the samples demonstrated a ferromagnetic and the second an antiferromagnetic sign of bilinear coupling J_1. But a strong biquadratic contribution J_2 lead to a non-collinear magnetic ordering of iron layers in both samples and made it possible to measure the coupling temperature dependence using FMR technique (see Figs. 1 and 2).

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MAGNETIC RESONANCE IN CLUSTER-GLASS TYPE Fe/Cr LAYERED SYSTEMS

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Magnetic Fe/Cr superlattices with extremely thin ($t_{Fe} < 10$ Å) iron layers were investigated by SQUID magnetometery and ferromagnetic resonance (FMR) technique. The aim of the work was to study magnetic properties of the system as ferromagnetic iron layers became discontinuous.

The multilayer (ML) $[Fe(t_{Fe})/Cr(t_{Cr})]_n$ samples ($n \sim 50$) were prepared by MBE technique on MgO(100) substrates. Two types of structures were grown: FM-type samples with $t_{Cr} = 20$ Å which corresponded to FM interlayer coupling in Fe/Cr systems, and AFM-type samples with $t_{Cr} = 10$ Å that provided AFM interlayer interaction. Each series consisted of samples with different nominal iron layer thickness in the 2 – 6 Å intervals. Static and dynamic magnetic properties of the system were measured in a wide 2 – 400 K temperature range.

Depending on temperature and nominal iron layer thickness, the samples showed three different regimes. At high temperatures, the superparamagnetic (SP) and magnetically ordered ML structures were observed, depending on iron and chromium layer thicknesses [1]. At low temperatures, the presence of irreversible magnetic states was discovered in all the samples. The observed new magnetic phase demonstrated a set of typical spin glass (SG) properties [2]:

1. Anomalous hysteresis loops with virgin curve lying below the remagnetizing one.
2. Frequency dependent maximum of the real part $\chi'(T)$ of AC susceptibility. The position of $\chi'(T)$ maximum showed a SG-like dependence on the frequency of the applied magnetic field.

Investigations of resonance properties in this low temperature phase show a strong dependence of the absorption curve shape on sample magnetic history. Figure 1 demonstrates the absorption curves obtained for one of the samples during the following procedure:

1. The sample is cooled from room temperature to 4 K in zero field (ZFC procedure).
2. The magnetic field H_1 is applied and the absorption curve is measured with the field decreasing from $H = H_1$ to $H = 0$.
3. Procedure 2 is repeated with increasing H_1 values.

Fig. 1 shows that the resonance is missing for small H_1 values and a pronounced absorption peak appears only for sufficiently large H_1 values.

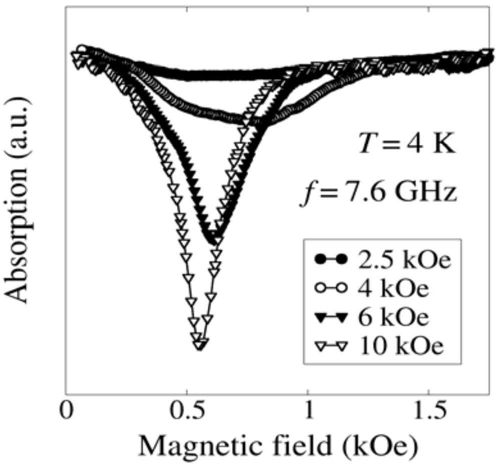

Fig.1. Field dependence of microwave absorption in $[Fe(3.5\ Å)/Cr(20\ Å)]_{30}$ sample obtained after ZFC procedure followed by applying the magnetic fields of different strength (see text).

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CALCULATION THE SWR SPECTRA IN TWO-LAYER EXCHANGE-RELATED STRUCTURE

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In a large number of works a theoretical model for calculating the spectra of SWR is based on the notion of surface anisotropy, where the degree of spins pinning is described by the difficulty of measured and badly controlled phenomenological characteristics – the constant of surface anisotropy, which is an integral function of several parameters (thickness, magnetization and anisotropy field) of surface layer. It often leads to the divergence of experimental and calculated results.

For calculation the spectra of SWR in two-layer films which based on the obtained expressions for the high-frequency sensitivity, in which the consolidation is described not by the surface anisotropy constants, but by the appropriate boundary conditions for free and interlayer border two films. Absorbed by the film power high-frequency field is determined by the imaginary part of high-frequency susceptibility $\tilde{\chi} = \tilde{\chi}' - i\tilde{\chi}''$. Absorbed power is determined by the diagonal component $P \sim \chi''_{xx}$. The dependence, in which most often the spectra of SWR is register $d\chi''_{xx}/dH$, as well as the experimental spectrum of SWR are presented in Fig. 1.

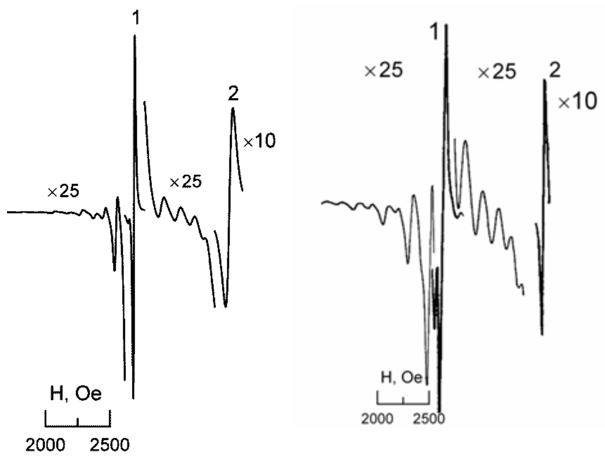

Fig. 1.Experimental and calculated spectra of SWR.

We see that the whole nature of the design spectrum, the resonance field items SW-modes, their relative intensity and width correspond to the experimental values.

This method of calculation allows determining the type of spectra of SWR and its basic parameters, which are depended on various parameters of a two layers of film. Also, this method allows the calculation and for films consisting of more layers.

ON THE MAGNETIC STRUCTURE OF FRUSTRATED QUASI-ONE-DIMENSIONAL ANTIFERROMAGNETS $LiCu_2O_2$ AND $NaCu_2O_2$

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We report the magnetic resonance study of the magnetically ordered phases of the quasi-one-dimensional antiferromagnets $LiCu_2O_2$ and $NaCu_2O_2$. Investigations were performed on the stoichiometric single crystal samples free of twin structure.

Low-frequency branches of the antiferromagnetic resonance spectra can be phenomenologically described as oscillations of a rigid exchange spin structure, planar for $LiCu_2O_2$ and collinear for $NaCu_2O_2$. The ESR data along with NMR results obtained on Li^+ and Na^+ ions allow to propose the low temperature magnetic structures formed in magnetic fields. For the high field phase of $LiCu_2O_2$ at **H||b** and **H||c** we propose a planar spiral structure with the spin plane perpendicular to the applied field. For **H||a** in the whole field range we expect a collinear spin-modulated structure with the direction of an antiferromagnetic vector **l||a**. For $NaCu_2O_2$ a collinear spin-modulated structure is realized in all field orientations with **l||a**.

EXCITON STATES IN QUASI-1D MOTT-HUBBARD INSULATOR $LiCuVO_4$

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The quasi one-dimensional spin-1/2 chain cuprates have drawn much attention because of the exotic magnetic properties and variety of ground states originating from competing nearest neighbor (NN) and next-nearest neighbor (NNN) interactions. Chains of CuO_4 plaquettes also serve as an excellent model system to explore the exciton formation and interplay between the long-range exchange and Coulomb interactions in cuprates.

Spectroscopic ellipsometry was used to investigate the low-lying electronic excitations in the strongly correlated spin-chain copper oxide $LiCuVO_4$ in the range 0.75 - 6.5 eV over a temperature interval 7 - 300 K. Strong anisotropy of the charge transfer *p-d* excitations was observed. Our data reveal a pronounced redistribution of the spectral weight of the optical conductivity along the Cu-O chains from the 3.5-4.4 eV range to a weak two-peak structure centered at 2.15 and 2.95 eV upon cooling near the magnetic ordering temperature. We identify these two bands as exciton states associated with the upper Hubbard band that emerge at $U-V$ and $U-V/2$ as a consequence of the long-range Coulomb interaction $V_m = V/m$ ($U \approx 3.75$ eV, $V \approx 1.6$ eV). Surprisingly the lowest exciton has much smaller weight than the second exciton at higher energy. We point out that the temperature dependence of the SW of the two excitons is determined by the NN and NNN spin-correlation function, respectively. Thereby the optical measurement provides interesting insight into the frustrated magnetism of these compounds.

EXCITATION SPECTRUM OF XY-PYROCHLORE ANTIFERROMAGNET $Er_2Ti_2O_7$

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Antiferromagnets on a pyrochlore crystal lattice are known to have a strongly frustrated nearest-neighbour exchange interaction, which can not stabilize a unique magnetic ground state. The magnetic structure of these systems is determined to a large extent by other forces, whose interplay provides a variety of ordered patterns and peculiar spin dynamics. The study of Heisenberg pyrochlores [1] revealed a presence of both gapped resonance branches and quasi-local excitations existing due to a macroscopic degeneracy of the ground state. In the present work we investigate the electron spin resonance (ESR) spectra of a XY-system $Er_2Ti_2O_7$ below ordering temperature T_N=1.2 K. The experiment was performed on a He^3 cryostat in the frequency range 20 to 80 GHz. The frequency-field diagram of ESR spectrum under magnetic field applied along [100], [110] and [111] crystal axes is shown in Fig. 1. Three main spectral line are observed: (i) an increasing branch $\nu=\gamma H$ (line A), (ii) a decreasing branch softening near H_c=16.5 kOe (line B), and (iii) one more linear increasing branch which appears above H_c (line C, for H||[111] it is split into a doublet C1,C2).

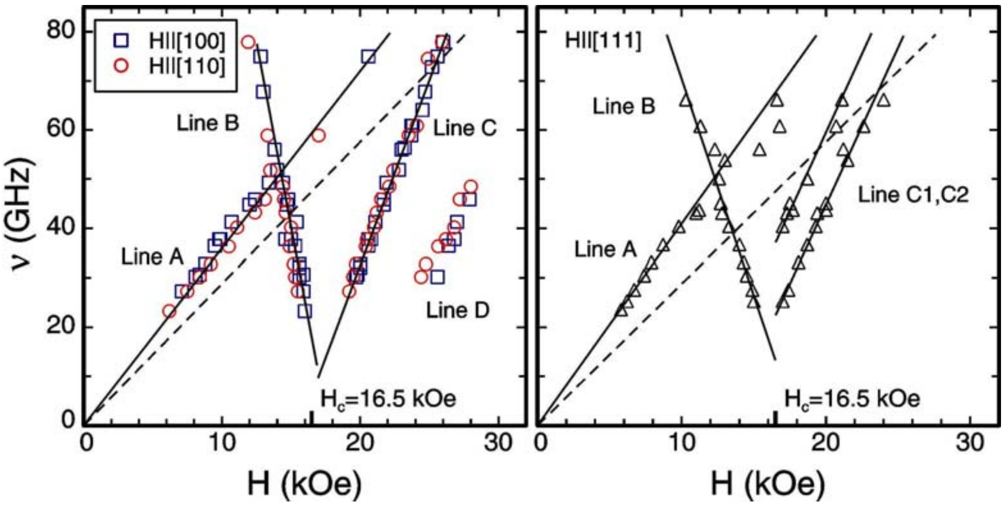

Fig. 1. The frequency-field diagram of the magnetic resonance spectrum observed in $Er_2Ti_2O_7$ at T=0.45 K in three principal directions of the external magnetic field. Solid lines are linear guides to data points, dashed line is a paramagnet with g=2.

Starting from the approximation of a single Er^{3+} ion in D_{3d} local crystal field, one can attribute the Line A to the splitting of the lowest Kramers doublet in a magnetic field, while the Line B can signify lowering of the level from the first excited doublet. The intersection between levels results in softening of the Line B at H_c=16.5 kOe. According to neutron scattering data [2] this field corresponds to a dramatic variation of the ordered structure through the quantum critical point. The field behaviour of the Line C above H_c is consistent with the specific heat data also presented in [2]. Possible interrelation between the ground state of a single Er^{3+} ion and change of a macroscopic magnetic ordering under field is discussed.

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ELECTRON SPIN RESONANCE AND MAGNETIC POLARONS IN EuB_6

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Strongly correlated magnet EuB_6 attracts attention as a material with complicated ferromagnetic ordering, which nature still remains subject of debates. It is believed that unusual transport properties of this material are caused by the magnetic polaron (MP) effects. In recent publications [1,2] it was supposed that MP formation strongly affects the electron spin resonance (ESR) at low temperatures leading to a complicated spectrum consisting of several lines. Moreover, in the available literature there is no agreement about either the ESR line width or temperature dependence of this parameter. In order to elucidate these problems we have carried out cavity measurements of a high frequency (60 GHz) ESR for a single crystal of EuB_6 at temperatures 4.2-50K in magnetic field up to 7 T. It is found that in conditions of a homogeneous magnetic field in the sample the ESR spectrum in EuB_6 is formed by a single line at all temperatures studied including the ferromagnetic ordering region T_C~15 K, whereas the presence of the gradient of the magnetic field in the samples induces double peak ESR structure al low temperatures [3]. The developed procedure of the baseline subtraction and absolute calibration of the ESR data has allowed obtaining resonant magnetoabsorption in the units of the magnetic permeability. For the quantitative description of the ESR line shape we suggested a new analytical approach applicable for the cavity measurements of a metal with an arbitrary magnetic permeability including strongly magnetic case and obtained full set of the resonant microscopic parameters, namely the oscillating magnetization M_0, g-factor and the line width. We argued that additional boundary condition should be taken into account in the case of magnetic resonance in cavity experiments. Our analysis has explained the visible resonance line shift and revealed a coincidence of the oscillating magnetization defining the resonance amplitude with the static magnetization. The anomalous growth of the line width below Curie temperature T_C ~15 K is discovered. We argue that the ESR in EuB_6 is not seriously affected by interaction with MP and reflects merely the oscillation of the Eu^{2+} localized magnetic moments, which can be well understood within mean field approximation. However some minor features of the magnetic resonance like small temperature variation of the g-factor may be attributed to the MP effect [3].

