## FORTHCOMING INSTITUTE CONFERENCES

### MAY 2015 – JULY 2017

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2015 Joint UK-Japan Workshop on Physics and Applications of Superconductivity

Conference Programme

Sunday 12 April 2015
16:00 – 18:00  Conference registration (Keynes Building, King’s College)
18:00 – 20:00  Welcome reception (Old Library, Emmanuel College)

Monday 13 April 2015
08:30  Conference registration

Chair:  Mark Ainslie, University of Cambridge, UK
09:00  Conference welcome
09:10  Welcome and introduction to bulk HTS materials research at Cambridge
       Guest speaker: David Cardwell, University of Cambridge, UK
09:30  (keynote) Understanding and control of electromagnetic behaviors of high \( T_c \) superconductors toward their attractive applications
       Naoyuki Amemiya, Kyoto University, Japan
10:15  Hydrogen cryomagnetics - Superconductivity for decentralised energy
       Bartlomiej Glowacki, University of Cambridge, UK
10:35  Refreshments, Exhibition and Poster session A

Large-scale applications

Chair:  Naoyuki Amemiya, Kyoto University, Japan
11:10  (invited) Application of superconducting technologies to DC electric railway feeding systems
       Hiroyuki Ohsaki, University of Tokyo, Japan
11:30  Overlook of Japanese HTS application projects and related activities
       Kenichi Sato, Sumitomo Electric, Japan
11:50  New advancements in superconducting magnets for research applications
       Ziad Melhem, Oxford Instruments NanoScience, UK
12:10  Theoretical and experimental reports on the design and fabrication of 4KW HTS motor based on HTS stacked tapes
       Mehdi Baghdadi, University of Cambridge, UK
12:30  Lunch, Exhibition and Poster session A
Bulk superconductivity

Chair: David Cardwell, University of Cambridge, UK

13:30 (invited) Improved flux pinning and critical current densities in sintered bulk MgB$_2$
Muralidhar Miryala (on behalf of Masato Murakami), Shibaura Institute of Technology, Japan

13:50 (invited) A 17.6 T Trapped Field in Ag doped Bulk GdB$_2$Cu$_3$O$_{7-\delta}$
John Durrell, University of Cambridge, UK

14:10 Magnetizing process and trapped field of REBaCuO and MgB$_2$ superconducting bulks
Hiroyuki Fujishiro, Iwate University, Japan

14:30 Recent progress in RE-Ba-Cu-O Bulk superconductors and applications
Hidekazu Teshima, Nippon Steel & Sumitomo Metal Corporation, Japan

14:50 Materials preparation and magnetization of bulk superconductors
Mitsuru Izumi, Tokyo University of Marine Science and Technology (TUMSAT), Japan

15:10 Reliable growth of primary and recycled (Sm, Gd, Y)Ba$_2$Cu$_3$O$_{7-\delta}$bulk superconductors
Yunhua Shi, University of Cambridge, UK

15:30 Refreshments, Exhibition and Poster session A

Bulk superconductivity II / Modelling superconductors

Chair: Hiroyuki Ohsaki, University of Tokyo, Japan

16:00 Single grain YBa$_2$Cu$_3$O$_{7-x}$ bulk superconductors fabricated by buffer-aided top seeded infiltration and growth process
Namburi Devendra Kumar, University of Cambridge, UK

16:20 Modelling and comparison of trapped fields in (RE)BCO bulk superconductors for activation using pulsed field magnetisation
Mark Ainslie, University of Cambridge, UK

16:40 Multiphysics simulation for YBCO coil using line current magnetic energy minimization
Weijia Yuan, University of Bath, UK

17:00 Multiphysics analysis of a high field HTS insert coil
Chris Riley, Cobham Technical Services, UK

17:20 Close of day one

18:30 Conference drinks reception and dinner (The Hall, King’s College)
2015 Joint UK-Japan Workshop on Physics and Applications of Superconductivity

Tuesday 14 April 2015

Superconducting materials I

Chair: John Durrell, University of Cambridge, UK

09:00 (keynote) Chemical strategies to improve critical current properties of HTS materials
Jun-ichi Shimoyama, Aoyama Gakuin University, Japan

09:45 Recent progress of iron-based layered oxypnictide superconductors
Yoichi Kamihara, Keio University, Japan

10:05 Spectromicroscopy of phase-separated iron-chalcogenide superconductors
Susannah Speller, University of Oxford, UK

