PASREG 2021

12th International Workshop on Processing and Applications of Superconducting Bulk Materials

Program and Abstracts

November 11 - 14, 2021

SHANGHAI, CHINA

Welcome to PASREG 2021

Dear PASREG attendees,

It is a great honor and my pleasure to welcome all of you in Shanghai at the 12th PASREG. The fast development of green energy and maglev transportation bring great opportunities and maket demand to HTS bulk superconductors. Shanghai Univeristy has been committed to the research of HTS materials for more than 20 years and we were very happy to accept the challenge of organizing the workshop.

Since its first years PASREG has mainly been focusing on processing and characterization of (RE)BCO large grain materials. However, with the development of new materials (such as MgB_2 and iron pnictides) and the increasing participance of researchers from this area, the organizing committee decided to modify the original name to the more general Workshop on Processing and Applications of Superconducting Bulk Materials – although we will retain the title PASREG, due to its long well-established tradition.

I am pleased that our program not only contains many interesting presentations from the fields of basic research and materials science, but also shows the progress in the promising applications and use of HTS materials. This is a trend we have all been waiting for.

I would hereby like to thank to all of you who have helped us preparing for this workshop, namely the members of our organizing committee, guest editors and finally also to the generous sponsors of the event.

On behalf of Shanghai University and all the organizers, I wish the workshop is interesting and fruitful one for you. Thank you for joinning the workshop online or onsite, enjoy the conference! May the epidemic end soon so that all of us can get together again in person.

Chuanbing Cai

PASREG2021 Chair

Director of Shanghai Key Laboratory of High Temperature Superconductors

Head of Department of Physics, Shanghai University

Contents

Organization

Conference Chairs:

Chuanbing Cai - Shanghai University

Xin Yao - Shanghai Jiaotong University

Organizing Committee:

David Cardwell - University of Cambridge

Philippe Vanderbemden - University of Liege

Herbert Freyhardt - University of Houston

John Durrell - University of Cambridge

Wangming Yang - Shanxi Normal University

Mitsuru Izumi - NTI TOBA College

Zigang Deng – Southwest Jiaotong University

Difan Zhou – Shanghai University

Local Organizing Committee:

Difan Zhou, Xihua Zong, Yong Zhao, Zhuo Sun, Jianhua Yang, Cuiyu Yang, Yulei Jiao, Yibing Zhang, Xinmao Yin, Guoqiao Zha, Ming Yan, Chuanbing Cai, Dengsong Zhang

PASREG 2021 SUST Guest Editors:

David Cardwell, University of Cambridge

John Durrell, University of Cambridge

XinYao, Shanghai Jiaotong University

Venue/hotel:

The conference takes place in the conference hall of GUCUN PARK HOTEL

No. 4788, Hutai Road, Baoshan District, Shanghai

Contact to organizer/host:

PASREG 2021

Shanghai Key Laboratory of high temperature superconductivity

Shanghai University, Baoshan District, Shanghai

tel.: + 8613812528692, Pasreg2021@163.com

Sponsors / Exhibitors

We welcome support from Industry for PASREG 2021. The workshop has been made possible by generous support of the following organizations:

Instructions for Presenters

All online presentations take place in the VOOV MEETING.

The meeting room named “Pasreg 2021” with ID: 596 9218 0967, and pass word: 2021

You can join with the following link: https://meeting.tencent.com/dm/N1Um6ydScGFN

Oral Presentations

Please make sure that the duration of an invited presentation should not be longer than 15 minutes, it will be followed by 3 minutes for questions from the audience. And a regular presentation should not be longer than 10 minutes followed by 2 minutes of questions. The session chair will be showing you the remaining time.

All presenters are asked to notify the session chair of their presence before the session starts, so that he/she knows are present.

Offline participants can bring it on a USB drive in PDF or PPT/pptx/PPS format at least 30 minutes before your session starts. A microphones and laser demonstration pointers /clickers will be provided for your demonstration.

Poster Presentations

The poster session will take place on line. All the posters will be uploaded to an on-line folder. And will also be combined into a single file and be circulated during the poster session. The participants are encouraged to discuss openly or privately via voov meeting during the workshop. Please send your poster to us via E-mail before November 10th.

SUST Conference Publications

Special Issue of Superconductor Science and Technology (SUST)

IOP will publish selected papers in a Special Issue of Superconductor Science and Technology (SUST) which is an international, multidisciplinary journal on all aspects of superconductivity.

All contributions to the Special Issue are expected to report new and original results on processing, characterization and application aspects of bulk superconductors and will be reviewed in line with the usual editorial criteria for the journal.

Abstracts of those who opted for SUST publication were reviewed by the Guest Editors and subsequently invites for publications were sent to the potential authors. Deadline for articles submission will be March 31, 2022. In Peer Review stage the Guest Editors are involved for issues of scope, and adjudication where referees disagree.

Contact Information

For any publication related info please contact PASREG2021 co-chair Xin Yao at xyao@sjtu.edu.cn

Conference Venue

The workshop will be held at the GUCUN PARK Hotel, 4788 HuTai Road, Shanghai.

GUCUN PARK HOTEL

SHANGHAI HALL MEETING ROOM

Program at a glance

THURSDAY, NOVEMBER 11, 2021

14:00 - 19:00 Registration (Gucun park hotel lobby)

FRIDAY, NOVEMBER 12, 2021

08:30 - 09:00 Opening
09:00 - 10:12 SESSION F-I
10:12 - 10:40 Coffee Break and Group Photo
10:40 - 11:58 SESSION F-II
11:58 - 14:00 Lunch
14:00 - 15:30 SESSION F-III
15:30 - 15:50 Coffee Break
15:50 - 16:00 Welcome from David
16:00 - 18:40 SESSION F-IV
18:40 CONFERENCE DINNER

SATURDAY, NOVEMBER 13, 2021

08:30 - 10:00 SESSION S-I
10:00 - 10:20 Coffee Break
10:20 - 11:56 SESSION S-II
11:56 - 14:00 Lunch
14:00 - 15:00 POSTER
15:00 - 16:36 SESSION S-III
16:36 - 17:00 Coffee Break
17:00 - 18:40 SESSION S-IV
18:40 DINNER

Sunday, NOVEMBER 14, 2021

Discussion and Lab Tour

Full Program

THURSDAY, NOV 11

14:00 – 19:00	Registration (Gucun Park Hotel Lobby)

FRIDAY, NOV 12

SESSION F-I:

CHAIR: Chuanbing Cai / Difan Zhou

08:30 – 09:00	**(F-I-1)**	**Masato Murakami,** *President of Shibaura Institute of Technology, Japan* **Zhuo Sun,** *Chairman of Shanghai Vacuum Society, China* **Siyi Gong,** *College Dean and Vice President, Shanghai University* Welcome speech
09:00 – 09:18	**(F-I-2)**	**Xin Yao,** *Shanghai Jiao Tong University, China* (Invited) Progress in the growth of high performance REBCO superconductor bulks in SJTU
09:18 – 09:36	**(F-I-3)**	**Miryala Muralidhar,** *Shibaura Institute of Technology, Japan* (Invited) Importance of Superconducting Materials in the Endeavour to Stop Climate Changes
09:36 – 09:54	**(F-I-4)**	**Wanming Yang,** *Shaanxi Normal University, China* (Invited) Effect of average grain radius on the levitation force and trapped magnetic flux of a single-domain GdBCO bulk
09:54 – 10:12	**(F-I-5)**	**Yong Zhao**, *Fujian Normal University, China* (Invited) Dynamical magnetic drag of high-T_c superconducting maglev vehicle
10:12 – 10:40		**Coffee Break and Group Photo**

SESSION F-II:

CHAIR: Yong Zhao / Yufeng Zhang

10:40 – 10:58	**(F-II-1)**	**Yufeng Zhang,** *Shanghai University of Electric Power, China* (Invited) The superconductivity properties of the multiseeded GdBCO bulks prepared with the introduced buffer with the modified TSMG

10:58 – 11:16	**(F-II-2)**	**Michael R. Koblischka,** *Shibaura Institute of Technology, Japan*
		(Invited) Limitations for possible trapped fields in RE-123 bulks
11:16 – 11:28	**(F-II-3)**	**Sai Srikanth Arvapalli,** *Shibaura Institute of Technology, Japan*
		Improved properties in sintered MgB_2 bulk superconductors by novel technique
11:28 – 11:40	**(F-II-4)**	**A. Koblischka-Veneva,** *Shibaura Institute of Technology, Japan*
		Measuring residual strains/stresses in MgB_2 bulk samples by means of EBSD
11:40 – 11:58	**(F-II-5)**	*Chinainstru & Quantumtech*
		Scanning Magnetic Field Microscope with a Diamond Single-Spin
11:58 – 14:00		**Lunch**

SESSION F-III:

CHAIR: Jun Zheng / Zhiyong Liu

14:00 – 14:18	**(F-III-1)**	**Denis Gokhfeld,** *Kirensky Institute of Physics, Russia*
		(Invited) Trapped field in perforated superconductors
14:18 – 14:36	**(F-III-2)**	**Jun Zheng,** *Southwest Jiaotong University, China*
		(Invited) A reconstructed three-dimensional HTS bulk electromagnetic model considering J_c spatial inhomogeneity and its implementation in a bulks combination system
14:36 – 14:54	**(F-III-3)**	**Dadiel Joseph Longji,** *Shibaura Institute of Technology, Japan*
		(Invited) Improved Connectivity of MgB_2 Bulk Superconductor via In-situ-Ex-situ Co-Synthesis
15:54 – 15:06	**(F-III-4)**	**Yassine Slimani,** *Imam Abdulrahman Bin Faisal University, Saudi Arabia*
		Effect of WO_3 Nanostructured Materials Incorporation on the Superconducting Performances of $YBa_2Cu_3O_{7-d}$ Compound
15:06 – 15:18	**(F-III-5)**	**Essia Hannachi,** *Imam Abdulrahman Bin Faisal University, Saudi Arabia*
		Systematic research on the impact of carbon nanotubes as artificial pinning centers on the properties of REBCO superconducting bulk

15:18 – 15:30	**(F-III-6)**	**Xiaodong Li,** *Technical University of Munich*
		Thermal-hydraulic analysis of the cooling system in a high-temperature superconducting axial flux motor
15:30 – 15:50		**Coffee Break**

SESSION F-IV:

CHAIR: Devendra Namburi / Difan Zhou

15:50 – 16:00	**(F-IV-1)**	**David Cardwell,** *University of Cambridge, UK*
		Welcome speech
16:00 – 16:18	**(F-IV-2)**	**Yunhua Shi,** *University of Cambridge, UK*
		(Invited) The facet lines and the uniformity of (RE)BCO-Ag single grains
16:18 – 16:36	**(F-IV-3)**	**Plechacek Jan,** *Can Superconductor, Czech Republic*
		(Invited) Development of EuBCO/Ag bulks for commercial applications
16:36 – 16:54	**(F-IV-4)**	**Frank N. Werfel,** *Adelwitz Technologiezentrum GmbH, Germany*
		(Invited) New technologies of bulk HTS application
16:54 – 17:12	**(F-IV-5)**	**Susannah Speller,** *University of Oxford, UK*
		(Invited) Microstructural engineering of MgB_2 bulk superconductors
17:12 – 17:30	**(F-IV-6)**	**Jun-ichi Shimoyama,** *Aoyama Gakuin University, Japan*
		(Invited) A new synthesis method for high quality RE123 bulks, SDMG
17:30 – 17:48	**(F-IV-7)**	**Jean Leveque,** *Université de Lorraine, France*
		(Invited) Superconducting using bulk HTS for Aircraft propulsion
17:48 – 18:06	**(F-IV-8)**	**Devendra Namburi,** *University of Cambridge and University of Glasgow, UK*
		(Invited) Microstructural engineering of (RE)BCO bulks: Challenges and advancements
18:06 – 18:18	**(F-IV-9)**	**Mike Beck,** *University of Cambridge Engineering Department, UK*
		Dynamics of Magnetic Flux Penetration into Ring-Shaped Bulk High Temperature Superconductors

18:18 – 18:36	**Ania Wronski,** *Superconductor Science and Technology*
	Instruction to Superconductor Science and Technology
18:40	**Dinner**

SATURDAY, NOV 13

SESSION S-I:

CHAIR: Zigang Deng / Mitsuru Izumi

08:30 – 08:48	**(S-I-1)**	**Mitsuru Izumi,** *Toba College, Japan*
		(Invited) HTS Bulk and Applications in Rotating Machines
08:48 – 09:06	**(S-I-2)**	**Zigang Deng,** *Southwest Jiaotong University, China*
		(Invited) The Development of HTS Pinning Maglev in SWJTU
9:06 – 09:24	**(S-I-3)**	**Hiroyuki Fujishiro，** *Iwate University, Japan*
		(Invited) Experimental validation of a Hybrid Trapped Field Magnet Lens (HTFML) using all-REBaCuO bulks
09:24 – 09:42	**(S-I-4)**	**Tetsuo Oka,** *Shibaura Institute of Technology, Japan*
		(Invited) Magnetic Separation for Ni-Plating Waste Liquid Using HTS Bulk Magnet
09:42 – 10:00	**(S-I-5)**	**Wenjiang Yang,** *Beihang University, China*
		(Invited) Translational levitation of a permanent magnet above the splicing plane of superconducting blocks and its motion damping and loss properties
10:00 – 10:20		**Coffee Break**

SESSION S-II:

CHAIR: Huadong Yong / Xinmao Yin

10:20 – 10:38	**(S-II-1)**	**Huadong Yong,** *Lanzhou University, China*
		(Invited) Crack problem in High Temperature Bulk Superconductor under Pulse field Magnetization

10:38 – 10:56	**(S-II-2)**	**Takemi Onoue,** *Graduate School of Frontier Sciences, The University of Tokyo, Japan*
		(Invited) Electromagnetic loss analysis of superconducting magnetic bearings by FEM based on H-φ and A-V formulation
10:56 – 11:14	**(S-II-3)**	**Aki Yamamoto,** *Tokyo Univ. of Agricul. Technol., Japan*
		(Invited) High Critical Current Density Iron-pnictide Bulks by Data Driven Process combined with Advanced Electron Microscopy
11:14 – 11:32	**(S-II-4)**	**K. Takahashi,** *Gakushuin University, Japan*
		(Invited) Validation of a quasi-microgravity space exploiting a high-gradient trapped field magnet (HG-TFM) as a desktop-type magnetic field source
11:32 – 11:44	**(S-II-5)**	**Chi Sing Tang,** *A*STAR, Singapore*
		Unravelling Superconductive Properties Using Broad-range Spectroscopic Techniques
11:44 – 11:56	**(S-II-6)**	**Ping Zhu,** Shanghai *University, China*
		Growth of a non-toxic high temperature superconductor: (Cu,C)-1234 with potential high performance
11:56 – 14:00		**Lunch**

SESSION S- III:

CHAIR: XinYao / Wanming Yang

14:00 – 15:00	**(S -III-1)**	**Poster**
15:00 – 15:12	**(S -III-2)**	
15:12 – 15:24	**(S -III-3)**	**Zhaoxin Liu,** *Beihang University, China*
		Research of an Evershed Composite Superconducting Bearing and its Application to Sensitive Component for sub-micron-level Thrust Testing
15:24 – 15:42	**(S -III-4)**	**Laura Gozzelino,** *Politecnico di Torino, Torino, Italy*
		(Invited) Magnetic field mitigation by MgB2 and hybrid passive shields

15:42 – 16:00	**(S -III-5)**	**Philippe Vanderbemden,** *University of Liege, Belgium*
		(Invited) Behaviour of neighbouring bulk trapped field magnets with parallel or orthogonal magnetizations
16:00 – 16:18	**(S -III-6)**	**David Cardwell,** *University of Cambridge, UK*
		(Invited) Advanced (RE)-Ba-Cu-O bulk superconductors with improved superconducting and mechanical properties
16:18 – 16:36	**(S -III-7)**	**Yeekin Tsui,** *University of Cambridge, UK*
		(Invited) A trapped field of 1.3 T in a ring-shaped Gd-Ba-Cu-O bulk superconductor by the pulsed field magnetization method
16:36 – 17:00		**Coffee Break**
17:00 – 17:18	**(S -III-8)**	**Jacques Noudem,** *Normandie University, France*
		(Invited) Could MgB_2 superconductors be used in Maglev vehicles
17:18 – 17:30	**(S -III-9)**	**Hajdova Petra,** *Slovak Academy of Sciences, Slovakia*
		Microstructure and Superconducting Properties of GdBCO-Ag Single Grain Bulk with CeO_2 Addition
17:30 – 17:42	**(S-IV-1)**	**Yiteng XING,** *Normandie University, France*
		High critical current density of MgB_2 bulk superconductor fabricated by Spark Plasma Sintering
17:42 – 17:54	**(S-IV-2)**	**Vito Cientanni,** *University of Cambridge, UK*
		Modelling the record trapped field by pulsed field magnetisation of a composite bulk MgB_2 superconducting ring
17:54 – 18:12	**(S-IV-3)**	**Mark Ainslie,** *University of Cambridge, UK*
		(Invited) Portable, desktop high-field magnet systems using bulk high-temperature superconductors
18:12 – 18:30	**(S-IV-4)**	**John durrell,** *University of Cambridge, UK*
		(Invited) A reliable technique to fabricate superconducting joints between single grain, Y–Ba–Cu–O bulk
18:30 – 18:40	**(S-IV-5)**	**David Cardwell,** *University of Cambridge, UK*
		Closing speech
18:40		**Dinner**

can superconductors

HTS BULKS AND MATERIALS

- Y/Gd/EuBCO melt-textured bulks
- REBCO Sputtering Targets
- REBCO Powders and Granulates
- BSCCO Current Leads, Magnetic Shields
- Superconductivity Demonstration Kits

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Quantum Diamond

Atomic Force Microscope

Product Introduction

Quantum Diamond Atomic Force Microscope (QDAFM)

Quantum Diamond Atomic Force Microscope (QDAFM) spectrometer is a quantum precise measuring instrument based on both nitrogen-vacancy (NV) center in diamond and AFM scanning imaging technology. By quantum control and readout of spin in luminous NV center defect of probe, magnetic property imaging of samples is acquired quantitatively and losslessly. With nanoscale high spatial resolution and single spin ultra-high detection sensitivity, QDAFM is a innovate technology to develop and study high density magnetic storage, spintronics and quantum techniques applications.