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SPIN WAVES IN QUANTUM HALL FERROMAGNETS: SPECTRA AND RELAXATION TIMES

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Spin waves in a spin-polarized quantum Hall (QH) system are purely electronic excitations and represent spin-flip related intra-Landau-level collective modes where the change of total spin numbers is $\nu S = \nu S_z = -1$. These belong to the kind of lowest energy excitations in a QH ferromagnet and have a ~ q^2 energy dispersion when two-dimensional wave vector q is much smaller than the inverse magnetic length. In the integer QH regime (at fillings $\nu = 1,3,...$) spin wave is effectively a two-particle excitation, i.e. a spin-exciton consisting of an electron on the upper spin sublevel of the half-filled Landau level and an effective hole remaining on the lower one. The spin-exciton spectrum can be calculated in the first order approximation in terms of parameter r_s which is the ratio of the characteristic electron interaction energy to the cyclotron energy [1]. Spin wave states in fractional QH regimes are composite excitations because they can couple to charge-density waves. (The latter are spinless excitations where only electrons of the lower spin sublevel participate.) Composite spin excitations are described in this case by double-exciton modes. However, if the coupling is ignored (which is quite reasonable in the case of a fractional QH ferromagnet where fillings are $\nu = 1/3, 1/5,...$), then the spin wave spectrum may again be found within the single-mode (single-exciton) approximation [2]. Recent experiments on Raman scattering [3] and appropriate theoretical studies show that at a general fractional filling ν both single-exciton and double-exciton spin-wave states coexist.

Spin-wave relaxation processes in QH ferromagnets are determined by different relaxation channels. The relaxation occurs through two types of interactions: (i) by an interaction which does not conserve the spin number; and (ii) by an interaction responsible for dissipation of energy, because every spin wave possesses at least the Zeeman energy. Analysis reveals that there are two relevant mechanisms changing spins -- the spin-orbit coupling of electrons confined to a two-dimensional channel and the superfine coupling to lattice nuclei, and three dissipation mechanisms: (i) by effective Coulomb interaction of spin waves renormalized to an effective dipole-dipole interaction; (ii) by electron-disorder interaction (electron in a smooth random potential); and (iii) by electron-phonon interaction leading to the dissipation due to phonon emission (absorption). Besides, when calculating transition matrix elements, one should take into account the features of QH ferromagnets distinguishing between odd-integer filling and specific fractional fillings (e.g., at $\nu = 1/3, 1/5$). There are thereby several relaxation channels responsible for diverse physics of the relaxation and for crossovers between different relaxation processes depending on magnetic field, temperature, and other parameters [4]. As a result, spin-wave relaxation times in QH systems range between several nanoseconds and tens of microseconds.

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INHOMOGENEOUS MAGNETOELECTRIC INTERACTION AND NOVEL RELATED PHYSICAL PHENOMENA

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Symmetry of various multiferroics allows the interaction linear in gradient of order parameter that is expressed by Lifshitz-like invariant $P_i n_j \nabla_k n_m$, where **P** is electric polarization, and **n** is order parameter vector. The interrelation between spatial modulation of order parameter and electric polarization, known as flexoelectric effect in liquid crystals, in the case of magnetic media causes various effects both in static and dynamic properties.

This flexomagnetoelectric interaction appears as spatially modulated spin structures stabilized by electric polarization [1] and inverse effect of ferroelectricity induced by spin modulation [2]. Even in the homogeneous antiferromagnetic state when spatially modulated structure is suppressed (as it happens in bismuth ferrite thin films <500nm)) the latent flexomagnetoelectric interaction can manifest itself in antiferromagnetic structure [3]. The ferroelectric domain wall induces magnetic inhomogeneity, so in presence of ferroelectric domain structure the ground state of antiferromagnetic system is not uniform anymore. If antiferromagnetic and ferroelectric domain structures coexist, then the above-mentioned effect can appear as a pinning of antiferromagnetic domain structure at ferroelectric domain walls. It can explain the coupling of ferroelectric and antiferromagnetic domains reported in manganites [4].

Spatial modulation can be caused not only competing exchange interaction (like in manganites [2]) or due to the inhomogeneous magnetoelectric effect (like in bismuth ferrite [1]) but can also be the result of relaxation of micromagnetic structure minimizing the energy related to the stray fields. The electric polarization associated with the magnetic domain wall was predicted theoretically in [5]. In the recent paper [6] the nucleation of the Neel-type domain wall in magnetic media at critical electric field has been predicted. The motion of the magnetic domain walls in electric field has been observed in the 10μm thickness epitaxial iron garnet films, grown on the GdGG substrate [7,8].

The existence of flexomagnetoelectric interaction in the homogeneous state, though in a latent form, manifest itself not only in static structures but also in dynamical properties of multiferroics, particularly in magnon spectra: the dispersion curve has a minimum at finite wave vectors for waves propagating in the direction perpendicular to the electric polarization in the case of multiferroic [9] or perpendicular to the external electric field in the case of centrosymmetric ferromagnetic media [10].

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MAGNETIC SUSCEPTIBILITY AND MAGNETORESISTANCE OSCILLATIONS IN THE SEMICONDUCTOR – MULTIFERROIC $Eu_{0.8}Ce_{0.2}Mn_2O_5$

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In a diluted semiconductor- multiferroic $Eu_{0.8}Ce_{0.2}Mn_2O_5$ at a low temperature in sufficiently high magnetic field, oriented along the c axis, oscillations of magnetic susceptibility and magnetoresistance have been found. The oscillations arise in one-dimensional semiconductor superlattices formed in the single crystal bulk of $Eu_{0.8}Ce_{0.2}Mn_2O_5$ due to charge carrier self-organization. Superlattice characteristics were controlled by a magnetic field. The oscillation frequency $F \approx 10^6$ Oe and charge carrier concentration $n \approx 5\ 10^{12}$ (cm^{-2}) obtained are typical of de Haas-van Alfven oscillations in semiconductor superlattices [1].

With temperature growth, when a hopping from the conductive 2D layers of superlattices increases, a formation of the layer superstructure (due to the percolation phase transition at $T \approx$ 185 K) occurs. Formation of the layered superstructure happens and without magnetic field. However, an application of sufficiently high magnetic field oriented along the c axis brings to formation of modified homogeneous superstructure at higher temperature (than at case of $H = 0$). We can track for stepwise processes of the superstructure formation in sufficiently high magnetic field by means of magnetoresistance study. An irreversible negative magnetoresistance changing and magnetoresistance oscillations have been found under the stepwise magnetic field applications. The magnetoresistance oscillations have been observed until temperatures at which the isolated superlattices existed.

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PHASE TRANSITIONS, SOLITON LATTICES AND ELECTRIC POLARIZATION IN $\boldsymbol{R}Mn_2O_5$ OXIDES

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Magnetic transitions are analyzed from in paramagnetic state to an incommensurate magnetic structure and then to ordered phase with long-range antiferromagnetic order and thereafter to a new incommensurate magnetic structure in RMn_2O_5 oxides [1]. It is shown that a transition from paramagnetic to incommensurate phase is associated with exchange as well as relativistic interactions and can be described apart from the basic magnetic order parameter, by an associated order parameter (electric polarization along the y axis of the crystal). In this case the emergence of electric polarization in the system below the transition temperature to an incommensurate phase is not accompanied by a change in the crystal symmetry since a spatial inversion as a symmetry element disappears below this temperature due to the emergence of a long- range magnetic order.

Below the transition temperature to incommensurate magnetic structure, a magnetic soliton lattice is formed, which can be accompanied by formation of electric polarization domains. The commensurate antiferromagnetic phase is formed at a temperature below which the existence of the soliton lattice is disadvantageous from the energy point of view. The spatial distribution of the polarization in commensurate magnetic phase is uniform over the sample, but under specific conditions, the spatial distribution of the polarization can have the form of a static soliton. The thermodynamical potential descriptive of the phase transition from in antiferromagnetic to a new incommensurate structure include the Lifshit`s invariant. This invariant contain a gradients of the order parameter along the x axis, but not contain an items associated by Dzjaloschinski`s invariants. In this case the formation of the soliton lattice described above is become impossible. However the exact solution has been arrived of the nonlinear equations received from the minimum of the potential below of the transition temperature from antiferromagnetic to an incommensurate magnetic structure. This solution has a form of the kinks along of the z axis and oscillates along of the x axis. The kink distribution can possess an ordering character. In this case a new type of the soliton lattice appears in the system.

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EXCITATION OF ELECTROMAGNONS BY ALTERNATING ELECTRIC FIELD IN $TbMnO_3$

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After the discovery of colossal magnetoelectric (ME) effect in the ferroelectromagnet $TbMnO_3$ [1] the interest in the studying of ME phenomena significantly revived. Besides numerous investigations of thermodynamical ME properties of ferroelectromagnets the first observations of hybrid spin-phonon excitations (electromagnons) predicted forty years ago [2] have been appeared [3,4].

In this work the excitation of electromagnons by alternating electric fields of different orientations in helical antiferromagnet- ferroelectric $TbMnO_3$ has been analyzed. Frequency dependence of dielectric constant in incommensurate antiferromagnetic state below the temperature of ferroelectric ordering T_c was obtained in the frame of Lagrange's method where damping was taken into account. In the cases when a.c. electric field $\vec{e}$ is perpendicular to the spontaneous polarization $\vec{P}$ ($\vec{e} \parallel x$ and $\vec{e} \parallel y$) electromagnons are excited only for $\vec{e} \parallel x$ on the frequency which is independed of temperature. Dielectric constant ε_{xx} has no anomaly near T_c. These conclusions correspond to experimental results [4].

Anomaly in the frequency dependence of dielectric constant near T_c is predicted for a.c. electric field directed along the spontaneous polarization, $\vec{e} \parallel \vec{P} \parallel z$. In this case imaginary part of ε_{zz} has maximum at the lowest electromagnon frequency which is the soft mode of the transition at T_c (phason mode) and decreases near T_c.

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GIANT SECOND HARMONIC GENERATION IN MULTIFERROIC $TbMn_2O_5$

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$TbMn_2O_5$ is a joint-order-parameter multiferroic in which ferroelectric and magnetic order are parametrized by the same order parameter [1]. The interplay of the magnetic moments of the Tb^{3+}, Mn^{3+}, and Mn^{4+} ions leads to a complex phase diagram. Below 43 K the Mn^{3+} and Mn^{4+} order in a wavelike incommensurate antiferromagnetic structure. At about 38 K a commensurate magnetic order with a ferroelectric polarization P_1 along the *b* direction emerges. A spin reorientation at 24 K is accompanied by a significant drop in the value of the ferroelectric polarization. As proposed in [2] the decrease of polarization originates in the onset of a second contribution P_2 to the polarization oriented oppositely to P_1.

Here, the multiferroic properties of $TbMn_2O_5$ were investigated by optical second harmonic generation (SHG). Nonlinear optics is powerful method for investigating the ferroic and, in particular, the multiferroic properties because of its sensitivity to the respective symmetries inherent to the magnetically or electrically ordered state. Giant coupling of SHG to the spontaneous polarization of $TbMn_2O_5$ was observed. The symmetry reduction by the ferroelectric order is detected with a sensitivity eight orders of magnitude higher than in conventional ferroelectrics like $LiNbO_3$ and split-order-parameter multiferroics like $BiFeO_3$. The giant nature of the coupling points to an electronic rather than ionic origin of the spontaneous polarization in single-order-parameter multiferroics.

Polarization dependent measurements allowed us to separate three independent contributions to the spontaneous polarization in $TbMn_2O_5$. In addition to the contributions from the manganese sublattice already proposed by Hur [2] a polarization P_3 induced by the terbium sublattice was detected. Finally, spatially resolved measurements were performed to investigate the respective ferroelectric domain structure in the different magnetic phases of the compound.

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Posters

MAGNETOSTATIC WAVES IN BOUNDED QUASI-PERIODIC FERRITE STRUCTURES

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At present high interest to artificial structures and mediums of type of metamaterials is observed. In particular, concern to them the photon crystals representing periodic multilayered structures of various spatial dimensions *D* [1]. In a microwave range analogues of photon crystals are so-called magnon crystals 1D and 2D - dimensional in which magnetostatic waves (MSW) propagate. Magnon crystals are realized on the basis of thin ferrite films by creation in them of areas with a periodic spatial variation of parameters of films (a thickness *d*, magnetizations of saturation M_0) or boundary conditions on their surface [2-3].

In the report results of theoretical research of MSW characteristics in 1D - quasi-periodic ferrite structures of the limit sizes are presented. Structures of two types were investigated: the Cantor-like and Fibonacci-like, composed of ferrite layers of an identical thickness *d* and width a_1 and a_2 with various sizes of magnetization M_{01} and M_{02}, accordingly. The width of layers got out equal to $a_{1,2} = \pi/2k_{1,2}(\omega_0)$, where $k_{1,2}(\omega_0)$ - partial wave numbers of MSW, propagating on frequency ω_0 in corresponding homogeneous ferrite films of various magnetization. Characteristics of propagation of MSW in obtained quasi-periodic structures were investigated on the basis of a matrix-transfer technique [4], allowing finding coefficients of transmission *R*, reflexions *T* and density of modes $\rho = dk/d\omega$ of magnetostatic waves.
Research of dependences *T, R*, ρ from MSW frequency ω and characteristics of considered structures were carried out. It is shown, that in such quasi-periodic structures there are forbidden frequency bands (bandgaps), as well as in case of periodic magnon crystals. But detection the most sizes of the maximum density of modes is thus possible at smaller length of quasi-periodic structure. The obtained results can be used for creation of tunable of magnetic field linear and nonlinear devices on the basis of MSW in a microwave range.

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GENERATION OF CHAOTIC SOLITON-LIKE MICROWAVE PULSES IN RING SYSTEMS WITH FERROMAGNETIC THIN FILMS

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Generation of bright and dark envelop solitons in self-oscillating ring systems with the nonlinear elements on the basis of ferromagnetic thin films is well known [1, 2]. The envelop solitons can be generated in microwave (MW) frequency range when the various types of magnetostatic waves (MSW) are excited in the films. These results were obtained in the frequency range where MSW three-wave decay processes were disallowed and formation of the envelop solitons was coupled with the four-wave interaction processes only.

The possibility of autonomous generation of stationary sequence of chaotic soliton-like MW pulses in active ring system with the surface MSW delay line was demonstrated in [3]. This generation was observed in the frequency range where both three-wave and four-wave interaction processes were allowed. In this report the experimental and theoretical investigations of formation conditions of such pulses in active ring systems are carried out. In addition the possibility of control of chaotic MW pulse responses by the change of parameters of system elements is also investigated.