10:25 A cryogenic solid state NMR study on superconducting endohedral fullerenes
Richard Bounds, University of Southampton, UK

10:45 Refreshments, Exhibition and Poster session B

Superconducting materials II

Chair: Weijia Yuan, University of Bath, UK

11:15 (keynote) Superconductors in fusion energy tokamaks
Damian Hampshire, University of Durham, UK

12:00 Magnetic levitation between permanent magnets and HTS tape stacks in coil configurations
for bearing applications
Anup Patel, University of Cambridge, UK

12:20 Superconducting flux pumped magnets
Tim Coombs, University of Cambridge, UK

12:40 Experimental analysis on critical current degradation of HTS tape with different impregnation
materials
Huiming Zhang, University of Bath, UK

13:00 Lunch, Exhibition and Poster session B

Superconducting materials III / Charge density waves in cuprates

Chair: Anup Patel, University of Cambridge, UK

14:00 Soldered lap joints between RE-BCO coated conductors for demountable fusion magnets
Yeekin Tsui, Durham University, UK
2015 Joint UK-Japan Workshop on Physics and Applications of Superconductivity

14:20  Inductive resistance testing by SQUID magnetometry - A novel tool for characterising superconducting joints
       Greg Brittes, University of Oxford, UK

14:40  (keynote) Spin and charge fluctuations in high temperature superconductors
       Stephen Hayden, University of Bristol, UK

15:25  Refreshments, Exhibition and Poster session B

Charge density waves in cuprates

Chair: Anthony Carrington, University of Bristol, UK

16:00  Ionic displacements in the charge density waves in YBCO_{6.54} measured in the bulk by X-rays
       E M Forgan, University of Birmingham, UK

16:20  Charge density wave fluctuations in La_{2-x}Sr_xCuO_4 and their competition with superconductivity
       Thomas Croft, University of Bristol, UK

16:40  Correlation strength and Tc: quantum oscillations in YBa_2Cu_4O_6 under hydrostatic pressure
       Carsten Putzke, H.H. Wills Physics Laboratory, UK

17:00  Discussion panel: The future of superconducting applications
       Junichi Shimoyama, Kenichi Sato, Damian Hampshire, Ziad Melhem

18:00  Close of day two

Wednesday 15 April 2015

Small-scale / Electronics

Chair: Yuri Pashkin, Lancaster University, UK

09:00  (keynote) Ultra-energy-efficient adiabatic superconducting logic: what is the minimum energy limit in computation?
       Nobuyuki Yoshikawa, Yokohama National University, Japan

09:45  Development of NEMS resonators coupled to a nanoSQUID
       Ling Hao, National Physical Laboratory (NPL), UK

10:05  Tunable microwave oscillators based on an asymmetric flow of vortices in YBa_2Cu_3O_7.5
       Josephson-junction arrays and operating at 77K and above
       Boris Chesca, Loughborough University, UK

10:25  Refreshments
Properties of superconductors

Chair: Yuji Matsuda, Kyoto University, Japan

11:00 (keynote) Exploring superconductivity in the vicinity of electronic ordering
Hidenori Takagi, Max-Planck Institute/University of Tokyo, Germany/Japan

11:45 Rectifying a fundamental flaw in BCS theory
Xueheng Zheng, Queen’s University Belfast, UK

12:05 Superconducting metamaterial: Resonant response at visible wavelengths
Kaveh Delfanazari, University of Southampton, UK

12:25 Magneto-optical imaging: A tool for fundamental physics and applications of superconductivity
Pavlo Mikheenko, University of Oslo, Norway

12:45 Lunch

High $T_c$ superconductivity

Chair: Carsten Putzke, University of Bristol, UK

13:45 (keynote) Physics of iron-based high temperature superconductors
Yuji Matsuda, Kyoto University, Japan

14:30 Superconducting gap structure and quantum criticality in the iron-pnictide: $\text{BaFe}_2(\text{As}_{1-x}\text{P}_x)_2$
Anthony Carrington, University of Bristol, UK

14:50 Doping dependence of intrinsic Josephson properties in $\text{Pb}_{1.9}\text{Sr}_2\text{Y}_{1.4}\text{Ca}_x\text{Cu}_2\text{Y}_{1.6}$, $\delta$ epitaxial films
Sachio Komori, Kyoto University, Japan

15:10 The electronic structure of superconducting FeSe
Matthew Watson, University of Oxford, UK