Product features

- High precision quantitative magnetic imaging
- Non-invasive magnetic imaging
- Advanced quantum probe fabrication
- Magnetic detection sensitivity up to 1 $\mu T/\sqrt{Hz}$
- Spatial resolution of magnetic imaging up to 10nm
- Compatible with ambient conditions and cryogenic vacuum environment

Quantum diamond atomic force microscope
-ambient version

Quantum diamond atomic force microscope
-cryogenic version

Chinainstru & Quantumtech (Hefei) Co., Ltd.
Address：1-4F, Area A, E2 Building, Innovation Industrial Park II, High-tech District, Hefei, Anhui

Institute of Quantum Sensing of WUXI
Address：No. 2 Zhanqian Road, Huishan Intercity Railway Station, Huishan District, Wuxi

Chinainstru & Quantumtech (Shanghai) Co., Ltd.
Address：Room 8405，No.315 Emei Road, Hongkou District, Shanghai

CIQTEK

400-0606-976
www.ciqtek.com
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more information

上创超导
Shanghai Creative SuperConductor

2G-HTS

Company Introduction

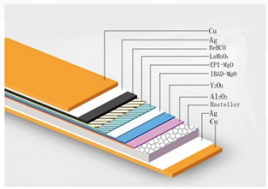
Shanghai Creative Superconductor Technologies Co., Ltd (SCSC), located in Fengxian, Shanghai, is a prominent manufacturer of 2G-HTS tapes in China invested in 2011 by Shanghai University, Shanghai Science and Technology Venture Capital Co., Ltd. and several forward-looking entrepreneurs.

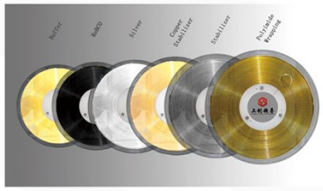
Leading in the HTS industrialization in Shanghai, SCSC is dedicated to the development of 2G-HTS tapes and related applied devices. By using the chemical method, SCSC has fulfilled the manufacturing equipment and technology development since 2013. The width and superconducting thickness of 2G-HTS tapes can reach 20mm, and 3.4 μ m respectively with single length of kilometers as well as the lowest cost in China. The unique chemical coating process and high quality performance allow SCSC renowned in China and worldwide.

In SCSC, dozens of the outstanding experts and technicians with different perspectives devote themselves to the development of HTS material technologies and power applications. The technical and management team is committed to play a positive and important role in the advance of smart grid, mag-lev, scientific facility etc. through the industrialization and scale production of 2G-HTS tapes.

Shanghai Creative Superconductor Technologies Co.,Ltd
TEL：021-37515861 FAX：021-37515791
ADD：No.4, Lane 2066,Wangyuan Road,Fengxian Distict,Shanghai,China

Specifications & Technical Parameters



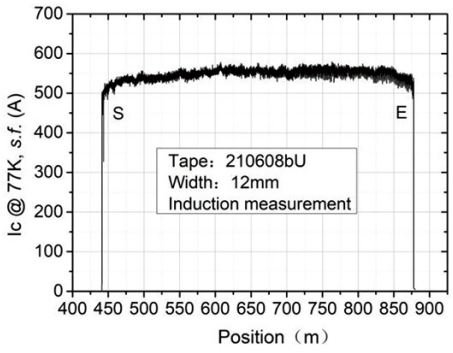


SCSC produces 2G-HTS tapes with hastelloy as substrate, REBaCuO as superconducting layer, copper as strengthen packaging layer and polymide as insulation layer.

	SCST-W4	SCST-W6	SCST-W12	SCST-W4 (Advanced)	SCST-W6 (Advanced)	SCST-W12 (Advanced)
宽度 Width	4±0.1mm	6±0.1mm	12±0.1mm	4±0.1mm	6±0.1mm	12±0.1mm
厚度 Thickness	80μm-250μm			80μm-250μm		
单根 Length	100m-1000m			100m-1000m		
临界弯曲直径 Critical Bending Diameter	20mm			20mm		
抗拉强度（室温） Tensile Strength *(room temperature)*	>400Mpa			>400Mpa		
临界电流范围（77K，自场） Min Ic*(77K,self-fields)*	90A-200A	150A-300A	300A-600A	300A-350A	450A-550A	900A-1100A
加强层材料 Stabilizer	Copper/Brass/Stainless steel			Copper/Brass/Stainless steel		

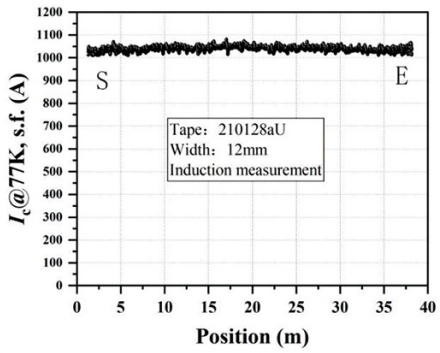
● lDifferent width can be customized according to your requirements

Performance Characteristics For Superconducting Tapes

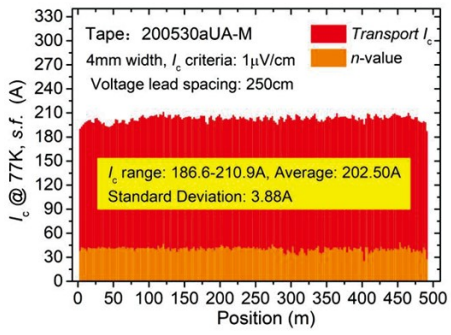


↑ The inductive test results of 12mm-wide 2G-HTS tape

thickness

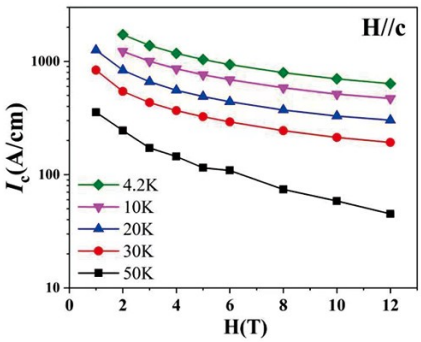


↑ The inductive test results of 12mm-wide 2G-HTS tape



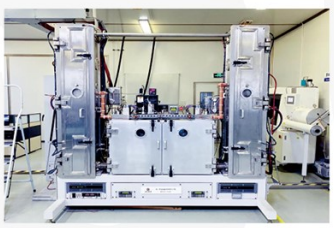
↑ The transport test results of 4mm-wide 2G-HTS tape

in-field performance



↑ The results of 10mm-wide 2G-HTS tape

Home-made Manufacturing Equipment



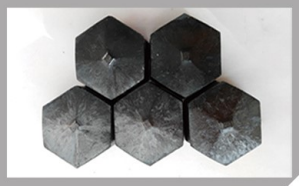
↑Sputter system for buffer layers

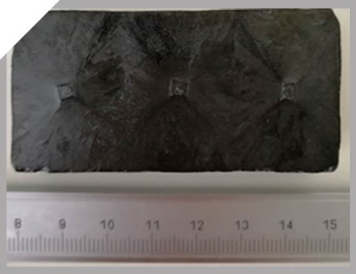
↑MOD facilities for superconductor layer

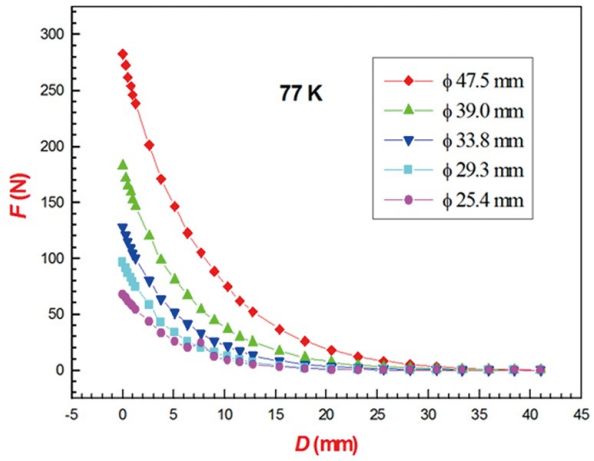
↑Equipment for four-probe transport measurement

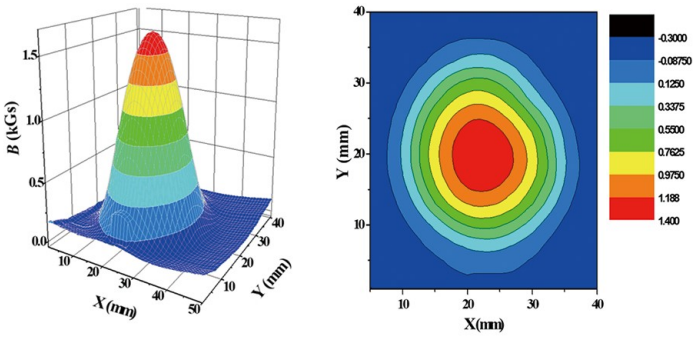
↑Equipment for dynamic XRD diffractometer

有研总院
GRINM









REBCO Bulks with high performance

Abstracts

T-01 **The Development of HTS Pinning Maglev in SWJTU**
Z. Deng, *Southwest Jiao Tong University, China*

T-02 **Evolution of long-time levitation performance of high temperature superconducting flux-pinning maglev**
W. Y. Lei, *Southwest Jiao Tong University, China*

T-03 **Research of an Evershed Composite Superconducting Bearing and its Application to Sensitive Component for sub-micron-level Thrust Testing**
Z.X. Liu, *Beihang University, China*

T-04 **Research of an Evershed Composite Superconducting Bearing and its Application to Sensitive Component for sub-micron-level Thrust Testing**
Z.X. Liu, *Beihang University, China*

T-05 **Trapped Field Performance of GdBCO Superconductor at Low-temperature**
Xiongfang Liu, *Shanghai University, China*

T-06 **Research in the Process Improvement of High Phase Purity $YBa_2Cu_3O_{7-\delta}$ Powder by Solid Sintering in SWJTU**
Rong Tang, *Southwest Jiao Tong University, China*

T-07 **The Dynamic Performance of HTS Pinning Maglev System after Heavy Loading and Unloading**
L. Wang, *Southwest Jiao Tong University, China*

T-08 **High superconducting properties of recycling multi-domain GdBCO bulk superconductors using improved infiltration technique**
M. Wang, *Xi'an Aeronautical University, China*

T-09 **The effect of temperature on the infiltration of liquid phase and properties of GdBCO bulk superconductor by TSIG method**
T.-T. Wu, *Shaanxi Normal University, China*

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T-01

The Development of HTS Pinning Maglev in SWJTU

*Z. Deng1,**
1) Applied Superconductivity Laboratory, State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, China
*Presenting author (email: deng@swjtu.edu.cn)

Abstract:
As a new maglev system, high-temperature superconducting (HTS) pinning maglev has the advantages of passive stabilization and no inherent magnetic resistance in the direction of travel, making it an important development direction of rail transit in the future. Since the first manned HTS pinning maglev vehicle born in 2000, and the test platform for HTS Maglev Evacuated tube transport (HTS Maglev-ETT) established in 2014, efforts have been done continuously to promote the technology into engineering application in Southwest Jiaotong university (SWJTU). Then, the first full-size HTS pinning maglev engineering prototype train was officially launched in SWJTU recently. Besides, a high-speed running test-platform for HTS pinning maglev has achieve the speed of 300 km/h, and aims at the speed of 430 km/h. Furthermore, an ultra-high-speed moving test-platform rail HTS pinning maglev, which is designed at the speed of 600 km/h, is pushing to completed. All those prototypes and test-platform built in SWJTU, is to promote development the development of HTS pinning maglev transit.

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T-02

Evolution of long-time levitation performance of high temperature superconducting flux-pinning maglev

W. Y. Lei[1,], J. Zheng[1],Z. C. Huang[1], W. H. Zhang[1] and Z. G. Deng[1]*
1) The authors are with the State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, China (e-mail: deng@swjtu.cn).
*Presenting author (email: 656549525@qq.com)

Abstract:
To explore the high temperature superconducting maglev levitation force for a long-time characteristics evolution, this paper uses the SCML-03 to conduct the long-time dynamic experiment. The dynamic simulation model was constructed based on COMSOL by using the magnetic field strength H method and the basic electromagnetic formula of superconductor, the accuracy of the model is verified by the 9.5 hours experimental results. Based on the simulation model, the variation of levitation force and levitation height decay of HTS maglev under the excitation of track irregularity for a long time is explored. Firstly, at constant rest and vibration amplitude, the logarithm of the levitation force versus time shows a linear relationship. Secondly, in the low frequency vibration environment (<10 Hz) where the self-oscillation frequency of high-temperature superconducting maglev is considered, frequency shows no significant effect on the levitation force decay. However, the lower the range of levitation heights during vibration, and the greater the levitation attenuation. Last but not the least, in the actual preload, the vehicle can be preloaded according to its vibration amplitude limit, when the vehicle vibration amplitude is within the preload range, it can greatly inhibit the levitation force decay, to ensure long-term levitation height stability.

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T-03

Research of an Evershed Composite Superconducting Bearing and its Application to Sensitive Component for sub-micron-level Thrust Testing

Z. X. Liu[1], W. J. Yang[1], F. W. Deng[1], P. Zhao[1], J. Z. Yan[1], J. T. Hu[1], and H. B. Tang*
1) School of Astronautics, Beihang University, Beijing 100191, China
*Presenting author (email: zy1915311@buaa.edu.cn)

Abstract:
Herein is displayed an Evershed composite superconducting bearing composed of a permanent magnet-permanent magnet (PM/PM) bearing at the top and a permanent magnet-superconducting (PM/HTS) bearing at the bottom. The principle of an Evershed composite superconducting bearing is to use the strong magnetic repulsion and attractive force of permanent magnets to support high loads, and at the same time use the magnetic flux pinning in Type II high-temperature superconductors to offset the instability in a system consisting of magnets only. Compared with a single superconducting bearing structure, the Evershed composite bearing has stronger carrying capacity, better verticality, smaller moment of inertia, lower damping and loss. What's more, Evershed composite bearing can be used to compensate the drift on the superconducting levitation due to flux creep and sustain a concise equilibrium point for a long time. In the Evershed composite bearing, there is generally two air gaps which exist PM/PM bearing and PM/HTS bearing respectively. In this study, we focus on the relationship between load characteristic and loss damping characteristic at different air gaps conditions, and explore the dynamic characteristics of bearing swing process. The results indicate that this type of bearing can effectively improve the load-carrying capacity and reduce the levitation loss and damping. Specifically, the coefficient of rotational friction can be as low as 10^{-8} at low speeds. The excellent bearing characteristics provide a crucial foundation for the sub-micron-level thrust measurement of space electric propulsion.