It is shown that the following conditions need to be carried out for the formation of chaotic soliton-like MW pulses: a) the use of a resonator in active ring for the signal generation at one of the eigenmodes; b) the formation of the narrow-band chaotic signal with the discrete spectrum that is coupled with the stochastic modulation of MSW by spine waves on this mode; c) the power in active ring should be higher then the modulation instability threshold. These conditions were carried out at the some correlation between the Q-factor of resonator, the value of magnetic field and the signal amplification factor in a ring. In particular, the increase of Q-factor of resonator is conditioned on generation of chaotic soliton-like MW pulses of large duration at the smaller amplification factor levels. This fact was determined on the basis of experimental investigations.

The parametric model from [4] which describes the three-wave interaction in a ring was used for the explanation of the experimental results. This model was modified by taking into account both three-wave and four-wave interaction processes in the MSW delay line and taking into account the presence of resonator in a ring. The good agreement between the experimental data and theoretical results was obtained.

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GENERATION OF WIDEBAND CHAOTIC MICROWAVE SIGNAL IN RING SYSTEM WITH NONLINEAR DELAY LINE ON THE BASIS OF COUPLED FERROMAGNETIC THIN FILMS

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In recent years, the research of an information transmission on the basis of chaotic signals has been actively carried out [1]. The use of the active feedback rings with the magnetic film nonlinear devices is one of ways of such signal generation [2, 3]. The interest to such systems is aroused by the electric tuning of signal band and the presence of two mechanisms of signal chaotization (narrowband and wideband) which is conditioned on the parametric excitation of spin waves [3]. It was shown [2], that a generation of wideband chaotic signal with the continuous spectrum is observed in the case of the presence of falling section on the dynamic response of nonlinear magnetostatic wave (MSW) delay line. It was determined, that one of the advantages of such self-oscillating systems with nonlinear passive element is high integral power level of a chaotic signal which has value 50-60% from saturation power value of amplifier. This is connected with an amplifier working in the regime of maximum output power at the wideband chaotic signal generation in a ring.

The multi-layer ferromagnetic structures, for example, two coupled magnetic films, enable to control the nonlinear microwave device responses which can be used in the active feedback rings. In these structures the presence of couple is conditioned on two MSW mode excitation (fast and slow) which propagate with various values of group velocities. In this case the new nonlinear effects appear which haven't been observed in a single magnetic film [4].

This paper reports for the first time experimental results of the chaotic signal generation in an active feedback ring with the nonlinear delay line on the basis of the coupled magnetic films at the magnetostatic backward volume wave (MSBVW) excitation. It was shown, that simultaneous excitation of two waves in a coupled structure leads to the appearance of pronounced falling section on the dynamic response of a delay line with two films which hasn't been observed on a delay line response with a one film [2]. The presence of the falling section is caused by the wideband chaotic signal generation with the continuous spectrum. It was determined, that regime of intermittency is observed in the case of some values of ring amplification factor at the wideband chaotic signal generation with both discrete and continuous spectrum.

This work was supported by the Russian Foundation for Basic Research (project no. 07-02-00639) and the Council of the President of the Russian Federation for Support of Leading Scientific Schools (project no. 355.2008.2).

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COEXISTANCE OF SPIRAL AND COMMENSURATE STRUCTURES IN A TRIANGULAR ANTIFERROMAGNET $KFe(MoO_4)_2$

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Magnetization, specific heat, magnetic resonance and neutron diffraction measurements are used to restore the entire magnetic phase diagram of $KFe(MoO_4)_2$. This stacked triangular antiferromagnet (T_N=2.5 K) demonstrates an unusual breaking of the spin system into two intercalated and almost independent 2D subsystems. One is a collinear antiferromagnet with a simple spin-flop behavior. The other is a spiral magnet with a set of commensurateincommensurate phase transitions. The various phases observed demonstrate either true three-dimensional or unconventional quasi-two-dimensional ordering. The variety of phases may be explained assuming two types of inequivalent magnetic planes with distorted triangular lattices of Fe^{3+} (S=5/2) ions. Indeed, due to a structural transition at T=311 K, adjacent planes occur inequivalent, with a different ratio of exchange integrals. According to the theoretical consideration of Nagamiya et al., a collinear or spiral structure arises depending on this ratio.

THE SPIN-LIQUID CORRELATIONS IN THE PROBLEM OF A SUPERCONDUCTING PHASE OF SPIN POLARONS ON A 2D KONDO LATTICE

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The electronic structure of the CuO_2 plane of high-temperature superconductors (HTSC) is reproduced sufficiently well within the Emery model. In the region of weak doping, one can pass to the effective Hamiltonian for which the homeopolar states of copper ions are characterized by the presence of the spin moment S = 1/2 and interconnected via the indirect exchange interaction. Hole current carriers of the oxygen subsystem interact with the localized spin moments of copper ions by means of the *s-d* exchange coupling. As a result, the energy spectrum of the Fermi excitations is described by a two-dimensional (2D) Kondo lattice.

In a normal phase, the Kondo lattice spectrum is found using the spin polaron concept [1,2] which considers the elementary excitation in a 2D antiferromagnet to be a hole surrounded by a cloud of the spin fluctuations. If a constant of the *s-d* exchange interaction exceeds the hopping integral, then such an approach reproduces the features of the pseudo-gap behavior of the HTSC [3] and makes it possible to find the region of implementation of the superconducting phase [4].

As is known, the spin-liquid correlations significantly affect implementation of the superconducting phase. Meanwhile, in [4] the superconducting phase was considered without taking these correlations into account. For this reason, it is necessary to develop the theory of the superconducting phase for an ensemble of the spin polarons with account for the mentioned correlations.

In this study, the effect of the spin-liquid correlations on the superconducting phase has been analyzed on the basis of the Mori projection technique for the effective Hamiltonian taking into consideration the effective interactions in the system of spin polarons. It is shown that the account for the spin correlations leads to the changes in the region of implementation of the superconducting phase and in critical temperature. Thus, the spin-liquid correlations play an important role in the description of high-temperature superconductivity in cuprates.

The interaction between spin polarons forms by virtual transitions to the one-hole triplet and two-hole states. This virtual process causes also the three-center interactions describing the correlated dynamics of spin polarons. It is shown that, unlike the *t-J** model, the three-center interactions favour superconducting pairing that provides implementation of the superconducting phase of *d*-type symmetry of the order parameter with high critical temperature. The obtained concentration dependence of the critical temperature indicates that the considered model of the interacting ensemble of spin polarons is really an alternative to the *t-J** model in interpretation of the properties of high-temperature superconductivity.

This study was supported by the Program "Quantum Physics of Condensed Matter" of the Presidium of the Russian Academy of Sciences, the Russian Foundation for Basic Research (project no. 07-02-00456a), and the Siberian Branch of the Russian Academy of Sciences (integration project no.53).

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ROLE OF CRYSTAL CHEMISTRY FACTORS IN EMERGING OF MAGNETOELECTRIC PROPETIES IN MULTIFERROIC $BiFeO_3$

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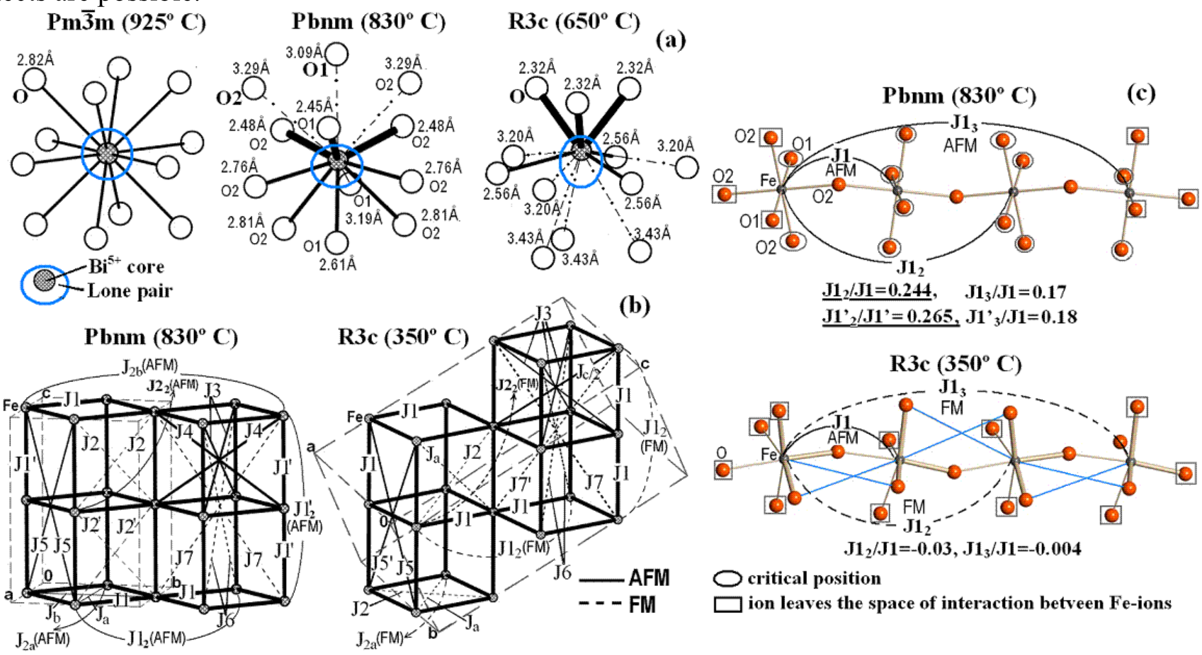
Multiferroic $BiFeO_3$ is essentially ferroelectric (FE) with magnetic ions, since antiferromagnetic (AFM) ordering occurs in them at much lower temperatures (T_N ~ 350-370ºC) than FE ordering (T_C ~ 810-830ºC). Up to present, it has been stated that increase of whether temperature or pressure resulted, in a step-by-step fashion, in the same effects: loss of magnetic ordering, suppression of the electric polarization and metallization. The objective of our study was to determine crystal chemical conditions at which the above effects are possible.



We have analyzed the experimental data available in literature. The analysis demonstrated that both ferroelectric – paraelectric and insulator – metal transitions are connected with a loss of the stereochemically active lone pair of electrons of Bi^{3+} and an increase of its localization degree around the atomic core. As a result, there occur both equalization of the Bi-O bond lengths and, as a secondary effect, equalization of the Fe-O bond lengths (Fig. a). We earlier observed the relation between the change of the lone pair stereochemical activity and the semiconductor–metal transition in homological series of non-transitional metals and double compounds on their basis [1].

According to our calculations with using the crystal chemistry method [2] on the basis of structural data [3], the nearest couplings $J1$ (Fig. b) along the Fe^{3+} sublattice parameters are strong AFM-couplings before and after the FE transition. They emerge under effect of bridge oxygen (Fig. c) while their strength decreases insignificantly with temperature decrease. The same bridge ions form the AFM $J1_2$-couplings with next-to-nearest neighbors in the chain which compete with the AFM $J1$-couplings. Competition persists after electric polarization during further temperature decrease until the state when additional oxygen ions located in critical positions enter the local coupling space between Fe ions (Fig. c). The change of the above ions positions correlates with increase of the Fe-O-Fe angle within the space group R3c. These ions only slightly reduce the strength of $J1$-couplings. Their main function consists in the fact that they switch the type of $J1_2$-coupling from the AFM-type to the FM-type by initiating the emergence of contributions to the FM component of this coupling and, therefore, eliminating the competition between $J1$ and $J1_2$. This very phenomenon comprises the crystal chemical basis of substantial difference in temperatures of FE and AFM orderings in $BiFeO_3$.

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STANDING SPIN-WAVE MODE EXCITATION IN PERMALLOY FILMS USING COPLANAR WAVEGUIDES

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The possibility for effective excitation of standing spin-wave modes in ferromagnetic films can be important for microwave applications because it may allow a significant increase in operational frequency of microwave devices. In this work we have developed a technique that allows the effective excitation of the lowest standing spin-wave mode in ferromagnetic thin films with unpinned boundaries. This technique is based on the use of a ferromagnetic film as a signal line in a coplanar waveguide structure. If the oscillating current in the signal line is uniform, then the microwave magnetic field across the thickness of the signal line is close to anti-symmetric, and this allows effective excitation of the lowest standing spin-wave mode which also has an odd profile across the midplane of the signal line.

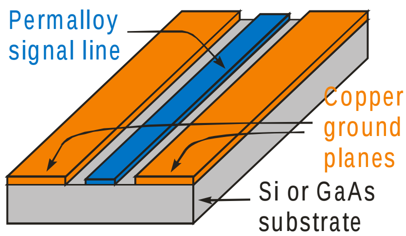

Fig. 5 Geometry of the studied structures.

We prepared coplanar waveguide structures with Permalloy (Py) ribbons as the signal line, see Fig. 1. Samples with different Py thicknesses, in the range from 20 to 80 nm, were fabricated using magnetron sputtering along with photolithography and lift-off techniques. Ferromagnetic resonance (FMR) was measured using a vector network analyzer.

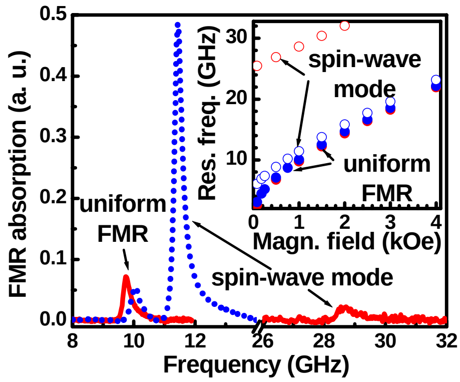

Fig. 4 FMR absorption vs frequency at 1 kOe for the samples with 80 (dotted line) and 20 nm (solid line) thick Py. Inset shows the resonance frequency for two observed modes as a function of the applied field for these

Fig. 2 shows data for two samples with 80 and 20 nm thick Permalloy ribbons. One can see absorption from both the uniform FMR mode and the lowest standing spin-wave mode. The spin-wave mode response was bigger than that of the uniform mode for the samples with thick Py and decreased as the Py thickness decreased.