15:30 High magnetic field studies of the vortex lattice structure in $\text{Y}_{0.98}\text{Ca}_{0.04}\text{Ba}_2\text{Cu}_3\text{O}_7$
Randeep Riyat, University of Birmingham, UK

15:50 The evolution of microwave conductivity in YBCO across the superconducting dome
Jordan Baglo, University of Cambridge, UK

16:10 Refreshments

16:40 Discussion panel: The future of superconductor physics
Mark Ainslie (Chair), Nobuyuki Yoshikawa, Anthony Carrington, E M Forgan

17:40 Closing remarks

18:00 Close of day three and conference
Poster Programme

Poster session A – Applications / Materials

P:01 The critical current of high field superconductors under strain for fusion applications
Paul Branch, Durham University, UK

P:02 Modular superconducting toroidal transformer with cold magnetic core
Boguslaw Grzesik, Silesian University of Technology, Poland

P:03 DC characterization and 3D modelling of a triangular-shaped, Epoxy-impregnated high temperature superconducting (HTS) coil
Di Hu, University of Cambridge, UK

P:04 Modeling of the current limiting performance of a resistive superconducting fault current limiter prototype
Fei Liang, University of Bath, UK

P:05 Superconducting solders for the 21st century
Tayebeh Mousavi, Oxford University, UK

P:06 The planet’s most important experiment
Mark Raine, Durham University, UK

P:07 The architecture of superconducting wires and tapes
Francis Ridgeon, Durham University, UK

P:08 FEM modelling of levitation forces between bulk superconductor and Halbach PM array
Mariusz Stepień, Silesian University of Technology, Poland

P:09 Fabrication and characterisation of nanocrystalline high-temperature YBa$_{2}$Cu$_{3}$O$_{7-x}$
Guanmei Wang, Durham University, UK

P:10 Intrinsic Josephson junction arrays in the high temperature superconductor Tl$_{2}$Ba$_{2}$CaCu$_{2}$O$_{8}$
Tim Wootton, London Centre for Nanotechnology, UK

P:11 A novel measurement method of current distribution for a multi-layer DC HTS superconductor cable
Zhenyu Zhang, University of Bath, UK

P:12 Doping effects in superconducting SmBa$_{2}$Cu$_{4}$O$_{7-x}$ bulk materials
Wen Zhao, University of Cambridge, UK

P:13 Numerical simulation and analysis of single grain YBCO processed from graded precursor powders
Jin Zou, University of Cambridge, UK
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Poster session B - Physics

P:14 First principles study of the electronic and magnetic structure of RESn$_3$ intermetallic compounds  
Benidris Ahmed, University Djillali Liabés of Sidi Bel-Abbes, Algeria

P:15 Broken time-reversal symmetry probed by muon spin relaxation in the caged type superconductor Lu$_6$Rh$_{16}$Sn$_{18}$  
Amitava Bhattacharyya, Science and Technology Facilities Council, UK

P:16 Transport characterisation of phase-slips in superconducting constrictions  
Aleksei Dmitriev, Moscow Institute of Physics and Technologies, Russia

P:17 Flux Line Lattice in KFe$_2$As$_2$ under H//c  
Hazuki Kawano-Furukawa, Ochanomizu University, Japan

P:18 Interaction between ferromagnetism and superconductivity in hybrid nanostructures  
Estefani Marchiori Pereira, University of Bath, UK

P:19 First-principles prediction of the magnetic ordering and the superconducting state in rare earth iron pnictides  
Abbaoui Said, University Djillali Liabés of Sidi Bel-Abbes, Algeria

P:20 N-values of 2G HTS tapes and coils  
M Chudy, University of Pretoria, South Africa
Oral abstracts

(keynote) Understanding and control of electromagnetic behaviors of high \( T_c \) superconductors toward their attractive applications

N Amemiya
Kyoto University, Japan

The advantages of superconductors are the current transport with extremely low losses and the generation of high magnetic fields in large spaces. Because electromagnetic behaviors of superconductors often deteriorate these advantages, their understanding and control are key issues for the attractive applications of high \( T_c \) superconductors. We focus on the ac losses in ReBCO coated conductors and the influence of the screening (magnetization) currents on the magnetic field quality in the magnets wound with ReBCO coated conductors. Both of them are related with the pinning of fluxoids in type-II superconductors. Ac losses are generated when fluxoids move against pinning forces, and the screening current distributions are determined by the pinning forces against fluxoids. The behaviors of fluxoids can be understood macroscopically by using Maxwell’s equations as the governing equations, while considering the nonlinear conducting properties of superconductors.