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T-04

Research of an Evershed Composite Superconducting Bearing and its Application to Sensitive Component for sub-micron-level Thrust Testing

Z X. Liu[1], W J. Yang[1], F W Deng[1], , J Z Yan[1], J T Hu[1], and P. Zhao[1]*
1) School of Astronautics, Beihang University, Beijing 100191, China
*Presenting author (email: zy1915311@buaa.edu.cn)

Abstract:
Herein is displayed a sensitive magnetic levitation testbed for measuring the sub-micron-level thrust generated by small thrusters typically employed in spacecraft station-keeping. The testbed is based on a magnetic levitation bearing design but incorporates Evershed composite bearings instead of more typical single superconducting bearings or electromagnetic bearings. The principle of Evershed composite bearings is to use the strong magnetic repulsion and attractive force of permanent magnets to support high loads, and at the same time use the magnetic flux pinning in Type II high-temperature superconductors to offset the instability in a system consisting of magnets only. Compared with a single magnetic bearing structure, the thrust testbed based on Evershed composite bearings has stronger carrying capacity, better true verticality, smaller moment of inertia and lower damping and loss. More importantly, Evershed composite bearings can be used to compensate the drift on the levitation testbed due to flux creep and sustain a concise equilibrium point for a long time. In this study, we focus on the relationship between load characteristic, loss damping characteristic and the two air gaps of the composite bearing, and explore the dynamic characteristics of bearing swing process. The results indicate that this type of bearing can effectively improve the load-carrying capacity of the testbed and reduce the levitation loss and damping. Specifically, the coefficient of rotational friction can be as low as 10^{-8} at low speeds. The excellent bearing characteristics lay a crucial foundation for the sub-micron-level accurate thrust measurement.

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T-05

Trapped Field Performance of GdBCO Superconductor at Low-temperature

Xiongfang Liu[1,2]，Difan Zhou[1,2]，Yibing Zhang[1,2]，Jinyu He[1,2]，*
Yuchen Wang[1,2]，Chuanbing Cai[1,2]

[1]The Department of Physics, Shanghai University, Shanghai 200444
[2]Shanghai Key Laboratory of Temperature Superconductors，Shanghai 200444

Abstract:
High-temperature superconducting bulks are valuable in magnetic levitation and low-temperature quasi-permanent magnets. Among them, GdBCO superconductors have certain advantages and greater potential in superconductivity compared with YBCO superconductors. In this study, high performance GdBCO superconductors were prepared by Top-seeded melt-textured growth , and the following aspects were optimized: (1) adding 10wt% - 20wt% Ag_2O powder to reduce the peritectic temperature of Gd123, while increasing the mechanical properties; (2) adding 1wt% - 2wt% of BaO to the precursor powder to suppress the Gd-Ba substitution during the growth process; (3) adding liquid phase source to assist the formation of superconducting phase in the melt at high temperature; (4) adding a 6 mm diameter buffer layer between the seed crystal and the bulk to eliminate elemental contamination and other problems. We measured the trapped field and magnetic flux relaxation of the GdBCO samples at 77 K and lower temperatures. The modified GdBCO bulk trapped 0.97T at 77K in a field-cooled magnetization process, and the trapped field performance is substantially improved below 60K（via fitting the data），which is related to the different number and types of flux pining centers inside the bulk induced by low temperature. This experiment explores the performance advantages of GdBCO bulks and the motion of magnetic flux at lower temperatures.

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T-06

Research in the Process Improvement of High Phase Purity $YBa_2Cu_3O_{7-\delta}$ Powder by Solid Sintering in SWJTU

*Rong Tang[1, *], Yunrui Song[1], Difan Zhou[2] and Zigang Deng[1]*

[1] Applied Superconductivity Laboratory, State Key Laboratory of Traction Power, Southwest Jiaotong University, 610031 Chengdu, China

[2] Shanghai Key Laboratory of High Temperature Superconductors, Department of Physics, Shanghai University, 200444 Shanghai, China

*Presenting author (email: tangrong@my.swjtu.edu.cn)

Abstract:

High phase purity $YBa_2Cu_3O_{7-\delta}$ (YBCO) powder is not only key raw material for the fabrication of YBCO bulk superconductor by Top Seed Melt Growth (TSMG), but also adopted as the target of the Pulsed Laser Deposition (PLD) process in preparation of YBCO film. Conventional technology usually goes through the steps of mixing, solid sintering, grinding, etc., which consume a lot of manpower and time. Comparative study of such processes was studied and the improvement methods were reported in this work. Firstly, the differences between wet and dry mixture technology were studied and it was found that an inhomogeneous defect caused by inconsonant deposition was inherent and ineludible during wet. XRD analysis showed that the composition uniformity of each part of the wet one was far worse than that of dry. Secondly, a neoteric mixing technology using in combination with planetary muller and 3-dimensional blender was introduced, which observably improve the efficiency of obtaining ideal mixture than the wet way. Finally, this work studied the grinding process of high hardness $YBa_2Cu_3O_{7-\delta}$ crystals. It can quickly and stably prepare micron-level high phase purity $YBa_2Cu_3O_{7-\delta}$ powder (the loss rate of less than 5%) by adopting diamondite equipment. A proper rotate speed and ball-to-powder ratio made the efficiency more than four times higher than the traditional process. This research is of great significance for the low-cost and large-scale preparation of YBCO bulk superconductors.

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T-07

The Dynamic Performance of HTS Pinning Maglev System after Heavy Loading and Unloading

L. Wang[1,2,], Z. Deng[2], S. Wang[2] and X. Zhou[2]*
1) School of Mechanics and Engineering, Southwest Jiaotong University, Chengdu 610031, China.
2) Applied Superconductivity Laboratory, State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, China
*Presenting author (email: 1225502251@qq.com)

Abstract:
High-temperature superconducting (HTS) Pinning magnetic levitation (maglev), with the advantages of passive stable levitation and ultra-low resistance, has attracted more and more attention from researchers around the world. In 2021, the world's first full-size HTS pinning maglev engineering prototype train was officially launched in SWJTU, China, which provides strong proof for the feasibility of engineering application of HTS Pinning maglev in civil train. In actual operation, the maglev train is under heavy loading and unloading frequently. Due to the hysteresis effect and relaxation effect, the levitation position and the dynamic response of the HTS maglev system can change after those loading and unloading. Therefore, this paper mainly focuses on the dynamic performance of the HTS maglev system after heavy loading and unloading. Firstly, the vertical loading and lateral guiding force are measured after a series of loading and unloading in different directions, magnitudes and speed. Secondly, the dynamic response of the HTS maglev system after the same loading and unloading is tested. Then, the flux and current density inside the superconducting bulks are gained though simulation. Finally, the overall influence of the heavy loading and unloading to the dynamic performance of the HTS pinning maglev system is analysed and presented. The studies in this paper can provide reference for the dynamic study of the HTS pinning maglev train.

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T-08

High superconducting properties of recycling multi-domain GdBCO bulk superconductors using improved infiltration technique

M. Wang[1,], Y.N. Wang[1], and W.M. Yang[2]*
1) School of Science, Xi'an Aeronautical University, Xi'an, China
2) School of Physics and Information Technology, Shaanxi Normal University, Xi'an China
*Presenting author (email: cwnanmao@126.com)

Abstract:
High temperature superconductor has become one of the hotspots of research, because of its high critical temperature, strong trapped flux density, stable suspension characteristics and large magnet levitation force. The single domain $REBa_2Cu_3O_{7-\delta}$ (REBCO) superconductors have the wide and potential applications in the high-tech fields, such as micro-magnet superconducting maglev train, superconducting motor and superconducting magnetic separation system. However, a large number of multi-domain samples are easy to produce in the preparation process, which leads the success rate to decrease significantly and the cost to increase considerably, which restricts its practical application process. Thus we develop a reliable method of recycling failed GdBCO sample by re-supplementing the liquid phase lost in the primary growth process and pretreating the failed sample as solid phase source billets. We recycle a series of GdBCO samples for different sizes by using this new technique successfully. The growth morphology, superconducting properties of the recycled GdBCO bulk superconductors are investigated in detail in this study. The results show that the key superconductivity properties have been significantly improved, which provide the scientific basis and new ideas for developing the low cost and high efficient yield of fabrication of the REBCO bulk superconductors.

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T-09

The effect of temperature on the infiltration of liquid phase and properties of GdBCO bulk superconductor by TSIG method

*T.-T. Wu, W.M. Yang**
College of Physics and Information Technology, Shaanxi Normal University, Xi'an 710062, China
*Presenting author (email: yangwm@snnu.edu.cn)

Abstract:
The optimization of heat treatment parameters for REBCO bulk superconductors by TSIG method is always a hot topic on the whole world. However, there is no systematic study on the temperature at which of liquid phase (LP) begins to infiltrate into the solid phase pellet (SPP), and how it infiltrates into SPP, and how the particles of SPP changed during the infiltration process. In this work, a set samples were fabricated with different infiltration temperatures (900℃-1060℃) by infiltration growth method. The macroscopic morphology of green Gd211 solid phase pellet (Gd-SPP) and the shrinkage of liquid phase pellet (LPP) with the same diameter were analyzed with different infiltration temperatures (T_i). The microstructure at the central region of the cross-section of Gd-SPP were observed. And the superconducting properties of single domain GdBCO bulk superconductors with different T_i fabricated by TSIG method were compared. The results show that (1) when T_i is 920℃, the LP begin to melt and infiltrate into the Gd-SPP from the central region on the contact surface. (2) The higher the infiltration temperature is, the more LPP infiltrated into Gd-SPP. (3) The LP has infiltrated into the whole Gd-SPP surface when T_i is 1020℃. (4) The Gd211 particle size of Gd-SPP increases with T_i ranging from 920℃ to 980℃, and the adjacent Gd211 particles gather together to form polymer groups. (5) A small quantity of LP is unevenly distributed in the central region of Gd-SPP cross-section when T_i is 980℃. (6) All GdBCO bulk superconductors with different T_i are of classical single-domain morphology, and the GdBCO superconducting bulk with 960℃ has the largest levitation force and trapping field. This study is helpful for us to fabricated the high quality REBCO bulk superconductors.

T-10

Effect of average grain radius on the levitation force and trapped magnetic flux of a single-domain GdBCO bulk

W. M. Yang, and X.X. Yan
Department of Physics, Shaanxi Normal University, Xi'an, Shaanxi, 710062, China
(email: yangwm@snnu.edu.cn)

Abstract:
Is the levitation force and trapped magnetic flux of fixed values for a given single-domain GdBCO bulk under fixed working condition ? it is yes generally. But we have found that it is much different if a very narrow slot was made inside the sample even the sample is still kept of single-domain GdBCO bulk. In this paper, a cylindrical single-domain GdBCO bulk have been prepared by the RE+011 TSIG process. The sample was cut along a diameter from the one side to the other for 4 mm by each times, the levitation force and trapped magnetic field have been measured before and after each cutting. Both of the levitation force and trapped magnetic field of the sample decreases monotonously with the increasing length of the cutting slot. it is found that the maximum levitation force, trapped field and trapped magnetic flux are obtained in the sample without any cutting slot, and are of 125.5 N, 0.82 T and 0.272 mWb respectively, which are about 1.64, 1.41, and 1.49 times higher than that of the sample bisected. The further theoretical analysis indicate that the levitation force and trapped magnetic flux of the single-domain GdBCO bulk is closely related with the average grain radius. Based on these results, the physical properties can be adjusted to meet our demand by introducing useful slots and without changing the shape of the samples.

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T-11

Translational levitation of a permanent magnet above the splicing plane of superconducting blocks and its motion damping and loss properties

Wenjiang Yang, Peng Zhao, Chaoxin Liu, Juntong Hu, Fuwen Deng and Haibin Tang*
1) School of Astronautics, Beihang University, 37 Xueyuan Road, Haidian District, Beijing, China
*Presenting author (email: yangwjbuaa@buaa.edu.cn)

Abstract:
Benefited from the combination of Messiner effect and flux pinning, a permanent magnet (PM) can give the self-stable levitation above a bulk superconductor. The phenomenon provides the basic principle of superconductors in wide applications such as HTS maglev trains and superconducting flywheel systems. When the superconductor works under some conditions without the flux pinning (for example zero-field cooling) , the PM will show free motion along multi freedoms due to the full diamagnetism of superconductor. This paper investigated the damping characteristics of the PM moved above the diamagnetic plane spliced by superconducting bulks. The spliced superconducting plane can get rid of the limitation of the size of the single superconducting bulk, and realize low-damping translational motion suspension in a large area. The article uses two methods to measure the in-plane force and loss of the PM translation when the superconducting plane works at different temperature. It is found that the in-plane force distribution in the PM translation shows with alternating peaks and valleys. The increase of the suspending air gap can reduce the in-plane force fluctuation and realize low-damping translation. The translational suspension force has the smaller value at the center of a single superconducting block, and can be measured at the level less than 1mN. The low damping characteristics bring the potential application of superconducting translational suspension in the low gravity ground simulation for attitude and orbit control experiments of satellites.

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T-12

Progress in the growth of high performance REBCO superconductor bulks in SJTU

*Xin Yao**
School of Physics and Astronomy, Shanghai Jiao Tong University, 200240 Shanghai, China
*Presenting author (email: xyao@sjtu.edu.cn)

Abstract:
Our recent progress in high superconducting properties of REBCO bulks grown by low cost processes (top-seeded melt-growth) is reviewed. First, time and cost saving precursor preparation for high trapped field RE123 bulks was realized by using modified precursor powders (MPP, RE_2O_3 and $Ba_xCu_yO_z$). Second, for recycling failed and hard-to-melt SmBCO bulk, a two-step process was applied, in which the sample was completely melted under a high temperature of 1175°C (nearly 100°C higher than its T_p), and then transformed into an easy-to-melt one by quenching. After that, the sample was re-grown into a single-grain bulk with high performance. Third, by enhancing cooling rate and Ba-rich precursor, we obtained NdBCO grains with high T_c of 95K in air. Considering the brittle nature of NdBCO materials, we used a gradual acceleration cooling mode to grow a NdBCO bulk (16 mm in dia.), which has a high trapped field of 0.6 T. Fourth combining superheating nature of REBCO thin film with doping effect, we report a novel film, Mg-doped NdBCO film/YBCO-buffer/MgO crystal, which as a seed endured a T_{max} of 1128 ºC and induced the growth of SmBCO bulks, the highest T_{max} of NdBCO seed materials used by cold-seeding.

T-13

Crack problem in High Temperature Bulk Superconductor under Pulse field Magnetization

H D. Yong[1,2,], H Chen[1,2], and Y H. Zhou[1,2]*
1) Key Laboratory of Mechanics on Disaster and Environment in Western China, Ministry of Education of China, Lanzhou University, Lanzhou, China
2) Institute of Superconducting Mechanics, Lanzhou University, Lanzhou, China
*Presenting author (email: yonghd@lzu.edu.cn)

Abstract:
The bulk superconductors have potential to trap larger magnetic fields. Due to the changes in temperature and oxygen content during the preparation process, cracks and holes are generated inside the bulk. In addition, the current density distribution is different within the growth boundary and the growth area of the bulk for top seeding technology. During the magnetization of the bulk, a larger magnetic field will cause the bulk to withstand an electromagnetic force, which may be larger than the mechanical strength. The pulse field magnetization has been used for the magnetization of superconducting bulk widely. However, because of the sharp increase in the magnetic field during the magnetization process, a large amount of heat is also generated inside the bulk. These heat will influence the current density and the trapped magnetic field in bulks. The bulk will suffer a combination of Lorentz force and the thermal stress during the pulse magnetization process. As a result, the stress will concentrate around the crack tip and even cause the crack propagation. We study the fracture behaviour of bulk superconductor with the internal crack under the Lorentz force and thermal stress generated by the non-uniform current density during the pulse field magnetization process. The Extend Finite Element Method with New Mark method is used to calculate the dynamic intensity factor (DSIF). The results show that the non-uniform current density has impact on the DSIF. With the time increase, the DSIF of non-uniform current density is larger than the uniform current density. The stainless steel sleeve can reduce the dynamic stress intensity factor effectively.