The complex behavior in Fig. 2 indicates that the microwave field may not be purely even or odd about the midplane of the Py ribbon. This suggests that modification of the current distribution could be used to alter the relative absorption of the two modes. Taking this into account we performed additional experiments using thin Cu under and over layers sandwiching the Py. Because Cu has a much higher conductivity this allows the adjustment of the microwave current distribution and the resulting field distribution in the Py film. The FMR data is shown in Fig. 3. These results demonstrate the possibility of increasing the standing spin-wave mode absorption.

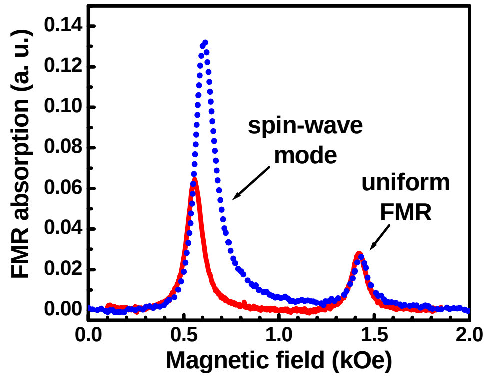

Fig. 6 FMR absorption vs magnetic field at 12 GHz for the samples with Cu(6 nm)/Py(50 nm)/Cu(6 nm) (solid line) and Cu(1 nm)/Py(50 nm)/Cu(2 nm) (dotted line) as the signal line.

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ON SOME NEW BRANCHES OF EXACT SOLUTIONS FOR THE NONDISSIPATIVE LANDAU–LIFSHITZ EQUATION

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The general solutions of the no-dissipative Landau–Lifshitz equations for uniaxial and biaxial anisotropic ferromagnetic media are obtained. The solutions are derived with use of the same substitution that gives the reason to combine these different problems in the same report. It is shown that at some particular combinations of parameters of integration the solutions coincide with those found before [1,2]. At the same time, in each class there are new branches of the solutions.

The first class of the solutions under consideration is the class of monoasymuthal solutions for the media with biaxial anisotropy. Here the stationary and oscillating solutions of the type of 360-degrees domain walls were found [3]. The solutions of this kind were found before only for the magnetic media in the external magnetic fields [1], however, these solutions belong to different sets.

The second class of the solutions considered is the class of traveling waves in a uniaxial ferromagnetic. The general solution of the problem is obtained in the form of the elliptic integral of the first kind. The solution contains five parameters, one of which is the velocity of the wave, and the last are the parameters of integration with two being just the shift parameters. So, the bifurcation space can be considered as three-dimensional one without loss of generality. It was found that the bifurcation manifold here consists of five surfaces, which separate the space into the regions, were the solution is either real and periodic of cnoidal type or complex. On the constituent surfaces the solution is expressed in the elementary functions. It is shown that the well-known Akhiezer–Borovik solution is the special case of this general solution, and the parameters corresponding to it belong to the limited interval on the coordinate axes in the bifurcation space. The general solution includes much more particular solutions expressed in hyperbolic functions. Among them there are the solutions with nonzero asymptotic, which can be considered as polarized solitary waves, spiral stationary solutions, and complex solitons containing as hyperbolic so and trigonometric parts. The physical meaning of such solutions must be investigated. The parameters for all these solutions in the bifurcation space belong to the limited regions on the surfaces of the bifurcation manifold. Out of these regions the parameters correspond to the particular solutions expressed in trigonometric functions. The parameters on the boundaries between the regions correspond to so-called algebraic solitons with power asymptotic.

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ON THE THIRD INSTABILITY POINT IN A TWO-SUBSYSTEM MAGNETIC CRYSTAL

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In a CuB_2O_4 metaborate the magnetic copper ions occupy two nonequivalent positions 2b and 4d in a crystal unit cell and form two geometrically different subsystems. Neutron scattering data [1,2] show that with a decrease in temperature the magnetic system at $T_N \approx 20$ K undergoes the transition from the paramagnetic to weak ferromagnetic phase commensurable with a crystal lattice. At $T_I \approx 9.5$ K, the transition to the incommensurable phase with wave vector q continuously growing from zero occurs; at $T_C \approx 1.8$ K, the transition to the phase with nonzero q which is nearly temperature-independent. Such a sequence of the phase transitions in the copper metaborate is confirmed by static and resonance measurements [3].

It has been usually supposed that the transition at T_N meets spin ordering at the 2b position (b-spins) and that at T_I, spin ordering at the 4d position (d-spins) [4], while the transition at T_C has been left for further investigation. However, the change in magnetization of d-spins with temperature according to the Curie-Weiss law with the paramagnetic Curie temperature of about 2 K makes one reconsider the current concept on the temperature of their ordering. In this study, we demonstrate in the mean-field approximation that this temperature can be just T_C, whereas T_I may correspond to a different instability point of the given magnetic system.

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TRANSFORMATION THE OF SWR SPECTRA IN THE FIELD OF LAYER'S TEMPERATURE PHASE TRANSITION

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In this work we study the effect of temperature on the spectrum of spin-wave resonance (SWR) in a three layer films, in which one of the layers of consolidation had a significantly lower Curie temperature T_C in comparison with two others.

If the temperature grows, the spectra of SWR in the perpendicular orientation on the plane of the film had a little change up to a temperature of 130 ^{o}C, and while the further increasing of the temperature the number of excited SWR modes changes.

The width of the lines of spin-wave (SW) modes (2ΔH), more significantly with the changing of temperature (Fig. 1). A monotonous increase of the wide of lines happens from room temperature to 130 ^{o}C and than it becomes extremely decrease.

The increasing of the wide of the lines in the range from room temperature up to 130 ^{o}C due to the fact that with increasing of temperature decreases the difference in resonance fields of homogeneous layers, and as a consequence, increases the depth of penetration of the spin waves in a layer of consolidation .

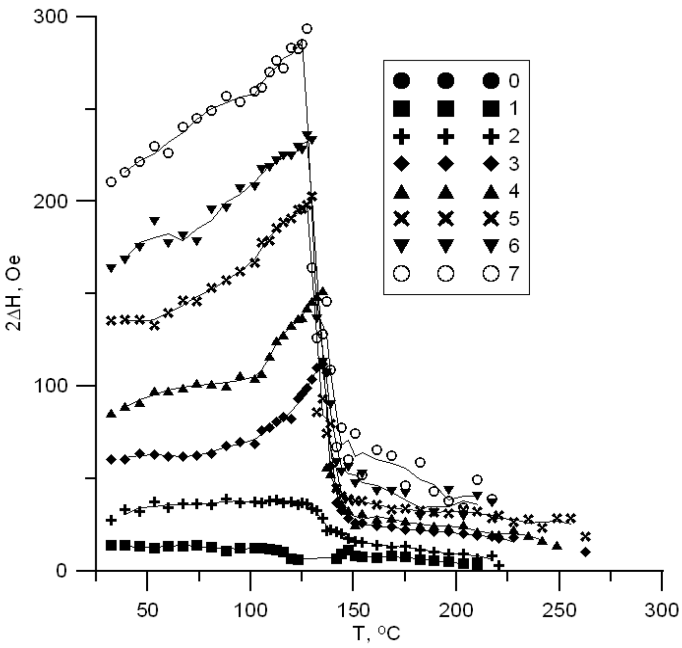

Fig.1. Temperature dependence 2ΔH of SW modes.

We found that when approaching T_C, there is a sharp decrease of wide of the line 2ΔH modes of spin-wave resonance (Fig. 1). For high-order modes 2ΔH it reduces approximately fivefold. In the temperature range from 150 ^{o}C to the Curie point the width of the lines practically did not change.

As can be seen from the figure the most sensitive to the magnetic are the modes of higher order.

SURFACE MAGNETOELASTIC WAVES IN YTTRIUM ORTHOFERRITE

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For description the mechanisms of domain wall (DW) braking take into account the excitation of magnetoelastic (ME) waves (ME) and wall (Winter) magnons [1]. Through a total explanation of the find out peculiarities on the $v(H)$ – curve for a moving DW in a weak ferromagnets has not been obtained. In this message, we give addditional the results of analysis of the effect of MEV on the DW motion in orthoferrites. We are investigated in waves whose phase velocities may coincide with the DW velocity. AVV [2] consider a family of surface acoustic waves for $(\xi k_x)^2 << 1$: $(v_{2n}/s_t)^2 = 1 + (n\pi/k_x h)^2 - (\xi D_{20})^2/((k_x D_{20})^2 + 1)$. The ME interaction increases the phase velocities of spin branches and decreases these velocities for acoustic branches as in the case of bulk waves. The greatest decrease in the velocity of sound is observed in the low frequency part of the spectrum, in which the spin system has time to tune itself to the elastic system. In the plate small thickness (h = 10 μm) the normal **SH** modes are shifted to the range of high spatial frequencies. The highest mode with a zero-dispersion region is $n_{max} = \xi h/\pi$, wich at the plattern thickness of h = 6 μm. In this case must been fire zero mode coinciding with bulk transverse sound along the x axis is excited as likely [3].

We studied plates $YFeO_3$ to cut perpendicular to the optical axis. In the speciments were set up by a two-domain structure, which was visually observed on the basis of magnetooptical Faraday effect. Driving of the DW from its initial balanced position was activated by a pulsed or alternating-current suppled in the Helmholtz coils. The DW dynamics was investigateded using the methods of interferometry, dark field, and double photography [3]. The sensitivity of interferometry method was $5 \cdot 10^{-10}$ m. Elastic vibrations were studied under the action of bipolar pulses of the driving field with amplitude of 21 Oe at frequencies of up to 10 MHz. The $YFeO_3$ sample was placed in an arm of a Michelson interferometer. The largest magnitude distorition induced by the motion of the DW was registrated in a frequency of 26.4 kHz was 7 nm. The observed elastic vibrations were harmonic, energy density was estimated at 4×10–2 erg/cm^3. The analogous distorition were observed at frequencies of 58 and 72 kHz in experiments at higher frequencies (up to 10 MHz). Flexural vibrations were studied by the dark field method. The power of radiation reflected from the sample surface was measured at a wavelength of 630 nm, and registered in the far-field optical zone with the help of photodiodes. In both methods, radiation was registrated with the help of FD-256 photodiodes (a time constant of 2 ns) a Tektronic TDS5054B oscillograph.

Thus, the results of calculations and experiments dates point that the motion of DWs in plates $YFeO_3$ is accompanied by the excitation bulk and also surface ME waves. In matter resonance, ME waves strongly impact on the DW dynamics. The spectral dependences of the modes in various types of surface ME waves increases the number of possible resonances at DW velocities out-of-phase with the velocities of bulk acoustic and spin waves. The DW dynamics depends on the thickness, shape, and state of the sample surface.

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PROPAGATION OF MAGNETOSTATIC SURFACE WAVES IN FERRITE GARNET FILMS WITH VARIABLE CROSS-SECTION

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Magnetostatic surface waves propagating in a pure yttrium iron garnet film with variable cross section are investigated in accordance with the relationship between the magnetostatic wave frequency and the internal magnetic field. External magnetic field was assumed to be directed tangentially at a random angle toward the direction of wave propagation. Dispersion characteristics of the magnetostatic surface waves were calculated. The possibility of the existence of modulation instabilities at this magnetic system was assayed. The problem of the possibility of development of magnonic crystals on the base of ferrite films with variable cross-section is described.

THE PECULIARITIES OF SPIN-WAVE RESONANCES IN ELECTROMAGNETIC WAVE PENETRATION THROUGH THIN MAGNETIC FILMS

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The method has been worked up that allows to calculate the transmission and reflection coefficients for electromagnetic wave which interacts with a thin metal film. The computation has been fulfilled with taking into consideration the exchange effects, surface spin pinning conditions and finite conductivity of the film. To agree with the experimental compliance, it is supposed that the metal film is sputtered on a dielectric substrate. Taking into consideration all possible wave types, the equations set has been obtained from which the transmission and reflection coefficients can be found numerically. The numerical computations have been carried out as applied to the parameters of Permalloy films and conditions of the experiment with the use of microwaves. The value areas of parameters have been determined in which the different types of resonance can exist. If the exchange factor is relatively small and surface spin pinning is weak, then the ferromagnetic resonance can only realize in the film. When the exchange factor is about 10^{-7} erg/cm, besides the ferromagnetic resonance, there are the spin wave resonance peaks in the wave penetration; their amplitudes increase on conditions that the surface spin pinning becomes stronger. Within the same value area of the exchange factor, the spin wave resonance is possible in the form of oscillations of the transmission coefficient.

The resonant phenomena experiments in electromagnetic wave penetration through thin Permalloy films have been carried out. In the films of different thickness, we watched experimentally the minimum of transmission coefficient corresponding to the ferromagnetic resonance and the oscillatory changes of transmission coefficient because of the spin wave resonance. Furthermore the spin wave resonance was observed with the resonance line which was badly resolved of quite unresolved from the ferromagnetic resonance line. It has been established that the spectra of ferromagnetic resonance line are almost the same for all investigated specimens despite the presence of other types of resonant phenomena in addition to the ferromagnetic resonance. The experimentally obtained DC magnetic field dependences of the transmission coefficient modulus have been compared with the numerically computed ones.

SPIN-WAVE ELECTRODYNAMICS PECULIARITIES OF A BOUNDED WEAK FERROMAGNET IN AN EXTERNAL DC ELECTRIC FIELD

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Using the example of a semibounded easy-plane weakly ferromagnetic crystal, magnetized tangentially to its surface, the conditions have been determined under which, with the application of an external dc electric field along the easy-magnetization axis, a number of anomalies arise at the transmission and localization of TE and TM electromagnetic waves through the interface between a nonmagnetic dielectric and a weak ferromagnet due to quadratic magneto-optical interaction (additional item in free energy of a kind $F_{mo} = -\lambda_{ijkl} l_i l_j E_k E_l$, existence of which is possible at any symmetry of magnetic crystal; l_i and E_k are the components of vectors of antiferromagnetism and electric field respectively).

For analysis, we will choose the well-studied two-sublattice model of a tetragonal easy-plane antiferromagnet with a weak ferromagnetic moment lying in the easy plane (xy) of the crystal. In this connection, the aim of this work is to determine the conditions, under which it is possible to change purposefully the character of the polariton dynamics of a bounded easy-plane weak ferromagnetic crystal using, whose direction of external dc electric field $\mathbf{E}_0$ is simultaneously collinear the easy magnetic axis (y) and orthogonal the ferromagnetic moment (x). In particular, the following was shown:

(i) Under total internal reflection conditions, depending on the external electric field magnitude, evanescent electromagnetic wave of the TM or TE type, propagating in a magnetic medium, can damp either monotonically ($\mathbf{E}_0 \parallel \mathbf{n}$; is normal to the surface of weak ferromagnet) or with oscillations ($\mathbf{E}_0 \perp \mathbf{n}$).