In this keynote talk, at first, I review the numerical modellings of ReBCO coated conductors with three-dimensional shape for electromagnetic field analyses, together with their applications to ac loss calculations. Then, I present recent topics on the influence of the screening currents on the magnetic field quality of the accelerator magnets. We made small dipole magnets using ReBCO coated conductors and measured their magnetic fields precisely: we measured magnetic field harmonics. The magnetic field harmonics were calculated for the dipole magnets using in the experiments as well as the dipole magnets designed for an accelerator system for carbon cancer therapy.

Hydrogen cryomagnetics - Superconductivity for decentralised energy

B A Glowacki\(^{1,2,3} \), E Hanley\(^2 \) and A Patel\(^1 \)

\(^1\)University of Cambridge, UK, \(^2\)University of Limerick, Ireland, \(^3\)Institute of Power Engineering, Poland

As we enter the second century of superconductivity, helium still prevails as the cryogenic coolant of choice. What does the future of helium hold? What can be done to avoid the squandering of this precious resource?

In this presentation, use of cryogenic hydrogen originated from renewable and low-\( \text{CO}_2 \) emission sources will be discussed. We suggest that 20 K of liquid hydrogen can ultimately displace helium as an indirect coolant in a range of superconducting electromagnetic devices. As is already well documented, superconductors have much potential underpinning the future developments in transportation, energy supply/storage and also in medical applications. Although superconductors that can operate at liquid hydrogen temperatures, such as \( \text{MgB}_2 \) and \( \text{YBa}_2\text{Cu}_3\text{O}_7 \), are not yet truly commercially available, research indicates that these will be feasible in the near future.
Large-scale applications

**(invited) Application of superconducting technologies to DC electric railway feeding systems**

H Ohsaki¹, K Qian¹, D Kumagai¹, T Akahori¹ and M Tomita²

¹University of Tokyo, Japan, ²Railway Technical Research Institute, Japan

We have studied the feasibility of applying superconducting technologies such as superconducting power cables, fault current limiters, and energy storage systems to DC electric railway systems. The superconducting technologies would be effective for novel design and efficient operation of next-generation DC electric railway systems, especially for their substantial energy saving and an efficient use of substations along the line.

In conventional electric railways, a DC feeding system is widely used, especially in railway lines with dense train traffic. However, the DC feeding system has some essential problems due to its low feeding voltage. The problems are a relatively lower efficiency of power transmission, a larger voltage drop along the feeder, the regenerative braking cancellation, the necessity of a large number of substations along the line, etc.

Introduction of a superconducting power cable can be a solution to these issues. It suppresses voltage fluctuations along the feeder, and allows trains to function their regenerative brakes more, thus improving energy efficiency. Moreover, the superconducting power cables could prevent electrical loads from concentrating on a single substation.

On the other hand, introducing superconducting cables has its own defects that it may introduce much higher fault current when a short-circuit fault or a grounding fault occurs. Compared to feeder lines, the superconducting cables connect the substations with negligible resistance, which makes it much easier for fault current to flow from other substations to the fault point, and consequently multiply the value of fault current. In order to protect the superconducting cables, it is important to figure out the precise value of the fault current within the whole system.

Numerical analyses using MATLAB-Simulink-based models have been carried out for a DC electric feeder system of railways with superconducting equipment to analyze the following subjects.

1) Energy saving effects, improvement of regeneration rate, and effective use of substations
2) Short-circuit fault currents, and the effective introduction of fault current limiters
3) Comparison with the results of introducing energy storage systems
4) Introduction of superconducting energy storage system
5) Thermal characteristics of superconducting DC power cables

At the Railway Technical Research Institute in Japan, they have performed experimental investigation of superconducting DC cable systems for DC electric railway feeding systems and successfully demonstrated the operation of trains supplied with electricity through a superconducting power cable.

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Fig. 1. Schematic view of the model railway line.

Fig. 2. An electric circuit model of a DC feeding system.
Overlook of Japanese HTS application projects and related activities

K Sato
Cryogenics and Superconductivity Society of Japan/Sumitomo Electric Industries Ltd., Japan

Many HTS application projects are ongoing such as power cables, a variety of high-field magnets and rotation machines. These projects are funded through METI/NEDO and MEXT/JST. Typical projects are including AC (66kV) and DC (1.5kV-10kV) power cables, 3T-10T/MRI & over 1GHz NMR magnets, ship propulsion motors (3MW) and 100kW motor for superconducting bus.