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T-14

The superconductivity properties of the multiseeded GdBCO bulks prepared with the introduced buffer with the modified TSMG

Y F Zhang [1,], Z W Lou[1], J Y Zhang[1], P H Zhang[1], C Y Li[1], Y Zhang[1], S Y Shen[1], J W Yuan[1], L Peng[1], J G Noudem[2], and M Izumi[3]*

[1] College of Mathematics and Physics, Shanghai University of Electric Power, 201306 Shanghai, China

[2] Laboratory of Applied Physics, Tokyo University of Marine Science and Technology, 135-8533 Tokyo, Japan

*Y F Zhang (email: 2009000018@shiep.edu.cn)

Abstract:

Multiseeding technique is a method to grow large-size REBCO high temperature superconducting bulk materials. However, due to the existence of grain boundaries between seed crystals, the superconductivity of the samples is not better than that of single grain samples. In order to improve the problems caused by grain boundaries and improve the superconducting properties of the samples, we introduced buffer layers of $GdBa_2Cu_3O_{7-\delta}$ and $0.4Gd_2BaCuO_5$ in the experiment. $YBa_2Cu_3O_{7-\delta}$ as the liquid source, two multiseeded $GdBa_2Cu_3O_{7-\delta}$ superconducting bulks with buffer layers were successfully prepared by improved top seed melt texture growth method (TSMG), the seed crystals arrangement of the two samples are 100 / 100 and 110 / 110, respectively. The microstructure and superconducting properties of the two samples were studied in detail, including the trapped field, critical temperature and critical current density. The results show that the trapped fields of the two samples show two peaks, and their maximum peaks are 0.35T and 0.36T, respectively. The use of buffer layers significantly reduce the grain boundary depth of the samples and play an obvious positive role in improving the superconducting properties. On the other hand, by analyzing the critical temperature and critical current density, we find that the superconductivity of the sample with 110 / 110 seed crystals arrangement is better than that of 100 / 100 sample.

Acknowledgement:

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T-15

Dynamical magnetic drag of high-Tc superconducting maglev vehicle

Y. Zhao[1,,2,3],[*]D. J. Zhou[1,2], F.N. Ca[3], J.J. Wei[3], W.J. Shi[1,2], C.H. Cheng[3], and Y. Zhang[3]
1) Fujian Provincial Collaborative Innovation Center for Advanced High-Field Superconducting Materials and Engineering, Fuzhou, 350117, China
2) College of Physics and Energy, Fujian Normal University, Fuzhou 350117, China
3) Key Laboratory of Maglev Train and Maglev Technology of Ministry of Education, School of Electric Engineering, and Superconductivity and New Energy R&D Center, Southwest Jiaotong University, Chengdu 610031, China
*Presenting author (email: zhaoyong@fjnu.edu.cn)

Abstract:
Running resistance is an important topic in the research of various maglev trains, and the magnetic drag due to magnetic interaction between levitation unit and the track is the focus in the studies of this topic. For traditional EMS and EDS maglev vehicles, the change behaviour of magnetic drag with running speed is relatively clear. However, for high-T_c superconducting (HTS) maglev trains, the change of the running drag with speed has not yet been unanimously recognized. In this paper, through the evacuated-tube maglev train platform, combined with the rotating track platform, the change of the running magnetic drag with the speed of the HTS maglev vehicle under different track smoothness and in the range of 0-250km/h is studied. It is observed that the amplitude of the transient drag force is much larger than the net effective drag force under various magnetic field fluctuations. A negative transient resistance was observed and its mechanism was studied.

Acknowledgement:
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T-16

A reconstructed three-dimensional HTS bulk electromagnetic model considering J_c spatial inhomogeneity and its implementation in a bulks combination system

Jun Zheng[*,1,2], *Yanxing Cheng*[1], *Huan Huang*[1], *Zigang Deng*[1]
1) State State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, People's Republic of China
2) Key Laboratory of Magnetic Suspension Technology and Maglev Vehicle, Ministry of Education, Chengdu 610031, People's Republic of China
*Jun ZHENG (email: jzheng@swjtu.edu.cn)

Abstract:
High-temperature superconducting (HTS) bulks in HTS Maglev systems are always arrayed in a combination to make full use of the applied magnetic field of the permanent magnet guideway (PMG). An excellent combination scheme improves the overall levitation and guidance performance significantly. In this paper, a three-dimensional (3D) electromagnetic model of the real HTS-PMG maglev system with an HTS bulk array was established. This model comprehensively expresses the influence of various factors on the *E-J* relationship and the 3D spatial distribution of J_c, including internal factors such as the inhomogeneity and anisotropy of electromagnetic characteristics, as well as external factors such as applied magnetic field and working temperature. A ternary function was proposed to describe the uneven distribution of J_c caused by the bulk's growth process, which is an interesting phenomenological modeling attempt. In the simulations of the bulks' combinations, perfect magnetic conductor (PMC) boundary conditions were applied on the contact surface to simulate two bulks touching each other. Besides, the research target includes reproducing the shapes, the orientations, and the combination scheme of HTS bulks in the real PMG magnetic field. The calculation results of levitation force of the cylindrical bulk under different spatial orientations above the PMG were compared with the experimental results, through which the accuracy of the model was verified. On this basis, the influence of the magnetic field generated by the superconducting current on the nearby bulk was further explored. It was found that this magnetic field has a small contribution to the total levitation force and a relatively obvious influence on the guidance force. When the lateral displacement is large, such as 5 mm, the magnetic field generated by the superconducting current slightly increases the total guidance force stiffness. According to more simulated conditions, some optimization strategies on bulk combinations were proposed. This work provides not only a 3D descriptive model for fitting the real multi-bulk-combination maglev scenarios but also some optimization strategies for the HTS maglev transportation applications.

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T-17

Study on a novel type of HTS maglev train integrated with floating and hanging

D. J. Zhou[1,2], L.M. Zhu[1,2], F.N. Cai[3], C.H. Cheng[3], Y. Zhao[1,2,3]*
1) Fujian Provincial Collaborative Innovation Center for Advanced High-Field Superconducting Materials and Engineering, Fuzhou, 350117, China
2) College of Physics and Energy, Fujian Normal University, Fuzhou 350117, China
3) Key Laboratory of Maglev Train and Maglev Technology of Ministry of Education, School of Electric Engineering, and Superconductivity and New Energy R&D Center, Southwest Jiaotong University, Chengdu 610031, China
*Presenting author (email: zdj007008009@163.com)

Abstract:
Compared with the traditional EMS and EDS maglev trains, the high-T_c superconducting (HTS) maglev trains have the advantages of self-stabilized suspension and guidance, simple structure, and environmental protection. However, the insufficiency of levitation force and levitation rigidity, and the high cost of permanent magnet guideway (PMG) hinder the realization of their practical applications. In this article we proposes a new type of HTS maglev vehicle configuration, which makes full use of the magnetic fields on both sides of the maglev rail, effectively reduces the cost of the magnetic rail under unit maglev force At the meantime, it combines the magnetic floating and the magnetic hanging into one, which is very significantly enhances load capacity and the guiding rigidity. For example, in the case of FCH = 20 mm (here FCH is the field cooling height), when the working height (WH) is 15 mm and 10 mm, the suspension force increases by 268% and 106%, respectively. In the case of WH = 10 mm and lateral displacement (LD) = ±20 mm, the guiding force increases by 182% and 201% at FCH of 20 mm and 25 mm, respectively.

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This work was supported in part by the Industrial Guidance (Key) Project of Fujian Science and Technology Department (Grant No. 2020H0013), Sichuan Applied Basic Research Project under Grant 2018JY0003, and the Open Project of the Key Laboratory of Maglev Train and Maglev Technology, Ministry of Education of China.

T-18

Enhancing the Superconducting Performance of $YBa_2Cu_3O_{7-\delta}$ Bulks with Nano-sized and Well Distributed Y_2BaCuO_5 Particles

Yanhan Zhu[1,], Yiqian Yin[1], Simin Huang[1], Difan Zhou[2], Veronika Kucharova[3], Katarina Zmorayova[3], Pavel Diko[3], and Xin Yao[1]*

1) Key Laboratory of Artificial Structures and Quantum Control (Ministry of Education), School of Physics and Astronomy, Shanghai Jiao Tong University, 200240 Shanghai, China

2) Shanghai Key Laboratory of High Temperature Superconductors, Department of Physics, Shanghai University, 200444 Shanghai, China

3) Department of Materials Physics, Institute of Experimental Physics, Slovak Academy of Science, 04001 Košice, Slovakia

*Presenting author (email: castiel1996@sjtu.edu.cn)

Abstract:

The refinement and uniformity of Y_2BaCuO_5 (Y211) are of vital importance in preparing large-sized $YBa_2Cu_3O_{7-\delta}$ (Y123) bulks with high field trapping ability by top-seeded melt-growth (TSMG). However, inherent enlargement and segregation of Y211 particles during the TSMG process have long puzzled researchers. Here, a novel method called L-MPP is reported, in which, instead of conventional precursor powder (CPP, Y123 plus Y211), modified precursor powder (MPP, Y_2O_3 plus $Ba_2Cu_3O_x$) is used to combine with a layered and compositional graded structure. Moreover, sizable Y123 bulks with a diameter of 25 mm were successfully prepared, rather than those of 16 mm reported in previous MPP work. The optical micrographs and quantitative analyses confirm that the Y211 particles in the L-MPP sample are visibly refined and better distributed simultaneously. As a result, the trapped fields of Y123 bulks significantly increase from 0.496 T of CPP to 1.01 T of L-MPP, and the levitation forces of them enhance nearly 50% from 46.2 N of CPP to 68.3 N of L-MPP. Most importantly, this method is widely applicable for preparing other REBCO (RE=rare earth) bulk superconductors.

Acknowledgement:

This work was supported by National Nature Science Foundation of China [grant number 51572171]; Chinese and Slovak Joint Research Project [grant number CN-SK-2017-0021, APVV SK-CN-2017-0009], the framework of the projects APVV-17-0625 and VEGA-2/0044/19.

T-19

High Critical Current Density Iron-pnictide Bulks by Data Driven Process combined with Advanced Electron Microscopy

A. Yamamoto[1,5], S. Tokuta[1,5], Y. Hasegawa[1], S. Kikuchi[1], A. Ishii[2,5] , A. Yamanaka[2,5], Y. Shimada[3,5], S. Hata[4,5]

1) Dept. of Applied Physics, Tokyo Univ. of Agricul. Technol., Koganei, Tokyo 184-8588, Japan
2) Dept. of Mechanical System Engineering, Tokyo Univ. of Agricul. Technol., Koganei, Tokyo 184-8588, Japan
3) Institute for Materials Research, Tohoku University, Sendai, Miyagi 980-8577, Japan
4) Dept. of Advanced Materials Science, Kyushu University, Kasuga, Fukuoka 816-8580, Japan
5) JST-CREST, Kawaguchi, Saitama 332-0012, Japan
*Presenting author (email: akiyasu@cc.tuat.ac.jp)

Abstract:
122 phase iron-based superconductors show high upper critical field (H_{c2} > 50 T) with small electromagnetic anisotropy (γ ~ 1-2)[1)] and large critical grain boundary angle (θ_c ~9°)[2)], and therefore is a promising material for applications in polycrystalline form. Foreseeing bulk magnet applications, Weiss et al. have reported demonstration of trapped field of 1 T for K-doped $BaFe_2As_2$ (Ba122) polycrystalline bulks synthesized by hot isostatic pressing[3)]. In this study, we synthesized K-doped Ba122 bulks in a highly pure Ar glove box from mechanically alloyed precursor powder which was prepared by high-energy ball-milling of elemental metals with the molar ratios of Ba:K:Fe:As = 0.6:0.4:2:2[4), 5)]. The mechanically alloyed precursor powder was then spark plasma sintered. Two approaches to optimizing the processing conditions were considered: optimization by researchers' experience and intuition, based on the knowledge of nanostructural analysis and multi-scale observations[6), 7)], and optimization by process machine learning[8)]. Bayesian optimization was applied to find the best input parameters that maximize the target output property, critical current density (J_c), on the experimentally available range of processing conditions. High J_c value exceeding 10^5 A/cm^2, which is among the highest in Ba122 bulk samples, was developed by both experiments guided by researchers and such an adaptive experimental optimization process.

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T-20

Measuring residual strains/stresses in MgB_2 bulk samples by means of EBSD

A. Koblischka-Veneva [1,2,*], *and M. R. Koblischka* [1,2]
1) Saarland University, Experimental Physics, P.O. Box 151150, 66041 Saarbrücken, Germany
2) Department of Materials Science and Engineering, Shibaura Institute of Technology, 3-7-5 Toyosu, Koto-ku, Tokyo 135-8548, Japan
*Presenting author (email: m.koblischka@gmail.com)

Abstract:
The analysis of residual strains/stresses within superconducting bulk samples is very important for the understanding of the resulting mechanical properties. As the MgB_2 bulk samples are intended for use as trapped field magnets, the sample will experience effects of magnetostriction, especially when charging the sample, e.g., using pulsed magnetic fields. Thus, the overall mechanical properties of the samples determine the fracture strength. On the other hand, the local residual strain/stress fields within the sample may provide a source of additional flux pinning, which will contribute to further increase the flux pinning properties and the critical current densities and to improve the reachable trapped fields.
Using the electron backscatter diffraction (EBSD) technique, we have shown recently that one can measure the residual strains/stresses down to the nanometer scale in various YBCO bulks. Thus, it is straightforward to apply the same analysis technique using the Kernel Average Misorientation (KAM) mappings also to MgB_2 bulk samples. In the present contribution, we show several such KAM mappings on various MgB_2 samples with and without embedded particles, and discuss the flux pinning effect of the strain/stress fields detected.

Acknowledgement:
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T-21

Unravelling Superconductive Properties Using Broad-range Spectroscopic Techniques

Chi Sin Tang[1,2]; Xinmao Yin[2]; Andrew T. S. Wee[3]
1. Institute of Materials Research and Engineering, A*STAR, Singapore
2. Shanghai Key Laboratory of High Temperature Superconductors, Physics Department, Shanghai University
3. Department of Physics, National University of Singapore, Singapore

Abstract:
With the discovery of copper oxide based (cuprate) high-temperature superconductors more than 30 years ago, extensive studies have taken place to unravel its physical properties and arising exotic phenomena. Nevertheless, the fundamental question on its superconductive mechanism persists despite tremendous research efforts both on the experimental and theoretical front. Besides, cuprates contniue to present diverse phenomena and novel challenges at the forefront of condensed matter research.

In this report, I will focus on the experimental studies of complex electronic and optical structures of cuprates. Based on an extensive set of experimental techniques including spectroscopic ellipsometry and several synchrotron-based spectroscopic techniques, we are able to unravel both the optoelectronic properties and the quasiparticle excitations of cuprate systems that span over a broad spectral range. These scientific investigations are crucial in unlocking new understanding in the intrinsic properties that govern unconventional superconductivity.

T-22

Advanced (RE)-Ba-Cu-O bulk superconductors with improved superconducting and mechanical properties

D. A. Cardwell1,, D. K. Namburi1, Y.-H. Shi1 and J. H. Durrell1*
1) Department of Engineering, University of Cambridge, Cambridge CB2 1PZ, United Kingdom

Abstract:

Extensive research has been carried out over the last three decades, in general, and over last 10 years, in particular, to produce single-grain, high-performance RE-Ba-Cu-O [(RE)BCO bulk superconductors, where RE is a rare earth element or yttrium, for a variety of high field engineering applications. This research has focused on three primary objectives: (i) the reliable fabrication of large, single-grain (RE)BCO bulk superconductors; (ii) enhancing flux pinning, and therefore the superconducting properties of individual single grains, and (iii) achieving large, trapped fields in (RE)BCO bulk samples by improving their mechanical properties via *in-situ* and or *ex-situ* reinforcement strategies.