(ii) The simultaneous existence of the ferromagnetic moment $\mathbf{m}_0$ and external dc electric field $\mathbf{E}_0$ leads to additional effects of refraction, such as negative and abnormal refractions. This effects are absence if $\mathbf{m}_0 = 0$ or $\mathbf{E}_0 = 0$.

(iii) For $\mathbf{E}_0 \neq 0$ the spectrum of not only surface, but also volume magnetic polaritons of both the TM and TE type can be nonreciprocal with respect to inversion of the propagation direction.

(iv) In the case $\mathbf{E}_0 \parallel \mathbf{n}$, the structures of the spectra of TM and TE surface polaritons significantly depend on the sign of $(\mathbf{E}_0\mathbf{n})$.

(v) In the absence of an external dc electric field the formation surface excitation of TM type is principally impossible in weak ferromagnet.

(vi) Both propagation and localization conditions of bulk TM or TE polaritons passing through the interface between magnetic crystal and nonmagnetic medium essentially depend on which (left- or right-handed) triple is formed by the positive directions of $\mathbf{k}_y$, $\mathbf{H}_0$ and $\mathbf{E}_0$.

ORIENTATIONAL DEPENDENCE OF MAGNETOSTATIC SURFACE WAVE BRAGG DIFFRACTION IN 1D MAGNONIC CRYSTAL

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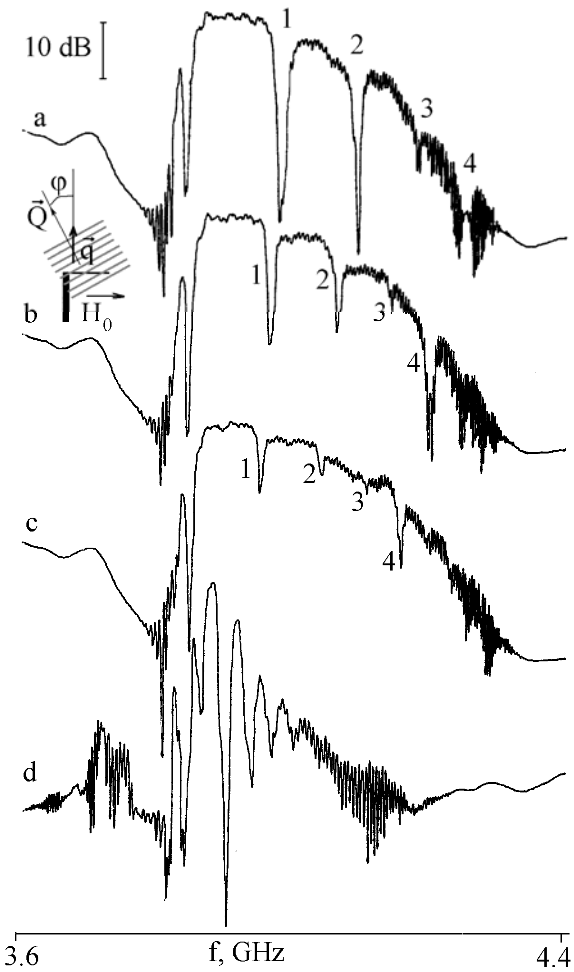
Bragg diffraction of magnetostatic surface waves (MSSW) propagating in 1D magnonic crystal (MC) was investigated depending of angle φ between the directions of MSSW q and MC $\vec{Q}$ wave vectors - see inset to the Figure. The MC composed of w=70 mkm width 0.66 mkm deep grooves separated by d=30 mkm lands etched in 4,1 mkm thick YIG film was rotated on the microstrip transducers of delay line. The figure demonstrates the amplitude-frequency characteristics obtained at tangential bias magnetic field of H_0=730 Oe at φ=0° (a), 10° (b), 20° (c) and 90° (d). One can see that curve (a) demonstrates four forbidden gaps at MSSW frequencies f_n with wavelengths λ_n (n=1,2,3,4) in good agreement with Bragg-Wolf condition $2d\sin\varphi = n\lambda$, where d is array period (100 mkm). Due to anisotropic character of MSSW dispersion the increasing of λ at increasing of φ was experimentally found in accordance with prediction of paper [1].



Further increasing of φ to 45° leads to arising of effective broadband suppression of MSSW in area of low q values (not shown in the Figure). Finally at φ=80° ÷ 90° propagating wave regions could be observed in addition to MSSW - see curve (d) for φ=90° case corresponding to MSSW propagating along the grooves. The observed regions can be associated with modes of narrow waveguide formed by lands between grooves. In the discussed geometry the demagnetization effect is known to results in increasing of narrow waveguide's eigen modes frequencies compare to continuos film case.

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HIGH-FREQUENCY CURRENT INDUCED INSTABILITY UNDER HIGH SPIN INJECTION

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An effect is considered of high-frequency current on the magnetic junction configuration. A conventional spin-valve model consisting of a pinned ferromagnetic layer (layer 1), thin spacer layer, ferromagnetic free layer (layer 2) and nonmagnetic layer (layer 3) closing electric circuit. The high-frequency current flows perpendicular to the layer planes (CPP mode). Stability is investigated of collinear (parallel or antiparallel) relative orientation of the pinned and free layers against small magnetization fluctuations under alternating current flowing with density $j(t) = j_0 \cos\Omega t$. The free layer is assumed to be thin compared to spin diffusion length and domain wall thickness, so that the macrospin approximation is applicable [1]. In this approximation, the modified Landau – Lifshitz – Gilbert (LLG) equation takes the form of a vector ordinary differential equation with additional terms corresponding to two known mechanisms of interaction between spin polarized current and magnetic lattice, namely, spin-torque transfer (STT) [2, 3] and spin-injection (SI) effective field [4].

In contrast with the contribution of the STT mechanism, the contribution of the spin-injection mechanism due to the *sd* effective field is proportional to the absolute value of the current density, so that it is the same for forward ($1 \to 2 \to 3$) and backward ($3 \to 2 \to 1$) currents. This leads to different spectra of the STT and SI terms in LLG equation: the former consists of the single frequency Ω, while the latter contains only the even harmonics of Ω frequency (including dc component). Therefore, two mechanisms do not interplay in the lowest-order resonance phenomena and may be considered separately.

A standard stability analysis [5] shows that the SI mechanism can lead to instability due to parametric resonance at $\Omega \approx \omega_0$, where ω_0 is the magnetization precession eigenfrequency in the free layer 2. At typical parameter values, the corresponding threshold current density amplitude is of the same order of magnitude as the threshold for the switching antiparallel configuration to parallel one by spin-polarized direct current [1]. Unlike the latter case, the parametric instability due to SI is possible both in antiparallel and parallel configurations, but corresponding thresholds are different.

The instability of the antiparallel configuration under high-frequency current flowing is possible also when the parametric resonance condition $\Omega \approx \omega_0$ does not fulfill. This is due to dc component of the *sd* exchange field. The STT mechanism does not lead to the parametric instability due to the fact, that the STT, in contrast with the spin injection, modifies the damping, not the eigenfrequency. A more detailed description can be found in [6].

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DIPOLE-EXCHANGE SPIN WAVES IN PERIODIC DIPOLE-COUPLED MULTILAYERS

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Latest achievements in magnetic thin-film growth technology enable one to obtain the layered magnetic systems with the predetermined film thickness and with well-defined interfaces. Accordingly it becomes possible to investigate properties of very accurately defined stacks of alternating magnetic and nonmagnetic thin films. Such multi-layered systems seem to provide a new type of material, which does not exist naturally. Ferromagnetic films in such structures are always coupled via long-range magnetostatic dipolar fields, thus forming new` characteristic modes of the stack – collective spin-wave modes. In the case when spin waves propagate in the film plane, the effect of formation of the collective modes manifests itself through splitting of the initial discrete dispersion spectra into the set of bands.

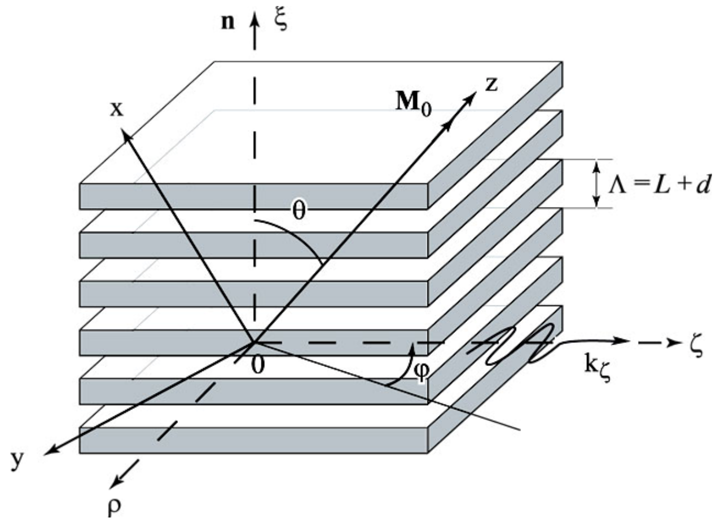

Fig.1. Magnetic multilayered structure

In this work we extend the previously elaborated analytical theory for the dipole-exchange spin waves in multilayered structures [1] to the case of the periodic ferrit-dielectric structure. In doing so, we introduce the Fourier amplitude of the total variable dipole magnetic film of the structure as a linear superposition of the Fourier amplitudes of the dipolar fields of all ferromagnetic layers of the structure and making use of the Bloch's theorem [2] we obtain the approximate spin-wave dispersion relation in analytical form.

The considered model takes into account the dipole-dipole and exchange interaction inside the ferromagnetic films, the interlayer dipole-dipole interaction, and also includes the influence of the surface anisotropy through the surface spin-pinning conditions on the both sides of the magnetic films. Since all the characteristics of the periodic structure appear in the final dispersion relation as parameters, one can easily obtain the dispersion characteristics and their dependence on different parameters for a wide class of the multilayered periodic structures. In this work we present the dependence of spin-wave spectrum of the model structure (Fig.1) on the ferromagnetic layers thickness, on the interlayer distances, and on the strength of the surface anisotropy. In particular, it is shown that the interlayer dipole-dipole interaction in the infinite periodic structure is influenced by the surface anisotropy much less than in two-layered structure due to the presence of a large total variable dipole field of the infinite stack of magnetic films.

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THE LAWS OF GEOMETRICAL OPTICS IN ANISOTROPIC GEOMETRIES

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The laws of geometrical optics for 2D geometries of anisotropic structures are presented through the analysis of the geometrical and mathematical properties of various isofrequency dependences which are also called sections of the wavevector surface [1]. We have considered the effect on wave propagation, reflection, and refraction of such geometric and mathematical properties of isofrequency dependences as the existence on them asymptotes, inflection points, and centers of symmetry, the number of symmetry axes, single- or multi-valuedness of the dependences, and the existence of extremum points on it. It was shown that if the isofrequency dependence of an anisotropic medium possesses some of these properties, then propagation, reflection, and refraction of waves can be accompanied by such phenomena as the impossibility of wave propagation in some directions or within some angular sector, nonreciprocality of propagation (when counter-propagating rays have different parameters), unidirectional propagation (when for a given ray there exists no counter-propagating ray and, in some cases, there is only a single direction, in the vicinity of which the energy can be transferred), negative reflection and refraction (when the incident, reflected, and refracted rays are on the same side of the normal to the interface), the emergence of two (or more) reflected or refracted rays, the absence of reflection altogether, and the irreversibility of ray paths in reflection or refraction. In particular, if the isofrequency dependence is not centrally symmetric, then reflection and refraction are nonreciprocal and manifest irreversibility of ray paths. If the isofrequency dependence is a function in some frame of reference (i.e., every abscissa value corresponds to a single ordinate value), the propagation of waves is unidirectional and, if the interface is parallel to the abscissa axis of this frame of reference, reflection is absent. The existence of inflection points in at least one curve of the isofrequency dependence always leads, for a certain orientation of the interface, to the appearance of two reflected rays. For a certain orientation of the interface and a certain polarization of the incident ray, two reflected rays appear when the isofrequency dependence contains no fewer than two curves, one of which is closed. It was shown that, for a given orientation of the boundary between two media with respect to the characteristic directions of the anisotropic medium, one can find out whether reflection and refraction are positive or negative at various angles of incidence by searching for the extremums and singular points of the isofrequency dependence in the coordinates connected with the normal and the interface between media. Most analyzed examples describe the propagation, reflection, or refraction of magnetostatic waves in ferrite films or various structures.

Reflection and refraction of a wave by a plane interface between 3D anisotropic media are considered also [2]. Examples of media whose isofrequency surfaces are ellipsoids have been analyzed. On the basis of 3D analysis performed for the above 3D geometry in the plane of isofrequency dependences and in the incident-ray plane, general mathematical criteria that make it possible to find out if reflection or refraction is positive or negative have been formulated. These criteria can be applied to determine the character of reflection and refraction of electromagnetic and acoustic waves in any anisotropic geometry.

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FERRITE GARNET FILMS WITH INCREASED THERMAL STABILITY OF SURFACE MAGNETOSTATIC WAVE SPECTRUM

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Use surface magnetostatic waves (SMSWs), excited in thin ferrite films, allows to solve a number of problems on processing signals in a range of frequencies from 0.5 GHz up to 20 GHz. The special attention by development of the given class of devices is given the temperature stabilization of their characteristics.

In the present work the results of research of influence of crystallographic magnetic anisotropy of ferrite films on temperature changes of a SMSW-spectrum are presented. It is necessary to note, that as a basis for construction of spin-wave devices serves yttrium iron garnet (YIG, $Y_3Fe_5O_{12}$), belonging to weakly anisotropic ferrites with a cubbic symmetry of the crystal lattice. The main factor of thermal instability of the magnetic oscillations spectrum in YIG films is the temperature dependence of the saturation magnetization. At the same time displays of crystallographic magnetic anisotropy in temperature characteristics of SMSWs in details were not investigated.