This presentation will describe some of the developments in the processing and properties of high-performance (RE)BCO bulk superconductors by the Cambridge Bulk Superconductivity Group, and will focus specifically on: (i) seeded melt-growth and infiltration-growth processes, (ii) the development of a Mg-doped NdBCO generic seed crystal, (iii) the development of a RE-2411 nano-phase for achieving improved flux-pinning performance, (iv) the integration of a buffer technique into the single grain growth process, (v) the addition of Ag to (RE)BCO samples, (vi) reinforcing (RE)BCO with suitable hybrid fibres, (vii) pre-stressing bulk superconductors with shrink-fit stainless-steel rings, (ix) double-sample and composite-type configurations and, finally, (x) a bench-top, practical approach to pulsed-field magnetization (PFM).

Single-grain (RE)BCO bulk superconductors of diameter between 2 and 4 cm have been studied extensively from an applications perspective for field cooling (FC) and zero-field cooling (ZFC), including PFM. It has been found that the samples trap fields of up to 2.2 T at 77 K at the surface of the single grains, which increases to ~ 8 – 10 T at 30 K. Sample assemblies reinforced under different configurations have enabled trapped fields of more than 17.5 T to be achieved, which is the current world record. More recently, hybrid (RE)BCO bulk superconductors containing Ag, composite and fibre-reinforcements are being developed specifically for both conventional, static devices and more challenging engineering applications where the presence of large electromagnetic stresses has been of concern for the operation of these ceramic-like materials.

Acknowledgement:

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T-23

Trapped field in perforated superconductors

D.M. Gokhfeld[1,], A.N. Maksimova[2], V.A. Kashurnikov[2], and A.N. Moroz[2]*
1) Kirensky Institute of Physics, FRC KSC SB RAS, Krasnoyarsk, 660036 Russia
2) National Research Nuclear University MEPhI, Moscow, 115409 Russia
*Presenting author (email: gokhfeld@iph.krasn.ru)

Abstract:
The profiles of the trapped magnetic field in superconducting plates with arrays of holes are investigated. An interaction of vortices with holes and other pinning centers is simulated with using the continuous Monte Carlo method. Vortex capture and release on the hole boundaries are introduced in algorithm. Secondary peaks corresponding to the holes emerge on the calculated trapped magnetic field profiles. It has been found that these peaks are not observed in plates with sufficiently strong pinning or when a computational mesh is coarse (a low resolution of probes). A simple formula, which accounts the excess flux trapping in the holes and the perturbation of current paths by the perforations, is suggested to describe a dependence of the trapped magnetic flux on the hole radius. The trapped flux increases with an additional perforation until an optimal density of perforating holes is reached. A further increase of perforation leads to a decrease of the trapped flux. Peculiarities of the trapped field profiles, which are inherent for macroscopic superconductors with artificial holes and for porous superconductors, are reproduced by the Monte Carlo calculations completed for much smaller samples. Calculation results are possible to extrapolate for samples with sizes of a few millimeters. Optimization of the total trapped flux can be attained by tuning the sizes, numbers and positions of perforations in superconductors.

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T-24

Microstructural engineering of (RE)BCO bulks: Challenges and advancements

Devendra K. Namburi[1,2], Yunhua Shi[1], Mark D. Ainslie, David A. Cardwell[1] and John H. Durrell[1]*

1) Department of Engineering, University of Cambridge, Cambridge CB2 1PZ, UK
2) Electronic & Nanoscale Engineering, University of Glasgow, Glasgow G12 8QQ, UK
* Presenting author: Devendra K Namburi (E-mail: ndevendra@gmail.com)

Abstract:
The talk will cover three important topics: (i) the successful and reliable growth of single-grain RE-Ba-Cu-O [(RE)BCO] bulk superconductors; (ii) engineering the microstructure of the (RE)BCO single-grain samples via an infiltration growth approach, and; (iii) reinforcing (RE)BCO bulk superconductor with Ag particles and SiC-based hybrid fibres. Focus will be on the significant advancements in processing and properties made particularly over the last 7 – 8 years in terms of advancing the fabrication of single-grain (RE)BCO samples and improving the microstructure of the material to yields better superconducting and mechanical properties.
The talk will identify the primary reasons for the occurrence of unavoidable microstructural problems associated with conventional, top seeded melt growth processing and how some of these critical issues have been addressed via processing advancements. The influence of the processing parameters on the microstructures of these materials, and hence on their superconducting and mechanical properties, will be discussed and relevant examples presented. Finally, despite the numerous advancements made in this research domain, the mechanical properties of these technologically important materials remain weak, due partly to their intrinsic ceramic-like nature. To address this processing challenge, Ag and SiC-based hybrid fibres have recently been introduced to bulk GdBCO single grains and the entire sample shrink-fitted with stainless-steel rings. This approach could possibly be a solution to the long-standing problem of manufacturing bulk (RE)BCO samples that can resist the huge electromagnetic stresses associated with high field applications.

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T-25

Systematic research on the impact of carbon nanotubes as artificial pinning centers on the properties of REBCO superconducting bulk

Essia Hannachi [1,] and Yassine Slimani [2]*

1) Department of Nuclear Medicine Research, Institute for Research and Medical Consultations (IRMC), Imam Abdulrahman Bin Faisal University, P.O. Box 1982, Dammam, 31441, Saudi Arabia

2) Department of Biophysics, Institute for Research and Medical Consultations (IRMC), Imam Abdulrahman Bin Faisal University, P.O. Box 1982, Dammam, 31441, Saudi Arabia

*Presenting author (email: hannechi.essia@gmail.com)

Abstract:

Electronic systems permeate all aspects of modern life including transportation, medicine, energy computing and communications. Optimizing functionality, performance and reliability in lowering costs are the driving forces in the search for electronic systems. In recent years, interest in investigating high-temperature superconducting composites (HTS) is increasing due to the fact that lots of them have found applications in microelectronics, medicine and the development of efficient systems used for energy production, accumulation, and transmission. REBCO is among the most important HTS materials owing to its transition temperature T_c~94K that exceeding the liquid nitrogen temperature (77K). Yet, there are some problems that stand against its applications. REBCO phase consist of a set of grains that are weakly coupled to each other. Theses weak-links contribute to the degradation of its critical current density under magnetic field. To overcome this problem, the addition of the artificial pinning center (APCs) can be an effective method to enhance the performance of REBCO. Four different types of APCs including 0D, 1D, 2D, and3D are existing. Particularly, the 1D APCs are used in low-field and high-temperature scenarios, like current limiters, cables, and transformers. CNTs have good mechanical strength, permanent stability at high temperatures, and they are suitable for reinforcing the brittle materials. These unique characteristics render them a significant candidate for practical applications of superconductors.

We propose in this work, to study the effect of CNTs inclusion on the superconducting and pinning properties of REBCO. The intra-granular as well as the inter-granular critical current densities were assessed and discussed.

T-26

New technologies of bulk HTS application

F. N. Werfel, U. Floegel - Delor, T. Riedel, P. Schirrmeister, R. Koenig, V. Kantarbar, M. Liebmann, and O. Vakaliuk
Adelwitz Technologiezentrum GmbH (ATZ), Torgau, Germany,

Abstract:
We favor HTS bulk development, which is significantly application-driven, and close to the final geometrical design. Trapped magnetic fields up to 16.85 T at 30 K and 9.5 T at 50 K in commercial YBCO bulk HTSs in double-sample stack is observed. A maximum trapped field of 9.78 T was attained in a 6 mm hollow space of the ring-shaped bulk HTS. These values are pre-requisites for magnetic applications. However, technical solutions are based on lower magnetic fields but require excellent cryostats. We describe new technologies for portable lightweight vacuum cryostats. Most solutions deviate from traditional practice in housing and cryogenics. We discuss Maglev projects, which are divided roughly in three factors. The first two are being a full concept and a corresponding design, while the third factor is being assembly, test phase and optimization. In Maglev transportation, we contribute to concepts with increased load and speed of magnetic trains levitated on a PM guideway. An assembly of portable LN_2 cooled cryostats on a magnetic track levitates and moves a load of 12 tons. On contrary, a high-speed vehicle suspended on four small-sized cryostats in an evacuated tube, attained a speed above 300 km/h. The overall design of new high-speed cryostats is kept robust and small. A linear motor accelerated the vehicle with 16 g in one second. Correspondingly, all technical, cryogenic and mechanical components have to withstand these high acceleration and force values. We discuss the cryostat design philosophy and the technical limits of the Hyperloop concept.

T-27

Microstructure and Superconducting Properties of GdBCO-Ag Single Grain Bulk with CeO_2 Addition

P. Hajdova[1,], P. Diko[1], M. Rajnak[1,2], J. Bednarcik[1,3], V. Antal[1], V. Kucharova[1], K. Zmorayova[1] and M. Radusovska[1]*

1) Institute of Experimental Physics, Slovak Academy of Sciences, Watsonova 47, 040 01 Kosice, Slovakia

2) Faculty of Electrical Engineering and Informatics, Technical University of Kosice, Letna 9, 042 00 Kosice, Slovakia

3) P. J. Safarik University in Kosice, Faculty of Science, Institute of Physics, Park Angelinum 9, 041 54 Kosice, Slovakia

*Presenting author (email: hajdova@saske.sk)

Abstract:

It is shown that the amount of CeO_2 added to the bulk single-grain GdBCO superconductors (nominal composition 1 mol $GdBa_2Cu_3O_{7-\delta}$ + ½ mol Gd_2BaCuO_5 + 20 wt% Ag_2O + Z wt% CeO_2 (Z = 0.4, 1.0, 1.6) grown using the top-seeded melt-grow process have a significant effect on thermal behaviour, phase composition, microstructure and local superconducting properties. The observed behaviour is explained by the dissolution of Ce in the melt L' formed by monotectic melting of the samples. Ce dissolved in melt L' reduces the substitution of Ba by Gd in the Gd123 crystal lattice. This effect causes an increase in the superconducting transition temperature T_c with added CeO_2, an increase in T_c with distance from the seed and influences the critical current density by chemical pinning. The obtained results open a new effective way to improve the superconducting properties of LREBCO bulk single-grain superconductors grown in air.

Prepared samples were studied by differential thermal analysis, X-ray diffraction, scanning electron microscopy and magnetic measurement of local superconducting properties.

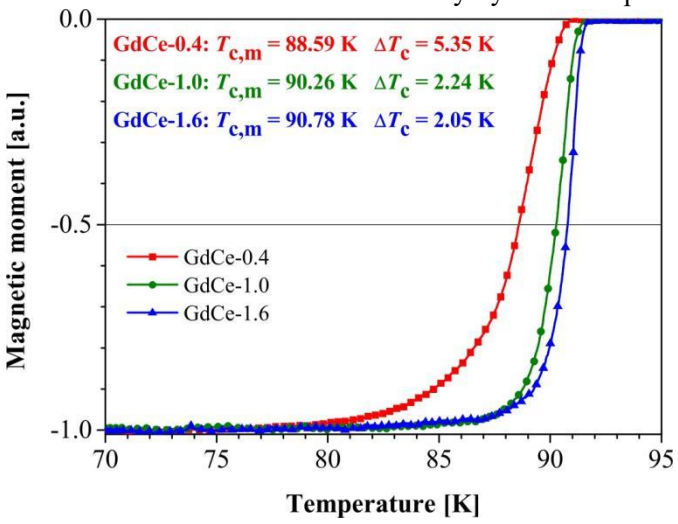

Fig. 1. Superconducting transition temperature curves for the specimens taken from the top surface of the samples with different addition of CeO_2.

Acknowledgement:

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T-28

Experimental validation of a Hybrid Trapped Field Magnet Lens (HTFML) using all-REBaCuO bulks

H. Fujishiro[1,], K. Takahashi[2], S. Namba[1], and M.D. Ainslie[3]*
1) Faculty of Science and Engineering, Iwate University, Morioka, Japan
2) Faculty of Science, Gakushuin University, Tokyo, Japan
3) Bulk Superconductivity Group, University of Cambridge, Cambridge, United Kingdom
*Presenting author (email: fujishiro@iwate-u.ac.jp)

Abstract:
The concept of a Hybrid Trapped Field Magnet Lens (HTFML) is described, which exploits two different characteristics of superconductors: the "vortex pinning effect" of an outer superconducting bulk cylinder, which acts as a trapped field magnet (TFM) using field-cooled magnetization (FCM), combined with the "diamagnetic shielding effect" of an inner bulk magnetic lens using zero-field-cooled magnetization (ZFC). The HTFML can reliably generate a concentrated magnetic field in the centre of the lens that is higher than the trapped field from the cylindrical bulk TFM and the external magnetizing field, even after the externally applied field decreases to zero. We predicted numerically a concentrated field of B_z = 13.5 T under an external magnetizing field of B_{app} = 10 T using an all-GdBaCuO cylinder and lens design based on independent temperature control. The HTFML device also shows an ultra-high magnetic field gradient product, $B_z \cdot dB_z/dz$, over ±3000 T^2/m, which is higher than that of existing superconducting magnets and applicable for quasi-microgravity experiments. In this presentation, we report the experimental verification of the HTFML for two cases. First, a maximum concentrated magnetic field of B_z = 3.55 T was achieved at the central bore of the HTFML after removing an applied field of B_{app} = 2.0 T at T = 20 K using a GdBaCuO magnetic lens and MgB_2 TFM cylinder. An all-(RE)BaCuO based HTFML could achieve a maximum B_z value of 9.8 T with B_{app} = 7 T at T = 40 K. The HTFML could prove useful to achieve higher magnetic fields and higher magnetic field gradient products for practical bulk superconductor applications.

Acknowledgement:
This research is partially supported from the Japan Society for the Promotion of Science (JSPS) KAKENHI Grant No. 15K04646, and from Adaptable and Seamless Technology transfer Program through Target-driven R&D (A-STEP) from Japan Science and Technology Agency (JST) Grant No. VP30218088419. Mark Ainslie would like to acknowledge financial support from an Engineering and Physical Sciences Research Council (EPSRC) Early Career Fellowship EP/P020313/1.

T-29

A reliable technique to fabricate superconducting joints between single grain, Y–Ba–Cu–O bulk superconductors

J V J Congreve[1], A R Dennis[1], Y Shi[1], C W Bumby[2], H Druiff[1], D A Cardwell[1] and J H Durrell[1,]*

1) Department of Engineering, University of Cambridge, Cambridge, United Kingdom
2) Robinson Research Institute, Faculty of Engineering, Victoria University of Wellington, Wellington, New Zealand
*Presenting author (email: jhd25@cam.ac.uk)

Abstract:
The production of large (RE)Ba–Cu–O single grains is limited by the intrinsic slowness of the grain growth process. An alternative to this slow and inflexible growth process would be to join many small single grains to form one large composite grain. Achieving this requires the development of the ability to make high-performance superconducting joints between bulks. We report on the use of single grain YBCO–Ag as an interface medium to achieve superconducting joints between (RE)BCO bulks. This joining technique is relatively quick and does not require tight process parameter control. We report on six joints produced from samples cut and joined in a variety of orientations. In addition, a joint was produced using bulk YBCO from two independent single grains. We show that this simple but effective joining technique makes it possible to produce composite grains with comparable superconducting properties to those of a single grain of the same size.

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T-30

Development of EuBCO/Ag bulks for commercial applications

J. Plechacek[1,], T. Hlasek[1], V. Plechacek[1], M. Lojka,[1,] F. Antoncik[1]*
1) CAN SUPERCONDUCTORS
*Presenting author (email: jan.plechacek@can-superconductors.com)

Abstract:
CAN SUPERCONDUCTORS has been supplying its REBCO bulks to market for 25 years. Until recently only YBCO melt-textured bulks were commercially offered, namely due their favorable price/performance ratio, especially for applications using the effect of levitation – in their interaction with permanent magnets. Recent R&D trends in bulk community showed a new bulks potential use in applications such as MRI, NMR, etc. where the main parameters are homogeneity of trapped magnetic field and its highest possible value. Aware of the limitations of YBCO in the above respect, CAN included first GdBCO/AG bulks among its product range two years ago and at the same time started working on development of Eu based bulks. The presentation introduces our latest achievements in this area. We show our path to reaching higher diameters of EuBCO/Ag bulks providing highest trapped magnetic field values as well as current limitations of their batch production.

Acknowledgement:
We would like to thank the team of BSC group in Cambridge (J. Durrell and his team) for their kind cooperation on characterization of our new materials.

T-31

Trapped field performance of single grain EuBCO bulk superconductors with and without artificial holes

J. Baumann[1], T. Hlásek[2], A. R. Dennis[1], Y. Shi[1], J. Plecháček[2], J. H. Durrell[1], D. A. Cardwell[1]
1) Department of Engineering, University of Cambridge, Cambridge, UK
2) CAN SUPERCONDUCTORS, Kamenice, Czech Republic
*Presenting author: Josef Baumann (email: jb2316@cam.ac.uk)

Abstract:
It has been shown that YBCO single grain bulk superconductors containing artificial holes exhibit superior mechanical and flux trapping properties to conventional YBCO discs fabricated by top-seeded melt growth (TSMG). These so-called thin-wall samples have an increased tensile strength compared to standard YBCO samples due to their intrinsically lower porosity, which results directly from the holes' presence. The tensile strength of these materials can be further improved by filling the artificial holes with stabilising materials such as steel, copper, or epoxy resin. Furthermore, YBCO single grain bulk superconductors containing holes can survive higher applied external fields at lower temperatures and trap higher magnetic fields than conventional samples.[1] EuBCO has a higher T_c and J_c than YBCO, which makes it particularly attractive for practical applications. Additionally, the trapped field of EuBCO is potentially more uniform spatially and typically more stable over a more extended period of time. This study reports the mechanical and flux trapping properties of single grain EuBCO bulk superconductors melt-processed with artificial holes and compares these with conventional EuBCO single grain samples.

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Acknowledgement:
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T-32

Improved Connectivity of MgB_2 Bulk Superconductor via In-situ-Ex-situ Co-Synthesis

J. Longji Dadiel1 , Jun Sugiyama1 , Naomichi Sakai1, Kento Takemura1 , Tetsuo Oka1, MiryalaMuralidhar and Masato Murakami1*
1Superconducting Material Laboratory, Graduate School of Science and Engineering, Shibaura Institute of Technology, 3-7-5 Toyosu, Koto-ku, Tokyo 135-8548, Japan
2Department of Physics, Tokyo University of Science, 1 Chome-3 Kagurazaka, Shinjuku City, Tokyo 162-8601, Japan
*Presenting author (email: na19102@shibaura-it.ac.jp)

Abstract:
Our recent research efforts on the improvement of connectivity and microstructural control of bulk MgB_2 via admixed *in-situ* and *ex-situ* synthesis and their effects on flux pinning behavior are summarized and analyzed. Different weight percentages with the ratio of *x* wt.% ex-situ powder were added to 1.0*g in-situ* powder via solid state synthesis process where x = 0, 15, 20, 25, 30, respectively. X-ray diffraction results confirmed MgB_2 as the major phase for all the samples. Magnetization measurement showed a slight decrease of critical temperature, T_c from 38.5 K to 37.8 K with the co-addition of *ex-situ* powder. Self-field critical current density, J_c at 20 K increased with the increasing of co-addition levels probably due to improved grain coupling. The highest self-field J_c obtained is 435 kA cm^{-2} with 15 wt.% co-addition level. Field dependent J_c at 20 K of the co-added samples is higher compared to that of the pure one. The present results show that a small amount of co-added *ex-situ* powder into MgB_2 is effective to enhance flux pinning and J_c. Consequently, the connectivity of the sintered bulk samples was observed by scanning electron microscopy. Our results show that ex-situ-in-situ co-synthesis develops the superior connectivity potential of MgB_2 bulk superconductor.

T-33

A new synthesis method for high quality RE123 bulks, SDMG

J. Shimoyama[1,], R. Sasada[1], T. Tomihisa[1] and T. Motoki[1]*
1) Aoyama Gakuin University, Sagamihara, Kanagawa, Japan
*J. Shimoyama (email: shimo@phys.aoyama.ac.jp)

Abstract:
RE123 melt-solidified bulks materials have been synthesized mainly by the top seeded melt growth (TSMG) method thus far. The bulks grown by this method are composed of *a*- and *c*-growth regions, resulting in different flux pinning properties due to different microstructure and crystallinity. In addition, crystal growth for a very long time is needed to obtain large bulks. Recently, we found that RE123 melt-solidified bulks can be grown on the already grown large RE'123 bulk plate having higher peritectic temperature than RE123. For example, Y123 melt-solidified bulks can be grown on a large Gd123 melt-solidified bulk plate[1]. This fail-proof method named as "Single Direction Melt Growth (SDMG) method" has several advantageous points compared to TSMG method, such as uniform growth direction simply determined by the crystal orientation of the bulk plate, short crystal growth time independent of bulk size, applicable for bulks having various shapes and recyclable bulk plates used as the seed crystal. We have confirmed that superconducting properties including field trapping characteristics are enough high even compared with those of bulks prepared by TSMG method. Furthermore, bulks with a large single domain were successfully grown on multiple crystal plates having the same crystal orientations. These results indicate that a new SDMG method is quite promising for the development of high performance RE123 bulk materials with shorter synthesis time and lower production cost.
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T-34

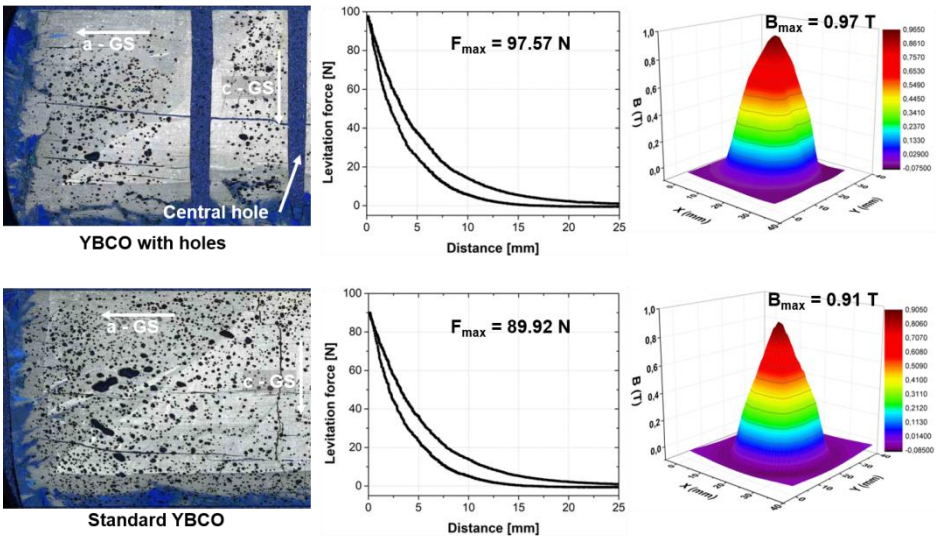
Influence of artificial holes on microstructural and superconducting properties of YBCO single-grain bulks

K. Zmorayova[1,], P. Diko[1], D. Volochova[1], V. Antal[1], T.Hlasek[2,3], V.Plechacek[2] and F. Antoncik[2,3]*
1) Institute of Experimental Physics, SAS, Watsonova 47, 04001 Kosice, Slovakia
2) CAN Superconductors s.r.o., Ringhofferova 66, 251 68, Kamenice, Czech Republic
3) Department of Inorganic Chemistry, UCT, Technická 5, 166 28 Prague 6, Czech Republic
*Presenting author (email: zmoray@saske.sk)

Abstract:

Investigation of microstructural and superconducting properties of standard single-grain YBCO bulk superconductor and the sample fabricated with artificial holes are presented in the current work. Macroscopic superconducting properties such as the levitation force and the trapped magnetic field at 77 K were supplemented by measurements of the transition temperature and the critical current density.

The levitation force and the trapped magnetic field were only slightly higher for the sample with holes. Detailed microstructural studies using polarized light optical microscopy and scanning electron microscopy have shown that artificial holes slightly reduce the absolute porosity of the sample with holes. For the measured trapped field, the decrease in the porosity of the a-growth sectors, which have a higher volume fraction of Y211 particles, and consequently a stronger pinning, is more significant. Also, the observed changes in the morphology of the oxygenation cracks can positively contribute to the increase of the macroscopic superconducting properties of the sample with holes.



Microstructure, levitation force and trapped field for YBCO with holes and in a standard sample.

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T-35

Numerical evaluation of magnetizing characteristics of REBCO bulk magnet excited by pulsed-field magnetization with various soft-iron yokes

K. Yokoyama[1,] and T. Oka[2]*
1) Ashikaga University, 286-1 Omae-cho, Ashikaga, Tochigi, Japan
2) Shibaura Institute of Technology 3-7-5 Toyosu, Koto-Ward, Tokyo, Japan
*Presenting author (email: yokoyama.kazuya@g.ashikaga.ac.jp)

Abstract:
We try to generate a strong magnetic field by exciting a REBCO bulk with pulsed-field magnetization (PFM). By using a soft-iron yoke, a trapped magnetic field can be increased due to exposing a large amount of magnetic flux to the bulk for a long time. However, the total weight of the system increases, resulting in a reduction of power density, which is an important parameter for an application such as a rotating electric machine. We study the influence of the soft-iron yoke on magnetizing performance by performing PFM experiments using pure-iron yokes with different shapes and diameters. The influence of yoke thickness was investigated experimentally. The thicker the yoke, the lager the amplitude of applied flux density becomes; furthermore, a magnetic field can be exposed for a longer time because the pulsed field decreases slowly after reaching a peak. This paper estimates the magnetizing characteristics when a 60-mm-diameter bulk is magnetized by PFM using the different shapes and diameters numerically, and compares the analysis results with experimental results.

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T-36

Validation of a quasi-microgravity space exploiting a high-gradient trapped field magnet (HG-TFM) as a desktop-type magnetic field source

K. Takahashi[1], H. Fujishiro[2], and M.D. Ainslie[3]*
1) Faculty of Science, Gakushuin University, Tokyo, Japan
2) Faculty of Science and Engineering, Iwate University, Morioka, Japan
3) Bulk Superconductivity Group, University of Cambridge, Cambridge, United Kingdom
*Presenting author (email: keita.takahashi@gakushuin.ac.jp)

Abstract:
A strong magnetic field exploiting superconducting technologies is a powerful tool to provide a quasi-microgravity space that can be used for magnetic levitation for any diamagnetic materials such as water, common metals and even cells of the human body. Large-single grain bulk superconductors have shown promising potential to be lightweight, mobile, and cost-effective as so-called trapped field magnets (TFMs). Recently, the authors presented the concept of hybrid-type bulk magnets: a high-gradient trapped field magnet (HG-TFM), in which conventional TFM cylinders are tightly stacked with "slit ring bulks" that act to modify the magnetic field distribution and its gradient. We firstly demonstrated, numerically, that the HG-TFM, which is magnetized by field-cooled magnetization (FCM) with an applied field of 10 T at 40 K, can generate a maximum magnetic field gradient, $B_z \cdot dB_z/dz$, of up to ~-6000 T^2/m at the intermediate position between each bulk. This $B_z \cdot dB_z/dz$ value is two times higher than that of other large-scale hybrid superconducting coil magnets that generate 30 T. Based on these numerical assumptions, we successfully demonstrated and validated magnetic levitation of pure water and bismuth particles inside a room-temperature bore of 25 mm dia. in the HG-TFM, with which a $B_z \cdot dB_z/dz$ of -1930 T^2/m and a trapped field, B_z, of 8.57 T were achieved by FCM with 8.60 T at 22 K. These results provide a key step forward towards the development of a practical hybrid-type TFM for magnetic levitation.

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T-37

Magnetic field mitigation by MgB2 and hybrid passive shields

L.Gozzelino[1,2,], M. Fracasso[1,2], R. Gerbaldo[1,2], G. Ghigo[1,2], F. Laviano[1,2], A. Napolitano[1,2], D. Torsello[1,2], M. A. Grigoroscuta[3], M. Burdusel[3], G. V. Aldica[3], P. Badica[3], M. Solovyov[4], F. Gömöry[4]*

1) Department of Applied Science and Technology, Politecnico di Torino, Torino, Italy
2) Istituto Nazionale di Fisica Nucleare, Sezione di Torino, Torino, Italy
3) National Institute of Materials Physics, Magurele, Romania
4) Institute of Electrical Engineering, Slovak Academy of Sciences, Bratislava, Slovakia
*Presenting author (email: laura.gozzelino@polito.it)

Abstract:
Superconductors provide a valuable solution for manufacturing low frequency magnetic shields able to guarantee very-low field background or a strong magnetic mitigation over a short distance cutting down electromagnetic compatibility problems. To meet the practical requirement of space-saving shielding solutions, in this work we investigated the shielding ability of MgB_2 bulks shaped as hollow-cylinder with a capped end (henceforth called cups) with an aspect-ratio of height to diameter approaching one. These shields were manufactured by Spark Plasma Sintering of MgB_2 powders added with hexagonal boron nitride powders, an approach allowing the fabrication of bulks machinable with cutting tools.
The experimental measurements of the shielding factors (SFs) carried out in the axial-field orientation evidenced a remarkable screening ability with SFs exceeding 10^4 and 10^2 near the closed extremity and in the inner half of the cup, respectively, up to a field threshold of 1.8T at the temperature T = 20K. Conversely, the shield shape curbs the SF values in the transverse-field orientation, where SFs not exceeding 50 were measured. To overcome this limitation, the effects of the superimposition of a cup-shaped ferromagnetic shell on the MgB_2 shield were investigated by a 3D numerical procedure based on the vector-potential formulation. This analysis highlighted that the ferromagnetic shell addition is very efficient in improving the SFs of the superconducting shield when the applied field is tilted with respect to the shield axis and that this effect is maximized if a vertical mismatch of the open end of the two cups is considered.

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T-38

Superconducting using bulk HTS for Aircraft propulsion

*R. Dorget[1,2], S. Ayat[1], R. Biaujaud[1] T. Lubin[2], *J. Lévêque[2]*
1) Safran Tech, Electrical & Electronic Systems Research group, Rue des Jeunes Bois, Châteaufort, 78114 Magny-Les-Hameaux, France
2) Université de Lorraine, GREEN, F-54506 Vandoeuvre, France
*Presenting author (email: jean.leveque@univ-lorraine.fr)

Abstract:
The electrification of aircraft propulsion requires electrical machines (motors and generators) with a high specific power while maintaining a high efficiency. The power density of conventional machines is limited by the saturation and the weight of the ferromagnetic circuit. Superconductivity in electrical machines allows to have similar or even higher magnetic field levels than conventional machines while partially or completely eliminating ferromagnetic materials, thus allowing an important weight reduction. In this context, the flux modulation machine is an interesting topology to exploit the properties of superconducting wafers and wires to create a machine with high specific power. This topology, in its axial flux form, is composed of a static superconducting coil supplied with direct current, a rotor composed of superconducting wafers and a conventional ironless armature on both sides of the rotor. Under the effect of the magnetic field of the coil, the superconducting pads deflect the magnetic field which creates a spatial variation of the magnetic field in the air gap which is used by the armature to generate the torque. This topology has the advantage of not requiring any rotating collector system since the coil is static. We present experimental tests of these YBCO superconducting plate at several temperature and tests results of this kind of superconducting motor.

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T-39

Portable, desktop high-field magnet systems using bulk high-temperature superconductors

M. D. Ainslie[1,], Y. Tsui[1], D. A. Moseley[2], A. R. Dennis[1], Y-H. Shi[1], M. R. Beck[1], V. Cientanni[1], D. A. Cardwell[1], J. H. Durrell[1]*
1) Department of Engineering, University of Cambridge, United Kingdom
2) Robinson Research Institute, Victoria University of Wellington, New Zealand
*Presenting author (email: mark.ainslie@eng.cam.ac.uk)

Abstract:
Magnetised bulk superconductors can be used as super-strength, stable permanent magnet analogues capable of providing magnetic fields of several tesla in a compact and portable magnet system. In addition to a large magnetic field, B, the magnetic field gradients (dB/dz, dB/dr) are naturally large. This makes them attractive for a number of engineering applications that rely on high magnetic fields and/or field gradients, including desktop nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI), magnetic separation and magnetic drug delivery systems.