It is known, that in films with monocrystal structure there is a dependence of characteristics of magnetostatic spin waves from the orientation of a vector of magnetization concerning a crystal lattice [1]. Within the limits of a task in view the temperature coefficients of frequency of SMSWs in tangent magnetic field have been studied (TCF, $\alpha_f = (1/f)(df/dT)$). The films model with cubic magnetic anisotropy and orientations of the {*aab*} type has been constructed. The given set of orientations is described by only one angular variable and at the same time covers all the basic crystallographic directions of a cubic crystal. In particular, the constructed model enables to compare {111} films, which are most widely used in spin-wave devices, with films of other orientations. From the equation of a dispersion of SMSW received in work [2], the formula for calculation of TCF has been deduced. The analysis of the deduced expression shows, that value of α_f in SMSW spectrum monotonously changes from value $(1/f_0)(df_0/dT)$ up to $(1/f_\infty)(df_\infty/dT)$, where f_0, f_∞ are the longwave and shortwave boundary frequencies of the spectrum. The analysis of the angular dependences of TCF in films of different crystallographic orientations shows, that the greatest anisotropy is peculiar to films with (001) and (110) orientations, and the least to (111) one. Besides, thermostability of the SMSW frequencies at films with (001) and (110) orientations and magnetized along an axis of <100> type considerably above, than at (111) film.

Measurements of temperature dependences of the SMSW frequencies *f*(T) have been executed on YIG films with {100}, {110}, {210} orientations and thickness from 9 up to 16 micron. The experimental data confirm the developed theoretical representations about essential influence of crystallographic magnetic anisotropy on formation of temperature characteristics of SMSWs inYIG films.

Using the properties of ferrite films described above, it is possible to improve the thermal stability of frequency-selective SMSW devices. In addition, by properly selecting the crystallographic orientation of the film surface and the magnetization direction, it is possible to provide for the mutual compensation of the parameters of other elements of SMSW devices.

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CHARGE TRANSFER TRANSITIONS IN MULTIFERROIC $BiFeO_3$ AND RELATED FERRITE INSULATORS WITH HIGH CURIE AND NÉEL TEMPERATURES

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The multiferroic materials with two or more coexisting order parameters are known since the 1960s, see review papers [1,2]. The possible interactions between different order parameters make these materials promising candidates for development of new spintronics and optoelectronics devices. Recent theories show that electronic contribution to multiferroic properties may be quite important and in some cases comparable to lattice contribution. In this sense the study of electronic structure in materials exhibiting multiferroic properties above room temperature is a challenging task. Among 3*d* transition-metal materials several iron oxides show multiferroic properties. In particular, iron Fe^{3+} ion with the electronic structure t_{2g} (3)- e_g(2) favors strong exchange interaction and highest magnetic transition temperatures in comparison to other 3*d* transition-metals oxides.

In this talk we report on optical response of the multiferroic $BiFeO_3$ and related complex iron oxides in a wide spectral range from 0.6 up to 5.8 eV studied by means of a spectroscopic ellipsometry. One of the two groups of materials includes iron borate Fe_3BO_6, orthoferrites $ErFeO_3$ and $Y_{.95}Bi_{.05}FeO_3$, hematite α-Fe_2O_3, and $Fe_{2-x}Ga_xO_3$ in which iron Fe^{3+} ions occupy only octahedral positions. The second group includes calcium ferrite $Ca_2Fe_2O_5$, lithium ferrite with spinel structure $LiFe_5O_8$, garnet ferrite $Sm_3Fe_5O_{12}$, and hexaferrite $BaFe_{12}O_{19}$ in which Fe^{3+} ions occupy both octahedral and tetrahedral positions. All compounds studied possess high Néel or Curie temperatures. We show that in this spectral range optical response is dominated by the *p-d* and *d-d* charge-transfer (CT) transitions.

At variance with several previous investigations we present a valid and unified assignment of dipole-allowed and dipole-forbidden CT transitions. All the ferrites investigated are qualified to be CT insulators with the band gap determined by a dipole-forbidden *p-d* CT transition. A noticeable enhancement of optical response near 4 eV in $BiFeO_3$ as compared with other related iron oxides is attributed to the CT transitions within the Bi-O bonds.

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MAGNETIC EXCITATIONS IN *R*$Fe_3(BO_3)_4$ MULTIFERROICS AT SUBMILLIMETER WAVELENGHTS

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Rare-earth iron borates $RFe_3(BO_3)_4$ attract a considerable interest in the last years due to their remarkable magnetic, magnetoelectric and other properties which are substantially determined by an exchange interaction of antiferromagnetic Fe and paramagnetic rare-earth (R) subsystems. In this work we have performed the first study of submillimeter magnetic resonance and dielectric properties of these materials in order to get additional data on their spin structure, magnetic interactions and structural phase transitions. Polarization measurements of transmission spectra of single crystalline plates of *R*=Y, Eu, Tb, $Gd_{0.5}Nd_{0.5}$, $Nd_{0.4}Y_{0.6}$ and $Nd_{0.95}Dy_{0.05}$ iron borates (a-cut of a trigonal crystal) were carried out by a submillimeter quasioptical backward-wave-oscillator spectrometer at the frequency range 3-20 cm^{-1} at the temperatures 3-300 K. The resonance modes were observed in easy plane $YFe_3(BO_3)_4$ and $EuFe_3(BO_3)_4$ as well an easy axis $TbFe_3(BO_3)_4$ crystals for ac field **h**||b and were identified as the high frequency antiferromagnetic modes of the Fe-subsystem $\nu_{Fe}^2=\gamma^2(K_{Fe}/\chi_\perp)$. This enabled to define anisotropy constant K_{Fe} = 2.7 10^5 erg/g stabilizing easy plane and field H_E =$M_0/2\chi_\perp$=680 kOe of Fe-Fe exchange. The corresponding resonance frequencies ν_{Fe} increase with lowering temperature and amount to ~4.5, 6 and 15 cm^{-1} at 4 K, respectively, in Y, Eu and Tb borates. The increasing of the ν_{AF} in $EuFe_3(BO_3)_4$ as compared with $YFe_3(BO_3)_4$ indicates on the additional anisotropic Eu^{3+} Van-Vleck contribution stabilizing the easy ab-plane $(\chi_{\perp c}^{VV}-\chi_c^{VV})H_{ex}^2$ which is in a good agreement with observed anisotropy of the Van-Vleck magnetic susceptibility $\chi_{\perp c}^{VV}>\chi_c^{VV}$ and allows to estimate the Eu-Fe exchange field $H_{ex}\approx$140 kOe. A noticeable increase of the ν_{AF} in the easy axis $TbFe_3(BO_3)_4$ revealed not only a change of the sign of the effective anisotropy constant but its significant negative value due to a strong contribution of the Ising Tb^{3+} ions with easy c-axis. $K_{eff} \equiv K_{Fe} - N\Delta_{Tb}\mathrm{th}(\Delta_{Tb}/k_BT)$ where $2\Delta_{Tb} \equiv 2\mu_{Tb}H_{exTb\text{-}Fe}$ – splitting of the ground Tb^{3+} quasi-doublet. The extracted values of the splitting $2\Delta_{Tb}(4K) \approx 30\ cm^{-1}$ and $H_{exTb\text{-}Fe} \approx 35$ kOe correspond nicely to the spin-flop transition field along c-axis. In the substituted easy axis $Tb_{0.25}Er_{0.75}Fe_3(BO_3)_4$ ν_{AF} is reduced by half, that shows a dominant contribution of Tb^{3+} ions in the effective anisotropy. Contribution of Er^{3+} ions is rather weak because of the small splitting.

The resonance modes observed in other iron borates for **h**||b and **h**||c were identified as magnetic excitations of *R*-ions (Nd^{3+} or Gd^{3+}) coupled with Fe-spin oscillations. In particular, for the easy plane $Gd_{0.5}Nd_{0.5}Fe_3(BO_3)_4$ two wide absorption modes at ~ 8 см$^{-1}$ and ~14-17 см$^{-1}$ were ascertained as Nd and Gd ones, respectively, which are determined by the R-Fe exchange splitting of the ground multiplets of the *R* ions. The theoretical analysis of the dynamic properties of the exchange coupled Fe- and *R*-subsystems has revealed also a significant mixing of corresponding spin oscillations accompanied by anti-crossing and intensity redistribution for the modes of the same symmetry. Taking into account peculiarity of Gd^{3+} and Nd^{3+} ground states a reasonable description of observed *R*-modes was obtained as well as low frequency AFMR Fe-modes were predicted. However, this classification is rather conditional due to mixing of the modes. Resonance lines observed in $Nd_{0.4}Y_{0.6}Fe_3(BO_3)_4$ and $Nd_{0.95}Dy_{0.05}Fe_3(BO_3)_4$ were identified as Nd-modes with frequencies ~10 and ~12 cm^{-1} (T=4K) which are shifted up as compare with Nd^{3+} ground state splitting (~8 cm^{-1}), indicating thus a dynamic coupling of the R-modes with the Fe-subsystem.

This work was supported by RFBR (07-02-00580-a).

FMR SPECTRA OF Ag/Fe(8nm)/Ag(0 ÷12nm)/Fe(8 nm)/Si(111) STRUCTURES

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Magnetic multilayered structures are actively investigated due to their application in different magnetic memory devices and magnetic sensors. Among variety of different ferromagnetic/nonmagnetic metal structures, Fe/Ag/Fe are received great attention because of the lack of interdiffusion between Fe and Ag. The aim of this work is investigation of FMR spectra of Ag/Fe/Ag/Fe/Si(111) structures depending on thickness d_{Ag} of intermediate Ag layer.

All specimens were obtained by thermal deposition technique at pressure about 10^{-8} Torr. Deposition rate was 1 and 0.45 nm/min for Ag and Fe respectively. Fe and Ag layer posses polycrystalline structure that was confirmed by RHEED technique. Magnetic parameters were determined by FMR technique at 9.8 GHz at room temperature.

Dependence of FMR linewidth on thickness of intermediate Ag layer possess slight oscillations at d_{Ag} ≈0÷2 nm. For d_{Ag} >3 nm the two separate lines were observed in the FMR spectra. The FMR linewidth of the upper film was several times greater than for bottom film.

Atomic force microscopy investigation shows that roughness of intermediate Ag layer/upper Fe layer interface is increased with increasing of thickness d_{Ag} . So possible reason of $\Delta H(d_{Ag})$ oscillations can be explained by exchange coupling between Fe layers with prevalence of biquadratic component caused by direct interaction via voids in Ag layer[1]. Appearance of two peaks in FMR spectra can be caused by decreasing number of voids in Ag layer and consequently by decreasing influence of direct coupling through the voids. So at definite thickness d_{Ag} >3 nm Fe layers can be considered as fully decoupled.

Work was supported by RFFI grants № 08-07-00119-a, 09-07-00186-a

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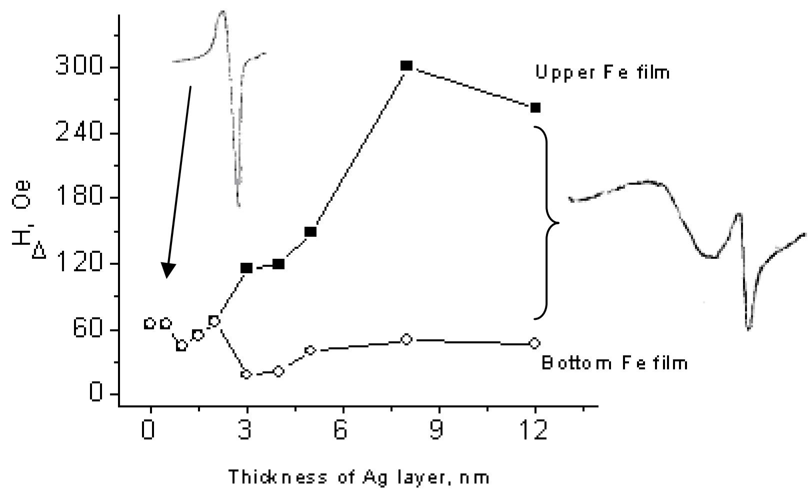

THICKNESS DEPENDENCE OF FMR LINEWIDTH OF THIN Fe FILMS

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Thin ferromagnetic films onto dielectric and semiconductor substrates are of great interest from the point of view of investigation the influence of surface morphology on magnetic parameters and also because of the wide application of thin films in magnitoelectronic.

One of the most important magnetic parameter of ferromagnetic film is FMR linewidth ΔH which is strongly influenced by surface morphology of thin film. This work is attributed to the investigation of influence of surface morphology and film thickness on FMR linewidth of epitaxial Fe/MgO(001), Fe/GaAs(001) and polycrystalline Fe/SiO_2/Si thin films obtained by thermal deposition in ultrahigh vacuum.

The deposition rate was 0.1÷0.7 nm/min as estimated by quartz oscillator. The substrate temperature was controlled using chromel-alumel thermocouple and didn't rise over 80^0 C during deposition. FMR linewidth was determined by FMR technique (9.8 GHz) at room temperature.
It is shown that values of ΔH decreases as film thickness increases that reflects fact of decreasing influence of surface morphology on ΔH. For polycrystalline Fe/SiO_2/Si thin films thickness dependence of ΔH is close to d^{-1}[1]. However, in the case of Fe/MgO(001) and Fe/GaAs(001) epitaxial films there is clear minima in thickness dependence of ΔH (see Fig.). The lowest values of ΔH (20-30 Oe) are reached at film thickness 3-6 nm depending on deposition conditions. This minima is not kept within the two-magnon relaxation model for ultrathin ferromagnetic films according to which thickness dependence of ΔH is d^{-1}, like for Fe/SiO_2/Si thin films. For thin epitaxial Fe/MgO and Fe/GaAs ferromagnetic films films this deviation from d^{-1} model can be attributed to the mechanism of "switching off" two-magnon relaxation of uniform precession of magnetization because of the exchange shift of the "bottom of spectra " of spin waves.

Work was supported by RFFI grants № 08-07-00119-a, 09-07-00186-a

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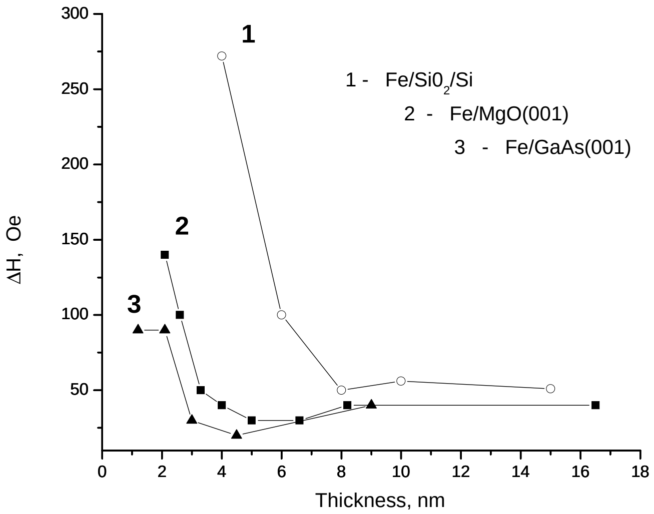

MICROMAGNETIC MODELING OF MAGNETIZATION PROCESS OF MAGNETIC MICROPARTICLES WITH DEFECTS

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OOMMF code [1] widely used for micromagnetic modeling both of the base state and microwave spectra of magnetic micro- and nanostructures. In this paper we numerically investigate an influence of defects in the form of holes on the magnetization (M-H) loops of square magnetic microparticle.

Note, that pinholes in the films may be generated at the initial stages of the film growing as a result of the islands coalescence. The number and the size of the pinholes depends on the technological parameters, difference in magnetic film and substrate surface energies, purity of the sputtered materials and etc. It is well known, that annealing of the ferromagnetic film may drastically change the surface roughness and leads to an increase of the films coercitivity.

The mask that was used for calculations in OOMMF code was generated from the atomic force microscope image of the films surface. All points of the surface having height smaller than average nominal film thickness were approximated as a hole, while other parts were approximated by constant height t equal to film thickness.

Calculations were performed for $Fe/SiO_2/Si$ films as deposited at room temperature and after annealing at 400^oC. The annealing process leads to an increase the film surface roughness and a number of holes of the mask. As a result the coercitivity field of the particle increases with respect to as deposited film. Results of the numerical modeling were found in qualitative agreement with experimental investigation of the hysterezis curves measured by vibrating sample magnetometer.

This work was supported by RFBR (grants # 09-07-00186 and # 08-07-00119).

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INFLUENCE OF MAGNETOSTRICTION ONTO THE CRYSTALLOGRAPHIC ANISOTROPY FIELD IN THE BARIUM HEXAFERRITE

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Influence of magnetoelastic forces on the anisotropy field is experimentally investigated. Research is conducted in the double layer structure barium hexaferrite - hexagallate strontium.
The change of the field of crystallographic anisotropy H_a in epitaxial films of barium hexaferrite is experimentally investigated in comparison with the bulk monocrystals. It is established that the summary H_a in the epitaxial films is by 0,5 – 1,0 kOe less tnan in the bulk monocrystalic samples. It is determined that it is connected with the magnetostrictive mechanism of thee influence onto the value crystallographic anisotropy constant K_1. The epitaxial films of single-axis barium hexaferrites are monocrystallic two-layer structures with the constant of crystal grids - a_1=5,89 A° for $BaFe_{12}O_{19}$ and a_2=5,82 A° for the substrate of hexagallate strontium (room temperature) [1]. Elastic tensions σ cause elastic deformations and, according to the magnetostrictive mechanism, the magnetostrictive energy connected with them F_σ [2]:

$$F_\sigma = -\frac{3}{2}\sigma\lambda \qquad (1)$$

$\lambda = -12,5\cdot 10^{-6}$ - magnetostriction constant [3], which is by order of magnitude greater than λ for ferrum yttrium garnet. In our case $F_\sigma = 3,0\cdot 10^{5}$ erg·cm^{-3}. The magnetostrictive energy stipulated by the deformations for $BaFe_{12}O_{19}$ is subtracted from the anisotropy energy (K>0), in contrast to yttrium iron garnet (K<0), for which the magnetostrictive energy is added up to the anisotropy energy. As for the case of a single-axis crystal $F_\sigma \approx K_1$, so additional anisotropy field the induced by it is $\Delta H_\sigma = 2F_\sigma / M = 1,6\cdot 10^{3}$ Oe .

$$H_a = \frac{\omega_o}{\gamma} - H_o + 4\pi M \qquad (2)$$

where $\gamma = 2.8\ GHz/kOe$ - is the gyrmagnetic ration, M –saturation magnetization, which for $BaFe_{12}O_{19}$ case is equal - 375 Gs. Fig.1 shows the results of resonance field bias depending on substrate thickness i.e., value of magnetoelastic deformations.

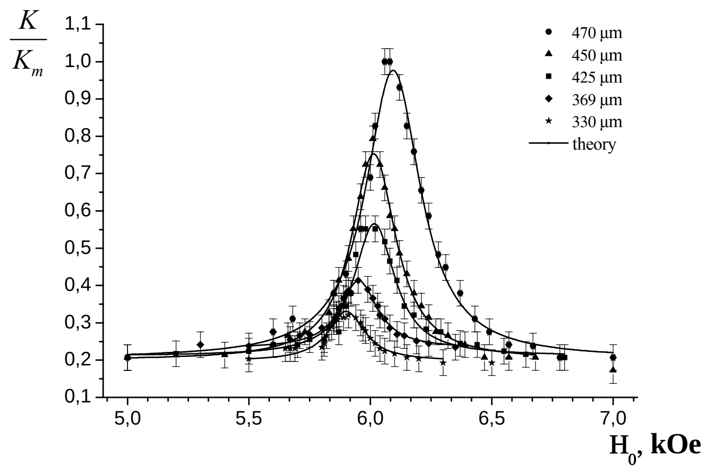

Fig.1 Normalized lines of absorption FMR for sample thickness t=12 мкм, geometry 2,1×0,7 mm^2 for differential thickness of substrate on a frequency 48.55 GHz.

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MAGNETO-OPTICAL STUDY OF OPAL-Fe_3O_4 PHOTONIC STRUCTURES

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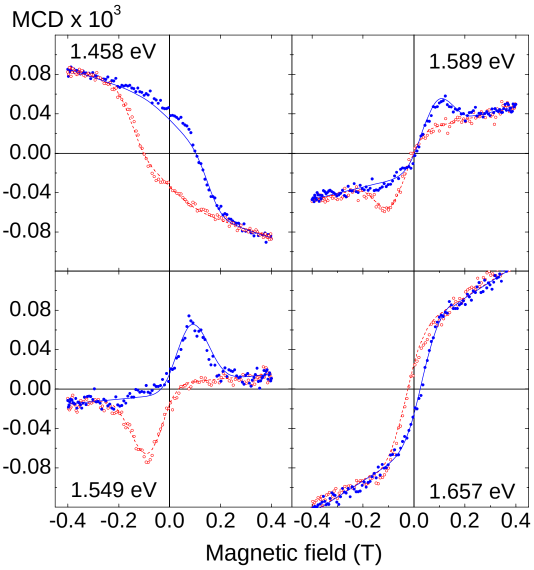
Photonic crystals are the optical analogue of atomic crystals, in which the atoms are replaced by macroscopic media with differing dielectric constants, and the periodic potential is replaced by a periodic dielectric function [1]. In photonic crystals interference phenomena give rise to the formation of specific photonic bands having high-transparency and high-reflectance regions.

We present experimental results the on magneto-optical properties of opal-Fe_3O_4 photonic structures which can be regarded as three-dimensional magnetic photonic crystals. The f.c.c. opal films with typical thickness of 5 μm were grown from SiO_2 spheres by using a vertical deposition technique [2]. Magnetite Fe_3O_4 was infiltrated into the opal film pores by a technology described in Ref. [3], resulting in opal-Fe_3O_4 photonic structures with a pore volume filling of 20-70%. Opal-Fe_3O_4 samples were characterized by optical transmittance, reflectance, magnetic circular dichroism, magneto-optical Faraday and polar Kerr effects measurements. The formation of a photonic band-gap in the spectral range of 1.6-2.0 eV was confirmed by these techniques. A strong enhancement of the polar MO Kerr effect and a modification of the Faraday effect was found near the photonic band-gap due to the localization of the light field.

The figure shows hysteresis loops for an opal-Fe_3O_4 sample with a pore volume filling of 70% at different photon energies, measured via magnetic circular dichroism. Surprisingly the shapes of the magnetic hysteresis loops are found to depend on the wavelength of light. This has been explained using a model taking into account two types of magnetite particles inside the opal matrix having different coercive fields and spectral behaviour [4].



Thus, we have designed and fabricated three-dimensional magnetic photonic crystal, based on opal films with magnetite Fe_3O_4 in the pores. A strong enhancement of the polar Kerr effect has been found near the photonic band-gap of about 1.8 eV. Unusual changes of hysteresis loops and their dependence on photon energy have been revealed in the spectral region where the magneto-optical effect reverses its sign.

The work is supported by the NWO-RFBR Project.

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MAGNETIC-FIELD-INDUCED SECOND HARMONIC GENERATION IN DILUTED MAGNETIC SEMICONDUCTORS (Cd,Mn)Te

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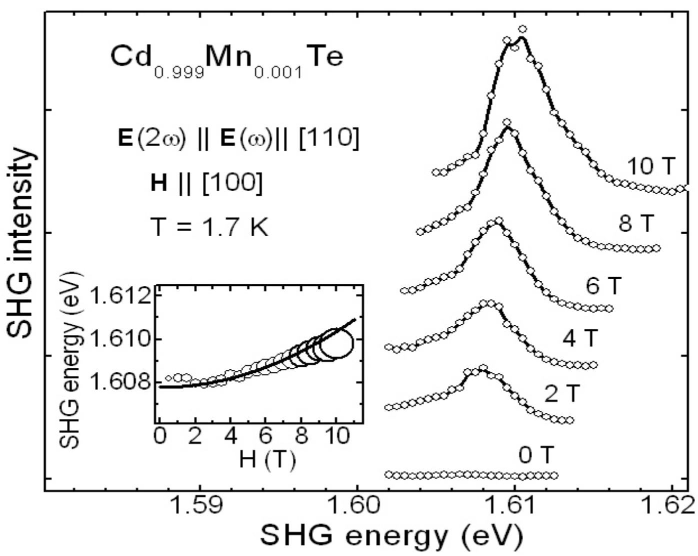
Diluted magnetic semiconductors belong to a large group of materials revealing plenty of various electronic, magnetic, optical and magneto-optical properties [1]. They are based on diamagnetic II-VI or III-V semiconductors with cations being partially or fully replaced by paramagnetic ions. The current research interest to this group of materials is based on potential applications in multidisciplinary fields such as spintronics, quantum computation and information processing.

Semiconductors (Cd,Mn)Te crystallize in zinc blende structure having the noncentrosymmetric point group $\bar{4}3m$ and possible nonlinear contributions to the second harmonic generation (SHG) are given by

$$\mathbf{P}^{2\omega} = \hat{\chi}^{(2)} : \mathbf{E}^{\omega}\mathbf{E}^{\omega} + i\hat{\chi}^{(3)} : \mathbf{E}^{\omega}\mathbf{E}^{\omega}\mathbf{H}^{0} + \hat{\chi}^{(4)} : \mathbf{E}^{\omega}\mathbf{E}^{\omega}\mathbf{k}^{\omega}\mathbf{H}^{0},$$

where $\mathbf{P}^{2\omega}$ is the nonlinear polarization, $\mathbf{E}^{\omega}$ is the electric field at the fundamental frequency, $\mathbf{H}^{0}$ is the magnetic field at zero frequency, $\mathbf{k}^{\omega}$ is the light wave vector, $\hat{\chi}^{(2)}$, $\hat{\chi}^{(3)}$ and $\hat{\chi}^{(4)}$ are nonlinear susceptibility tensors [2-4].

SHG spectra in the range of 1.2-3 eV were studied in magnetic semiconductors $Cd_{1-x}Mn_xTe$ (0.001<x<0.22) in broad temperature range and in magnetic fields up to 10 T [2-4]. Figure shows that in (001)-samples with x=0.001 spectrally narrow signals are observed at low temperature very close to the fundamental band gap. Field and temperature dependences of the SHG signals are shown which were found to be coupled to the magnetization of the Mn^{2+} ions.



Depending on the Mn content, magnetic-field-induced SHG signals arise from two distinctly different origins related to orbital and spin quantization of the band states in magnetic field. The orbital contribution dominates for zero and very low Mn concentrations, whereas the spin contribution dominates for higher Mn contents. These contributions can be distinguished by their characteristic dependencies of the SHG intensity on magnetic field magnitude. The orbital part of the SHG scales as square of the field strength in accordance with a phenomenological theory. In the case of the spin quantization, the SHG intensity scales linearly with the magnetization, a behaviour which is not expected from the phenomenological model.

The work is supported by the DFG-RFBR Project.

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OPTICAL AND MAGNETO-OPTICAL PROPERTIES AND ORIENTATION PHASE TRANSITIONS IN RARE-EARTH ORTHOFERRITES

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A. V. Kimel[3], A. Kirilyuk[3], and Th. Rasing[3]

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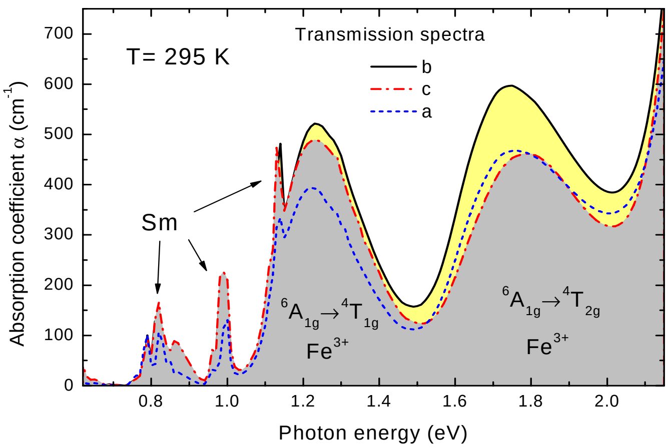
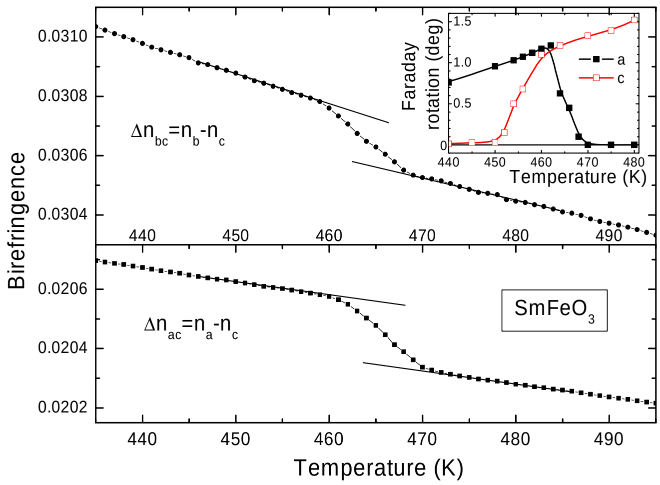
Orthorhombic rare-earth orthoferrites $RFeO_3$ with R being a rare-earth ion are magnetic insulators with high transparency in the visible and near-IR regions. They also have an anomalously high Faraday rotation, so they are promising materials for magneto-optic modulation and control devices. Recently they have attracted much attention as an object of experiments on ultrafast optical control of the magnetic state [1, 2]. All these observations are of importance for the development of novel concepts for high-speed magnetic recording and information processing.