In this presentation, we report our recent developments in the Bulk Superconductivity Group, University of Cambridge, in portable, desktop high-field magnet systems using bulk high-temperature superconductors, including:

- Cryogenic system design that emphasises flexibility and portability, with operating temperatures down to sub-50 K;
- A compact pulsed field magnetisation (PFM) system that includes pulse waveform control to modify the shape of the applied field waveform and solenoid- and split-type magnetising coil configurations.

We report a detailed summary of our recent experimental results, including comparisons of solenoid- and split-coil PFM and single- and multi-pulse (including multi-temperature) PFM, for a range of (RE)BCO bulk superconductor samples (Y, Gd and Eu) fabricated in-house and by commercial suppliers. In particular, we describe the reliable trapping of magnetic fields of ~3 T in disc-shaped bulks and record-high trapped fields in ring-shaped bulks greater than 1 T using multi-pulse, multi-temperature PFM.

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T-40

Limitations for possible trapped fields in RE-123 bulks

M. R. Koblischka[1,2,], and A. Koblischka-Veneva[1,2]*
1) Saarland University, Experimental Physics, P.O. Box 151150, 66041 Saarbrücken, Germany
2) Department of Materials Science and Engineering, Shibaura Institute of Technology, 3-7-5 Toyosu, Koto-ku, Tokyo 135-8548, Japan
*Presenting author (email: m.koblischka@gmail.com)

Abstract:
Although a lot of research efforts were spent to develop large-sized, superconducting bulks of the *RE*-123 type (*RE* denoting rare earth materials), the reachable trapped fields (TF) are limited to the range of 0.4 to 1 T at 77 K. Thus, stacks of coated conductors, having higher critical currents, begin to challenge the bulk samples for several applications. Here, we discuss the present situation of bulk sample processing and the prevailing limits of the bulk samples concerning the attainable flux pinning and the critical current densities, which are still manifold: (1) the pinning forces and the critical currents are still much lower than the depairing current density, but also lower than in coated conductors or thin films, (2) there are structural problems due to the splitting of the bulk sample in various growth sectors altering the current flow and crossing of grain boundaries, (3) the size and the spatial distribution of the 211 particles within the final bulk sample providing the flux pinning, (4) issues of other possible pinning mechanisms due to stresses/strains within the superconducting matrix and (5) issues concerning the magnetization and measurements of trapped fields. Some of the points mentioned were recently addressed by several authors, but it is essential to combine all the possible improvements into one sample to further push up the superconducting performance of the bulk samples.

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T-41

Dynamics of Magnetic Flux Penetration into Ring-Shaped Bulk High Temperature Superconductors

M.R. Beck1, , Y. Tsui1, D.A. Moseley2 , A.R. Dennis1 , Y-H. Shi1 , D.A. Cardwell1 , J.H. Durrell1 , M.D.Ainslie1*

1) Cambridge University Engineering Department, Trumpington Street, Cambridge, CB2 1PZ,United Kingdom

2) Robinson Research Institute, Victoria University of Wellington, Gracefield, Lower Hutt5010, New Zealand

*Presenting author (email: mrb70@cam.ac.uk)

Abstract:

Stacks of ring-shaped bulk high temperature superconductors (HTS) are ideal candidates for the generation of uniform magnetic fields for use in benchtop nuclear magnetic resonance (NMR) devices. However, for wide-spread commercial deployment, these stacks will need to be magnetized using a low-cost, portable magnetization technique such as pulsed field magnetization (PFM).

Whilst PFM has been shown to successfully magnetize disk-shaped bulk HTS, where trapped fields of around 5 T have been demonstrated, it is prone to inducing thermomagnetic instabilities in ring-shaped samples [1]. In finite ring-shaped samples, and in contrast to disc-shaped samples, magnetic flux propagates into the material from both the inner and outer edges of the sample. This induces a negative field at the inner edge of the ring which, if rapidly reversed during the application of a large magnetic pulse, results in significant heating that can induce a thermomagnetic instability

In this work, we build on Brandt's [2] analytical work for thin rings under zero field cooled magnetization using the finite element method for practical geometries and material properties. Following this, the model is expanded to account for realistic assumptions about the superconductor and system parameters under PFM, including thermal properties. Finally, we report the results of the experimental work performed to validate the models and discuss the implications of this on the PFM of ring-shaped samples.

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T-42

HTS Bulk and Applications in Rotating Machines

Mitsuru Izumi1,2
1) Toba College, National Institute of Technology (NIT), Mie 517-8501 JAPAN
2) Office of Liaison and Cooperative Research (OLCR), TUMSAT, Tokyo 108-8477 JAPAN
*Mitsuru Izumi (email: izumi-m@toba-cmt.ac.jp)

Abstract:
Energy and environment have been extremely highlighted under SDGs, and we are obliged to challenge to keep a sustainable development of a world community and a social system against Climate Change. Rotating machinery provide motors or generators in energy bases, industry, transportation and logistics. Growing population and economy indicate to eliminate dependence on fossil fuels. TUMSAT team has conducted an intensive study of R&D for superconducting rotating machinery under industry-academia collaborations. In the course of work, the team has participated in the joint study of the ship propulsion motor with 1G HTS wire. Subsequently, we have conducted a study for the proof of concept of the rotating machine with field poles composed of Gd-123 HTS bulks. In this study, both design and construction were carried out in TUMSAT. The machines have been studied for durability and long-time survivability.
We show a brief review of the publicized study of us on the HTS rotating machinery and try to concrete a potential application of HTS bulk rotating machinery to energy conversion of renewable energy such as marine and tidal currents. The concept may open the contribution to local power source supply in the coast and islands with reducing damage to the environment.

Acknowledgement:
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T-43

Importance of Superconducting Materials in the Endeavour to Stop Climate Changes

M. Miryala[*1], *S. S. Arvapalli*[1], *M. Jirsa*[2], *T. Naito*[3], *N. Sakai*[1], *M. Murakami*[1], *J. Noudem*[4]
[1]Shibaura Institute of Technology, 3-7-5 Toyosu, Koto-Ku, Tokyo 135-8546, Japan
[2]Institute of Physics ASCR, Na Slovance2, Praha8 CZ-18221, CZ
[3]Faculty of Science and Engineering, Iwate University, Morioka, 4-3-5, Ueda, Japan
[4]CRISMAT-CNRS, ENSICAEN, Normandy University, Caen, France

Abstract:
The further economic development, global peace, and future improvement of global community require the production of new materials capable to improve the quality of life. The global warming already increased to 1°C and is expected to rise by 1.5 °C to 2040. Current task is to avoid further rise of global average temperature and develop new technologies to restrict further CO_2 emission to the atmosphere. Anyhow, improvements to existing energy technologies have not been enough to reverse the climate change. A new class of cheap advanced materials is highly desirable. Superconducting materials, crucial for development of new superconducting, environmentally friendly technologies, convene to all above demands. Among the existing superconducting systems, MgB_2 superconductors are very interesting as they are easily and simply fabricated, tenable, low cost, with the raw materials easily available and light weight etc. These characteristics show commercial significance of MgB_2 superconductors. However, all applications require high values of trapped field governed by the critical current density (J_c). In this presentation we will present recent developments on MgB_2 material production and its characterization. The newly employed cost-efficient technique, "High Energy Ultra-sonication" produces nanoscale boron powders from regular commercial boron. This technique results in the high quality and high J_c performance sintered bulk MgB_2. The present talk elucidates the progress in fabrication of high-performance MgB_2 as well as $LREBa_2Cu_3O_y$ superconducting bulks and their applications.

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T-44

Could MgB_2 superconductors be used in Maglev vehicles?

J. Noudem[1], Y. Xing[1], P. Luigi Ribani[2], Giacomo Russo[2], A. Morandi[2] and P. Bernstein[1]*
[1]Normandie Univ, ENSICAEN, UNICAEN, CNRS, CRISMAT, 14000 Caen, France
[2]LIMSA, University of Bologna, Italy
* Email : jacques.noudem@ensicaen.fr

Abstract:
Investigations carried out up to now on superconducting Maglev trains have always planned to use YBCO or REBCO oxides as superconducting materials[1,2]. While MgB_2 enters more and more applications[3], bulk MgB_2 has not yet been seriously considered for Maglev projects. Its main drawback is its T_c that is low as compared to that of HTS oxides. As a consequence, the cooling costs are assumed to be much higher, although cryo-coolers able to provide a high cooling power at 20K are now available[4]. Bulk MgB_2 presents, however, advantages that could offset this inconvenient. Magnesium and Boron are abundant and available worldwide and MgB_2 is a light, low cost and high hardness material. The fabrication process of MgB_2 bulks by Spark Plasma Sintering-SPS[5] is simpler, takes much less time and is much less expensive than the techniques used for the growth of YBCO or REBCO bulks[6]. In addition, MgB_2 bulks can be made with *a priori* no limitation on their dimensions and shape.
The non-conventional SPS process is based on the combination of a high current and a mechanical high pressure applied directly to the powder material. This technique presents the advantage to provide dense materials in a few minutes while mastering their microstructure. A lot of works have been reported since the introduction of SPS in research laboratories, and many groups have tried to understand the densification mechanisms involved. After a brief history of the SPS technique, the characteristics of this process will be detailed and compared to those of the other sintering techniques.
The densification, and the functionnal properties of superconducting MgB_2 cryo-magnets sintered by SPS will be discussed. Levitation forces up to 400 N at 25 K measured on a 70 mm diameter MgB_2 disc will be reported. The effect of the thickness and the diameter of cylindrical superconductors on the levitation force and the condition for stability in superconducting magnetic levitation will be also analysed.

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T-45

Behaviour of neighbouring bulk trapped field magnets with parallel or orthogonal magnetizations

*Michel Houbart1 , Jean-François Fagnard1 , Devendra Kumar Namburi2 , Anthony Dennis2 , YunhuaShi2 , John Durrell2 and Philippe Vanderbemden1,**

1) University of Liege, Department of Electrical Engineering and Computer Science, B-4000 Liege, Belgium

2) University of Cambridge, Bulk Superconductivity Group, Cambridge CB2 1PZ, United Kingdom

* Presenting author (email: Philippe.Vanderbemden@uliege.be)

Abstract:

This presentation deals with the behaviour of bulk superconductors used as trapped-field permanent magnets. We investigate the situation where the bulk superconductors are first magnetized permanently and then brought next to each other, in view of generating a large magnetic flux density gradient. We first consider the approach of bulk cylindrical superconductors with parallel axial magnetizations, either along their symmetry axis (i.e. the translational motion is parallel to their axis) or sideways (i.e. the motion is perpendicular to their axis) [1]. We show that repeated approach / separation cycles yield an irreversible behaviour that can be reproduced qualitatively using a simple analytical model. Next, we consider the assembly of three cuboid bulk superconductors with orthogonal magnetization directions. Experimental results are obtained for bulk YBCO superconductors (~ 14 mm side) pre-magnetized independently and brought in close vicinity using a

computer-controlled motor capable of overcoming the repulsive force between them. Experimental results show that the approach of the magnetized superconductors leads to a redistribution of the current density in the central superconducting sample during the approach. This phenomenon can be reproduced correctly using a simple analytical model. We also compare the results obtained with trapped field superconductors to those obtained with permanent magnets.

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T-46

Improved properties in sintered MgB_2 bulk superconductors by novel technique

Sai Srikanth Arvapalli[*,1], *Muralidhar Miryala*[1], *and Masato Murakami*[1]
[1] Materials for Energy and Environmental Laboratory, Superconducting Material Group, Graduate School of Science and Engineering, Shibaura Institute of Technology, 3-7-5 Toyosu, Koto-Ku, Tokyo 135-8546, Japan

*Presenting author (email: na17502@shibaura-it.ac.jp)

Abstract:
In recent years, we successfully improved critical current density (J_c) of sintered in-situ bulk MgB_2 cost efficiently by means of inexpensive ultrasonically refined boron powder. We varied the ultrasonication medium and treatment duration in order to understand and optimize the refinement. Earlier, bulk MgB_2 prepared of boron ultra-sonicated in ethanol for 15 minutes showed J_c of around 300 kA/cm^2 at self-field (35% increase), 20 K without any compromise in critical transition temperature (T_c ~39 K) while 30 min in hexane medium showed 20% increase. Here we report another scenario, where we observed 35 % increase in J_c when using 15-30 minutes ultrasonically refined boron in distilled water media. Similar to ethanol media, there is no degradation of T_c, reflecting the high quality superconducting bulk. Rietveld phase analysis of X-ray diffraction pattern revealed completely formed MgB_2 with a low amount of MgO. Further, no unreacted Mg phases were observed similar to the case of hexane medium, probably due to high viscosity of distilled water than hexane medium. Microstructures observed using the Field Emission-Scanning Electron Microscope (FE-SEM) support the grain size refinement in the MgB_2 specimens. Flux pinning diagrams also point out to the peak at 0.2 supporting the strong grain-boundary pinning. This work suggests that ultrasonication media might have a strong role in refinement of boron as well as the final grain size of bulk MgB_2 and shows that this technique has great potential in improving the J_c performance/cost ratio of sintered bulk MgB_2.

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T-47

The facet lines and the uniformity of (RE)BCO-Ag single grains

Y. Shi[1,], T. Mousavi[2], A. R. Dennis[1], J. H. Durrell[1] and D. A. Cardwell[1]*

1) Department of Engineering, University of Cambridge
2) Materials Department, Oxford University

*Yunhua Shi (email: ys206@cam.ac.uk)

Abstract:
One of the increasing requirements for the application of bulk (RE)BCO high temperature superconductors (HTS) is to process materials with uniform properties, such as critical current density (J_c), and particularly under conditions of pulsed field magnetisation (PFM), which is a more practical method for magnetising large, individual single grains. J_c of single grains is associated with the presence flux pinning centres, which are typically non-superconducting particles embedded in a continuous, superconducting matrix with physical dimension of several tens of nano-meters. Many microstructural and processing features determining the local magnitude of J_c. This presentation will address issues associated with the uniformity of critical current density within (RE)BCO single grains, their related microstructure and resulting trapped field distribution at 77 K under conditions of field cooing, including contributory factors especially in the regions containing intrinsic existing different defects, on facet lines and along the a/b direction within large single grain. J_c-B curves at 77 K (and lower temperatures) of 24 sub-specimens cut from parent single grains at both the site of a facet line and along the a/b direction of two GdBCO single grains are compared, the limitations and variations in the J_c-B curves and the related grain microstructures are discussed. The effects of non-uniform J_c at these critical positions within the single grain on the shape of the measured trapped field contours across different rare-earth (RE)BCO systems are presented and discussed. The initial results suggest that, although an absolutely uniform J_c is difficult to achieve, it is, nevertheless, possible to engineer a rather uniform trapped field within an individual single grain.

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T-48

Microstructural engineering of MgB_2 bulk superconductors

S.C. Speller[1], Z. Gao[1], G. Matthews[1], T. Mousavi[1] and C.R.M. Grovenor[1]*
1) University of Oxford, Parks Road, Oxford, OX1 3PH, UK
*Presenting author (Susannah.speller@materials.ox.ac.uk)

Abstract:
The ability of bulk superconducting materials to generate higher magnetic fields than permanent magnets enables their potential application in portable, medium-field magnet systems. MgB_2 is a promising material because it has a reasonably high transition temperature (T_c = 39 K) and, unlike (RE)BCO, can be fabricated in bulk form by simple and cheap powder processing methods. However, the superconducting performance of MgB_2, especially its macroscopic critical current density (Jc), requires further improvement in order to provide a suitable magnetic field for practical applications. Here, we will report a summary of recent work by the Oxford group on a variety of methods for improving macroscopic J_c in ex-situ MgB_2 bulks processed by Field Assisted Sintering Technology. The work focuses on two elements: (i) increasing the connectivity between MgB_2 particles, and (ii) improving the intrinsic J_c of the MgB_2 by optimizing the pinning landscape. The first of these traditionally requires the use of higher processing temperatures that results in the coarsening of the microstructure and a decrease in intrinsic J_c. Therefore, we have developed a new method for improving connectivity at relatively low temperatures. In addition, we have explored the effects of a variety of additions, such as Y_2O_3, hBN and cBN together with the high energy ball-milling process on the microstructure and superconducting properties of MgB_2.

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T-49

Direct preparation of homogeneous REBCO bulks in various shapes using Single-Direction Melt Growth method

T. Motoki[1,], R. Sasada[1], T. Tomihisa[1], S. Nakamura[2], and J. Shimoyama[1]*
1) Aoyama Gakuin University, Sagamihara, Kanagawa, Japan
2) TEP Co., Tokyo, Japan
*Takanori Motoki (email: motoki@phys.aoyama.ac.jp)

Abstract:
It is of high importance for REBCO bulks to achieve both an increase in high field-trapping properties and improvement in the uniformity of B_T distributions for practical applications. In addition, bulks in various shapes such as rectangular and ring-shapes are required for applications such as motors or compact NMR/MRI systems, respectively. In the recent study, we have developed a new growth method called Single-Direction Melt Growth (SDMG), where REBCO bulks directly grows on a large ready-made REBCO bulk plate utilizing the difference of peritectic temperatures of REBCO [1]. Since REBCO bulks grows only vertically, homogenous bulks in various shapes with whole *c*-growth regions can directly obtained using SDMG method. We will present the latest results; direct preparation of rectangular, hexagonal and ring-shaped REBCO bulks with their field-trapping distributions will be shown. A new SDMG method is quite promising for the development of high-performance REBCO bulk materials in various shapes with lower production cost and higher reproducibility.
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T-50

Electromagnetic loss analysis of superconducting magnetic bearings by FEM based on *H*-φ and *A*-*V* formulations

T. Onoue[1,], S. Okumura[1], Y. Terao[1], H. Ohsaki[1], Y. Sakurai[2], T. Matsumura[2], N. Katayama[2]*
1) Graduate School of Frontier Sciences, The University of Tokyo,
5-1-5 Kashiwanoha, Kashiwa-shi, Chiba, Japan
2) Kavli Institute for the Physics and Mathematics of the Universe (WPI), The University of Tokyo,
5-1-5 Kashiwanoha, Kashiwa-shi, Chiba, Japan
*Takemi Onoue (email: onoue-takemi231@g.ecc.u-tokyo.ac.jp)

Abstract:
Superconducting magnetic bearings (SMBs) have excellent characteristics such as low loss, long lifetime, and low maintenance, which come from the contactless support of a rotor. As an example, SMB has been developed for a cosmic microwave background polarimeter because the low loss is required at the operation temperature of 4 - 50 K. When it is considered for use in a space mission, the required loss is as stringent as the order of mW at 4 K. It is important to study the electromagnetic field characteristics of the SMB systems and to optimize their design.

We have developed FEM analysis models of the SMB. In the SMB models, the stator has an array of YBCOs forming a ring, and the rotor is composed of permanent magnets arranged in a ring shape, steel components for magnetic circuits, and electrically conducting components. We have used the *H* formulation for the electromagnetic field in the superconductor, the *j* formulation for the magnetic field generated by the PMs, and the *A*-*V* formulation for the rotor eddy currents induced by the magnetic field generated by the superconducting currents in the stator. COMSOL Multiphysics was used for the analysis.

We have computed the superconducting current, the eddy current, and the energy loss. Specifically, we have investigated their dependence on the geometry, the critical current, the levitation gap, the rotational speed, etc. Based on the results, we discuss the SMB design optimization to decrease its energy loss.

T-51

Magnetic Separation for Ni-Plating Waste Liquid Using HTS Bulk Magnet

T. Oka [1,], K. Sudo[1], L. Dadiel[1], N. Sakai[1], H. Seki[1], M. Miryala[1], M. Murakami[1], T. Nakano[2], M. Ooizumi[2], K. Yokoyama[3] and M. Tsujimura[4]*

1) Shibaura Institute of Technology, 3-7-5 Toyosu, Koto-Ward, Tokyo, 135-8560 Japan
2) Niigata University, 5-50 Ikarashi-Ninocho, Nishi-Ward, 950-2181 Niigata, Japan
3) Ashikaga University, 268-1, Omae-cho, Ashikaga, Tochigi, 326-8558 Japan
4) Aichi Giken Co. Ltd., 50-1 Takeshita, Hitotsugi-cho, Kariya, Aichi, 448-0003 Japan
*Presenting author (email: okat@shibaura-it.ac.jp)

Abstract:
Nickel (Ni) is one of the rare earth resources. Since Ni-containing waste liquid is drained after several plating turns in the factories, the effective recycling technique is needed. A unique magnetic separation technique using HTS bulk magnet has succeeded in collecting the Ni-sulphate crystals which were fabricated from the Ni-plating waste liquid. Pulsed-field magnetizing method was employed to activate the magnet up to 2.80 T, which brought us 1.41-T field space on the channel. One can see green coarse crystals attracted from the flowing stream of mixture of Ni-saturated liquid and weakly-magnetic Ni-containing particles. The collected particles were identified as paramagnetic $NiSO_4/6H_2O$ crystals, showing slight differences in the particle sizes and the magnetic susceptibility between the samples attracted and not-attract to the magnetic pole. This preferential extraction suggests us a novel recycling method of Ni resource. The compound can be used again in the Ni-recycle process as a raw material.

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T-52

Modelling the record trapped field by pulsed field magnetisation of a composite bulk MgB_2 superconducting ring

V. Cientanni[1], M. D. Ainslie[1], H. Fujishiro[2], K. Takahashi[2]
[1)]Department of Engineering, University of Cambridge, Cambridge CB2 1PZ, United Kingdom
[2)]Department of Physical Science and Materials Engineering, Faculty of Science and Engineering, Iwate University, Morioka 020-8551, Japan

Abstract:
It has recently been shown that composite bulk superconducting rings of MgB_2, copper and iron can trap greater fields than previously possible with superconducting rings of MgB_2 alone. Hirano et al. [1] produced a record breaking trapped field of 1.61 T in this composite MgB_2 ring, illustrating the great potential of these easily manufactured and low cost superconducting permanent magnets. Leveraging a finite-element method modelling framework in a commercial software package (COMSOL Multiphysics), we have accurately replicated the experimental results that led to this record high trapped field. We extended our simulations to investigate how we can optimise these composite structures, to potentially trap even greater fields.
In this presentation, we report the novel modelling techniques employed to gain the demonstrated qualitatively and quantitative modelling accuracy:

- Successfully modelling the behaviour of a complex composite MgB_2 bulk acting as a trapped field magnet
- Modelling with great accuracy this record breaking trapped field, and provide clues to improving the trapped field performance further.

We suggest how the novel modelling techniques adopted in our simulations helped to achieve our success in numerically replicating the experiment. These techniques may be useful for those seeking to model other more complex superconducting bulks and structures. Our results indicate that the addition of the iron and copper into these superconducting bulks help to pulse-shape the applied magnetic field. The moderating effect is favourable to trapping greater magnetic fields, however, there are constraints that need consideration in designing a magnetising rig to exploit these.

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T-53

Thermal-hydraulic analysis of the cooling system in a high-temperature superconducting axial flux motor

Xiaodong Li[1,], Yue Wu[2], Dongbin Song[3], Yingzhen Liu[4], Wenjiang Yang[3] and Rafael Macián-Juan[1]*

1) School of Engineering and Design, Technical University of Munich (TUM), Boltzmannstr. 15, D-85748 Garching b. München, Germany

2) School of Electrical Engineering, Beijing Jiaotong University, 100044, Beijing, China

3) School of Astronautics, Beihang University (BUAA), No. 37 Xueyuan Road, Haidian District, 100191, Beijing, China

4) School of Electrical Engineering and Automation, Harbin Institute of Technology, 150080, Harbin, China

*Presenting author (email: xiaodong.li@tum.de)

Abstract:

Axial flux motors with high temperature superconducting (HTS) magnets have the ability to maintain an enormous increased air-gap flux density with a 17.6 Tesla trapped field for HTS bulks at 26 K, which could thereby meet the requirement of high-power density for electric and hybrid vehicles. The pulsed-field magnetization technique has been elaborated as the most efficient way in magnetizing these HTS magnets before they could be normally operated. However, power dissipation generated by the hysteresis loss during the magnetization process may affect the performance of HTS magnets and thereby influence the operation condition of the motor. Accordingly, this article aims to evaluate the thermal-hydraulic efficiency of a cooling system for the HTS axial flux motor. A superconducting axial flux motor with a cooling system for HTS stators is designed primarily, after which the trapped field property of HTS bulks under pulsed field magnetization have been studied. Models that describe the electromagnetic behaviour of HTS bulks are based on the H-formulation and T-A formulation based finite element method. Power dissipation of HTS bulks under pulsed-field magnetization has been treated as the heat source in the thermal-hydraulic process, while $k-\varepsilon$ model has been employed to describe the fluid behaviour of liquid nitrogen. It is shown that a large amount of heat could be generated during the magnetization process, especially in the process of high-field ($\geq$ 12 Tesla) magnetization, which thereafter increase the risk of quenching for HTS magnets. But it is also noticed that the supplement of copper structure in the stator can promote heat dissipation. It is also indicated that increase the flow rate of the liquid nitrogen could improve the efficiency of the cooling process and thereby enhance trapped field properties of the motor. The study verifies the feasibility of using HTS magnets in the axial flux motor, which provides a certain frame of reference for the study of high-power density machines.

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T-54

Effect of WO_3 Nanostructured Materials Incorporation on the Superconducting Performances of $YBa_2Cu_3O_{7-d}$ Compound

Yassine Slimani [1,] and Essia Hannachi [2]*
1) Department of Biophysics, Institute for Research and Medical Consultations (IRMC), Imam Abdulrahman Bin Faisal University, P.O. Box 1982, Dammam, 31441, Saudi Arabia
2) Department of Nuclear Medicine Research, Institute for Research and Medical Consultations (IRMC), Imam Abdulrahman Bin Faisal University, P.O. Box 1982, Dammam, 31441, Saudi Arabia
*Presenting author (email: yaslimani@iau.edu.sa ; slimaniyassine18@gmail.com)

Abstract:
$YBa_2Cu_3O_{7-d}$ (YBCO) material is one of the promising superconductor materials that could be used in diverse important applications. Nevertheless, bulk YBCO material display weak flux pinning, which results in diminishing the values of critical current density (J_c) and hence restrict their uses in several technological applications. One of the effective ways to overcome these problems is the boost of pinning strength by incorporating appropriate nanostructured materials within YBCO material. In this work, we have investigated the impacts of tungsten oxide (WO_3) nanoparticles and nanowires additions on the structural, morphological, electrical, and magnetic properties of YBCO superconductor. Samples were produced via solid-state reaction. Different characterization techniques including X-ray diffraction (XRD), scanning and transmission electron microscopes (S/TEM) and physical property measurement system (SQUID-PPMS) were employed. The values of J_c and flux pinning force density (F_p) were also determined. The structural and microstructural analyses revealed the successful development of the orthorhombic YBCO phase. The morphological observations showed that WO_3 nanowires improve the connectivity between YBCO grains and reduce the porosity by filling the voids between YBCO grains, however, the WO_3 nanoparticles are embedded within the YBCO grains. The values of J_c and F_p are significantly increased upon the incorporation of diverse WO_3 nanostructured materials. It has been established that the inclusion of WO_3 nanowires leads to better superconducting performances in comparison to WO_3 nanoparticles addition. The attained results revealed that the incorporation of appropriate nanostructured materials with specific characteristics could be an effective way to enhance the superconducting performances of YBCO materials.

T-55

A trapped field of 1.3 T in a ring-shaped Gd-Ba-Cu-O bulk superconductor by the pulsed field magnetization method

Y. Tsui[1], D.A. Moseley[2], A.R. Dennis[1], Y-H. Shi[1], M.R. Beck[1], V. Cientanni[1], D.A. Cardwell[1], J.H. Durrell[1], and M.D. Ainslie[1]

1) Cambridge University Engineering Department, Trumpington Street, Cambridge, CB2 1PZ, United Kingdom

2) Robinson Research Institute, Victoria University of Wellington, Gracefield, Lower Hutt 5010, New Zealand

*Presenting author (email: ykt27@cam.ac.uk)

Abstract:

One of the potential applications of ring-shaped, single-grain RE-Ba-Cu-O bulk superconductors is in desktop magnetic resonance imaging and nuclear magnetic resonance systems as an alternative to conventional permanent magnets. The higher magnetic field available from magnetized bulk superconductors could significantly improve the performance of such systems, as well as reduce their size and increase portability. The pulsed field magnetization (PFM) method provides a fast, compact and cost-effective method for magnetizing these materials as trapped field magnets. However, bulk superconducting rings are very susceptible to thermomagnetic instabilities during the PFM process, and thus, to date, the reported trapped fields in ring bulks magnetized by PFM are less than 0.35 T at the centre of single rings.

In this presentation, we will demonstrate that a trapped field of 1.3 T can be achieved in the bore of a ring using the PFM method. A single-grain Gd-Ba-Cu-O ring was employed in this study, with single- and multi-pulse PFM techniques used to magnetize the sample. The major findings of this investigation are:

(i) an increase in trapped field of up to nearly 60% was achieved using single-pulse PFM by controlling the waveform of the applied magnetic field, with a maximum trapped field of ~0.8 T achieved at 73 K; and

(ii) trapped fields in excess of 1 T were achieved reliably using the multi-pulse, step-wise cooling technique, with a maximum trapped field of 1.3 T at 55 K.

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- W.D. Armstrong Studentship in Engineering and Medicine (M.R. Beck)

T-56

High critical current density of MgB_2 bulk superconductor fabricated by Spark Plasma Sintering

Y.XING[1], P.BERNSTEIN[1], M. MURALIDHAR[2] and J. NOUDEM[1]*

1) Normandie Univ, ENSICAEN, UNICAEN, CNRS, CRISMAT, 14000 Caen, France
2) Materials for Energy and Environmental Laboratory, Superconducting Materials Group, Shibaura Institute of Technology, 3-7-5 Toyosu, Koto-ku, Tokyo 135-8548, Japan
*Presenting author (email: yiteng.xing@ensicaen.fr)

Abstract:
In this study, we investigated the superconducting properties of highly dense bulk MgB_2 samples prepared by unconventional "Spark Plasma Sintering" (SPS). Different precursors were used: i) the commercial powder MgB_2 ii) mixture of magnesium and nano boron powder (Mg + 2B) and iii) mixture of Mg and MgB_4 powder for an "in-situ" reactive synthesis. The density of obtained MgB_2 bulks was up to 99 % of the theoretical density of the material. Then structural and microstructural characterizations were carried out with these samples and correlated to their superconducting properties, in particular their critical current densities (J_c) measured at 20 K. A high J_c = 675 kA/cm^2 was obtained in self-field. Remarkably for a bulk MgB_2, J_c was above 10kA/cm^2 at 4T.

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Here you can acknowledge financial support and any other support from peoples not listed in co-author section. Text should be single-spaced in 10-point Times New Roman.

T-57

Growth of a non-toxic high temperature superconductor: (Cu,C)-1234 with potential high performance

*Ping Zhu, Yangyang Chen, Jinyu He, Difan Zhou, Feng Fan, Shuyun Tong, Zhiyong Liu, Chuanbing Cai**
Shanghai Key Laboratory of High Temperature Superconductors, Shanghai University, China

Abstract:
As a non-toxic and non-rare earth copper oxide superconductor, (Cu,C)$Ba_2Ca_3Cu_4O_y$ [(Cu,C)-1234] has a higher critical temperature (~ 116 K) and a higher irreversible field (~ 15 T @ 82 K). This study explored the feasibility of growing large (Cu, C)-1234 grains via the solid state reaction under non-high pressure conditions which has been considered necessary. We also investigated the a-axis growth of (Cu,C)-1234 superconducting thin films by pulsed laser deposition (PLD) technology.
We first prepared the precursor powders of $BaCuO_2$ and Ca_2CuO_3 by the solid state reaction method and explored the phase formation temperature of (Cu, C)-1234 by means of differential thermal analysis. Its micro morphology was characterized by SEM and EDS, and the existence of CO_3^{2-} groups was proved by Raman. On this basis, we successfully prepared (Cu,C)-1234 thin films on LaAlO3 single crystal substrates. We further investigated the in-situ epitaxial growth of (Cu,C)-1234 thin film on a textured polycrystalline $LaAlO_3$ film which had been previously deposited on the Hastelloy buffer layer (Hastelloy/Al_2O_3/MgO/$LaMnO_3$) using PLD. It laid the foundation for the wide application of (Cu,C)-1234 superconducting film.

Key words:
(Cu,C)-1234, high critical temperature and irreversible field, solid state reaction, Hastelloy buffer layer

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