We report on a study of the optical and magneto optical properties of $SmFeO_3$ and $DyFeO_3$. We investigated the absorption spectra in the energy range of 0.64–2.2 eV. Using spectroscopic ellipsometry we determined the dispersion of the real and imaginary parts of the complex refractive index along three crystallographic axes in the range of 0.64–5.4 eV.

Spontaneous spin-reorientation transitions are studied using temperature dependence of optical birefringence and magneto optical Faraday rotation. The change in birefringence due to spin-orientation transitions originates both from the temperature dependence of the crystallographic contribution and magnetic contribution [3]. Measured Faraday rotation agrees with the temperature dependence of the magnetization direction in the spin reorientation region [4].

The difficulties in using a material with both Faraday rotation and birefringence in devices are discussed.

The work is supported by the NWO-RFBR Project.

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FERROMAGNETISM IN THE QUASI-TWO-DIMENSIONAL SEMICONDUCTOR HETEROSTRUCTURES

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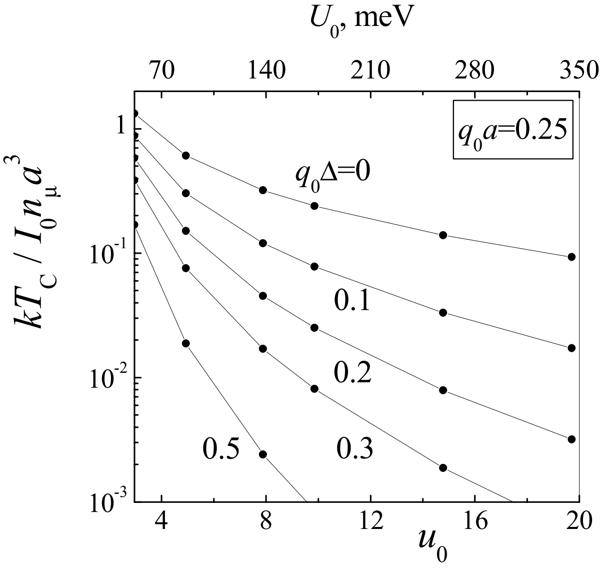
Kurchatov Institute, 123182 Moscow, Russia

In the framework of the mean field theory, we consider the ferromagnetism in the layer of magnetic impurity atoms indirectly interacting via the quasi-two-dimensional conductive channel in the neighbouring quantum well. It is the only known magnetic semiconductor structure where the carrier mobility in the channel is so high that carriers appear to be quasi-two-dimensional ones. The interaction arises by the indirect (e.g., Ruderman-Kittel-Kasuya-Yosida) mechanism due to penetrating wave functions of charge carriers (situated in the triangular quantum well) into the region where impurities are placed. We have found that the Curie temperature increases with decreasing the well depth (see Figure) and with increasing carrier concentration. In addition, the spatial distribution and the temperature dependence of the magnetization have been found. Results agree with the experimental data related to heterostructures based on diluted magnetic semiconductors of the $Ga_{1-x}Mn_xAs$-type.



Dependencies of the Curie temperature T_C on the well depth u_0 at different spacer thicknesses Δ. It has been assumed q_0a=0.25 that corresponds to the carrier density in the well N_s=4.5·10^{11} cm^{-2}. Here q_0=[(2m*/ ^{2})eF_0]$^{1/3}$, F_0 is the electric field in the heterojunction, Δ is the distance between the heterojunction plane and Mn layer, u_0=2m*U_0/ $^2q_0^2$, U_0 is the well depth, n_μ is the concentration of magnetic impurities, I_0 is the exchange constant (~1000K for interacting Mn impurities in GaAs).

MSW AUTOMODULATION IN RING RESONATOR UNDER EXTERNAL FORCE

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Self-action effects of dipole magnetostatic waves in non-linear ring resonator under external force was investigated in the framework of numerical solution of nonlinear Shreodinger equation with dissipative term. It was shown, that for input amplitude A_0 at point x=0 greater than some threshold amplitude A^{th} ($A_0>A^{th}$) MSW became unstable in nonlinear ring resonator.

1) The automodulation appearance haven't any relation with the fulfillment of the Lighthill criteria [1].

2) For MSW input amplitude $A_0=A^{th}$ the time dependence of the MSW envelope has a form of set of quasirectangular pulse train having periodicity $T \approx 2L/V$, where L is the length of the MSW delay line (the length of the ring resonator), V is the MSW group velocity.

3) The auto modulation threshold A^{th} is proportional to $L^{-0.5}$.

4) For input amplitudes $A_0>A^{th}$ automodulation demonstrates transit to chaos through intermittency.

The pointed items 1-3 indicate that MSW automodulation is a result of Ikeda instability [2]. This mechanism so far was excluded from consideration of MSW regular and chaotic automodulation in ring resonator systems that were observed in experiments [3,4].

The work was supported by RFBR grants 09-07-00186, 08-07-00119.

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SPIN-WAVE AND VORTEX EXCITATIONS IN THE STACKED TRIANGULAR-LATTICE ANTIFERROMAGNET WITH A WEAK INTERLAYER COUPLING

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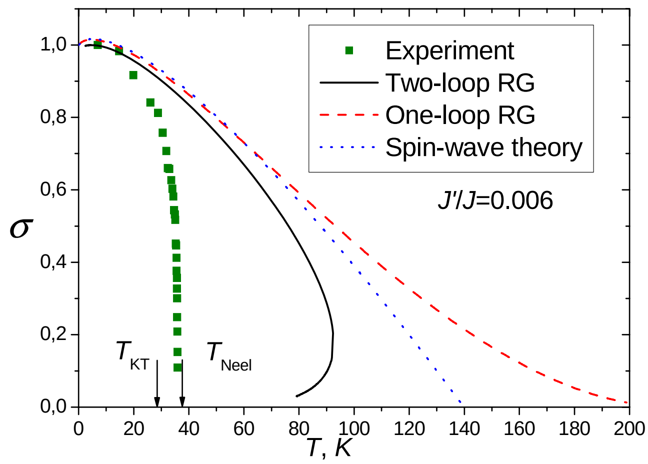
We consider a quantum Heisenberg antiferromagnet on the stacked triangular lattice in the renormalized classical regime by using the non-linear σ-model. In contrast to conventional non-linear σ-model for collinear antiferromagnets, we have two types of excitations: spin waves and $\mathbb{Z}_2$-vortices (visons). These vortices are to some extent similar to vortices of the XY model: they also have a finite activation temperature T_{KT} which is an analog of the Kosterlitz-Thouless temperature.

First we neglect vortices, which is strictly speaking justified only for $T<T_{\mathrm{KT}}$, and use perturbative renormalization group (RG) to account for spin-wave interactions. For J' J (J and J' are intralayer and interlayer exchange interactions) we obtain asymptotic expressions for the Neel temperature T_{Neel} and sublattice magnetization in the one- and two-loop approximations. The Figure compares the RG results for the sublattice magnetization with the spin-wave theory and neutron scattering data for VCl_2 [1]. One can see a large disagreement between the theory and experiment. At the same time, the RG approach in the case of collinear antiferromagnets (where vortex excitations are absent) leads to a quantitative agreement with experiment [2]. Therefore vortices are indeed imortant: they give the main contribution to sublattice magnetization for $T>T_{\mathrm{KT}}$ and determine the Neel temperature. To estimate vortex contribution to the Neel temperature we use the Monte-Carlo result for the correlation length of the pure two dimensional triangular antiferromagnet, $\xi(T)=A\exp\left[b/\sqrt{T-T_{\mathrm{KT}}}\right]$ for T T_{KT}, where $T_{\mathrm{KT}}= 0.28\,JS^2$ and $b = 0.77$ [3]. We define the Neel temperature for the quasi-2D model as a temperature where the crossover from 2D to quasi-2D regime occurs, so that $\xi(T_{\mathrm{Neel}})\approx a\sqrt{J/J'}$, and $T_{\mathrm{Neel}}\approx T_{\mathrm{KT}}+0.15JS^2\ln^{-2}\left(\frac{2J'}{J}\right)$. This formula for T_{Neel} is applicable for J' 10^{-14} J, and for smaller J' the result of RG approach works. For VCl_2 our estimation gives T_{Neel} = 37K which is close to the experimental value T_{Neel} = 36K [1]. The approach which will treat vortices and spin waves on equal footing is under construction.



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MULTIFERROIC AND MAGNETOELECTRIC BEHAVIOUR OF CONICAL SPIRALS

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We study the structure of domain walls in multiferroics with a conical spiral spin ordering, where magnetization coexists with electric polarization. Using an effective model for a frustrated spin system we investigate how the handedness of a conical spiral changes through a ferromagnetic domain wall. We find that for wide domain walls the handedness changes sign across the wall. As the sense of rotation of spins in the spiral determines the sign of induced electric polarization, in materials with wide domain walls ferroelectric and ferromagnetic domains are clamped. This clamping explains the inversion of electric polarization upon inversion of magnetic field observed in $CoCr_2O_4$.

We also study the effect of an applied magnetic field H on a screw helimagnet, where the spiral wave vector q is normal to the spiral plane. The external field deforms the magnetic screw into a conical spiral inducing electric polarization. We calculate the induced electric polarization as a function of the angle between H and q. We find that the competition between H and easy plane anisotropy leads to two different regimes. At low H the spin structure remains a screw spirals while at high fields it deforms to a conical cycloidal. Our results explain the magneto-electric effect in $ZnCr_2Se_4$.

Author Index


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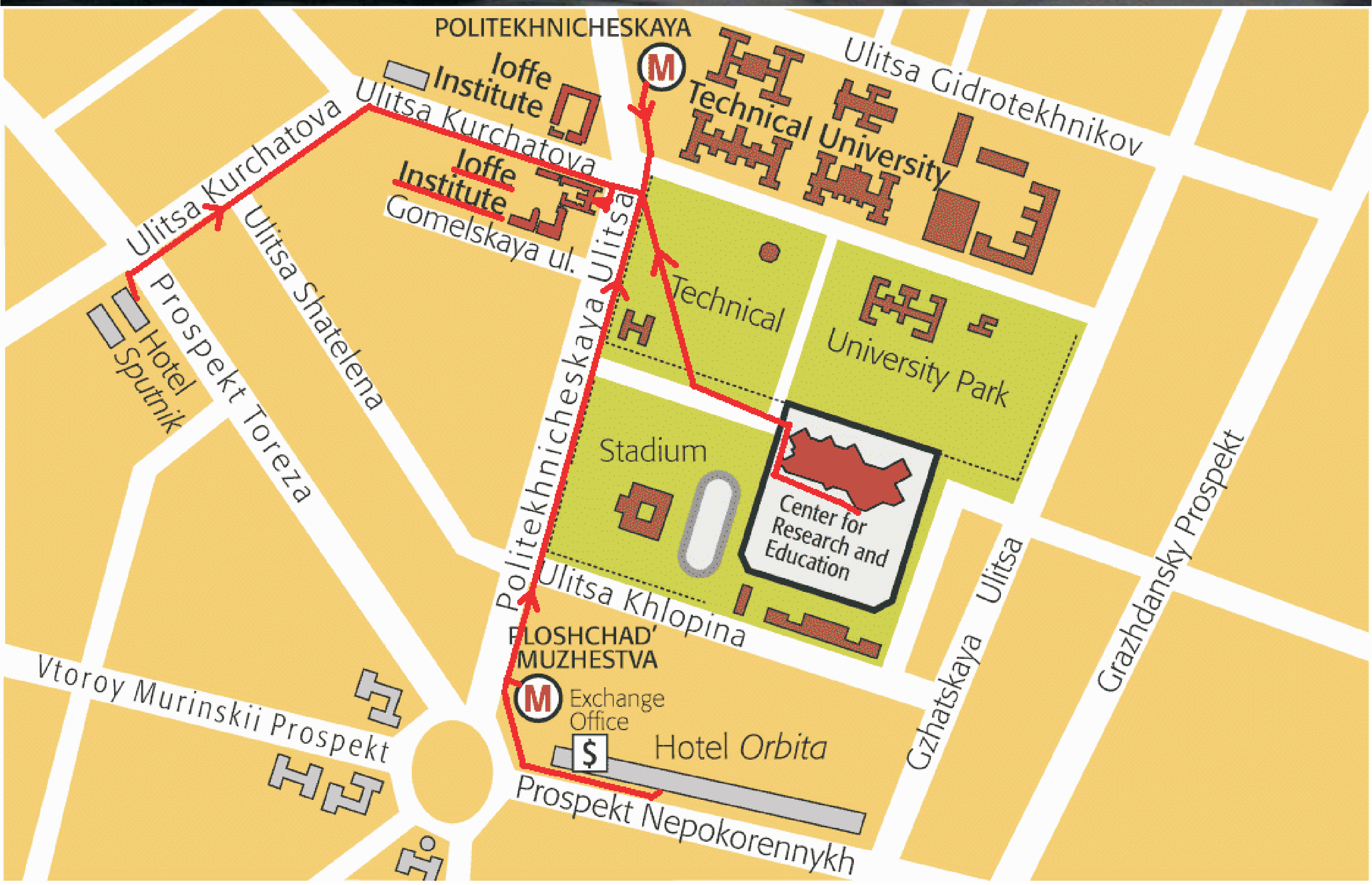
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