In this presentation, an overlook of Japanese HTS application projects will be introduced to make clear what will be targeted in a near future. Also, important industrial activities related with HTS application, such as improvements for materials upgrading and HTS magnet protection issues will be introduced.

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<td>S-Innovation ALCA 1.03 GHz NMR 3T/MRI</td>
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<td>(Total FY2014 Budget: 1.356 M$) (100W/$)</td>
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<td>Science Council of Japan</td>
<td>High Magnetic Field Collaboratory</td>
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<td>METI</td>
<td>NEDO</td>
<td>Yokohama HTS Cable Ishikari HTS/DC Cable* CC Magnet* M-PACC 3MW Ship Propulsion Motor 100kW Motor for Bus</td>
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<td>(Total FY2014 Budget: 1.484 M$) (100W/$)</td>
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Fig.1 Typical HTS application projects in Japan

New advancements in superconducting magnets for research applications

Z Melhem
Oxford Instruments NanoScience, UK

Recent advances in low and high temperature superconductors (LTS and HTS) have opened up a new era in superconducting magnet technology and applications. The new magnets include high field (HF) systems operating with and without cryogen as well coils using HTS material. The HF magnets are compact in size with enhanced access bore to permit insert coils and large or multiple samples for various research applications. Development of LTS outsert coils have been completed successfully to enable HF magnets greater than 22T using HTS inserts.
These LTS magnets are realised using new internal tin Nb3Sn/RRP® wires and innovative coil structure solutions complemented with effective magnet quench management. New advancements in HF coils will require effective handling of HTS materials. This talk presents an update on the development of a new generation of HF wide bore magnets for research and industry operating at low temperatures as well as report on preliminary results on coil technology using HTS materials operating at >4K for research applications.

Theoretical and experimental reports on the design and fabrication of 4KW HTS motor based on HTS stacked tapes

M Baghdadi, F Spaven and T A Coombs

University of Cambridge, UK

Abstract not available in a digital format.

Bulk superconductivity

(invited) Improved flux pinning and critical current densities in sintered bulk MgB₂

M Miryala¹, M R Koblischka² and M Murakami¹

¹Shibaura Institute of Technology, Japan, ²Saarland University, Germany

The presentation summarizes the state-of-the-art of the development of high performance bulk MgB₂ sintered material for superconducting super-magnet applications. Special emphasis is given on methods to further improve the critical current density (J_c) and mechanical performance of disk-shaped, bulk MgB₂ superconductors by optimizing the sintering conditions and adding silver and nanometer-sized MgB₄ particles. We prepared several sets of bulk MgB₂ material from commercial high-purity powders of Mg metal and amorphous B using a single-step solid-state reaction process. To optimize the sintering time, a set of samples was sintered at 775 °C with varying sintering duration ranging between 1 and 10 h (pure Ar atmosphere). A second set of samples was produced similarly at 775, 780, 785, 795, 800 and 805 °C (3 h, pure Ar atmosphere). X-ray diffraction analysis showed that both sets of samples were single phase MgB₂. Magnetization measurements confirmed a sharp superconducting transition with T_{c,onset} ≈ 38.2 K – 38.8 K. The J_c-values for MgB₂ samples produced for 1 h were the highest in all processed materials, i.e., the highest J_c value of 270 kA/cm² (20 K, self-field) was achieved in the sample produced at 775 °C, without any additional doping. In contrast, on the silver-added samples the microstructural observation with scanning electron microscopy confirmed that metallic Ag particles are embedded in the void regions, which will lead to the improvement of the mechanical performance. Furthermore, the J_c-values were also improved with Ag addition as compared to pure MgB₂ bulk. The sample with 4 wt% Ag-addition exhibited the highest J_c of 293 kA/cm² at 20 K and self field. The respective J_c values at 10 K were 400 kA/cm², 300 kA/cm², and 100 kA/cm² in self field, 1T and 2T. AFM observations indicated that the number of nanometer-sized grains and the dispersion of nanometer-sized, Ag-based Mg-particle within the bulk MgB₂ material, which are responsible for the improved J_c. Our results clearly demonstrate a strong relation between the microstructure achieved and the resulting pinning performance. The optimization of the sintering conditions adding Ag and MgB₄ are crucial to improve the performance of the bulk MgB₂ samples.
We have successfully demonstrated trapping of a magnetic field of 17.6 T in a bulk superconductor at 26 K. This is about 0.4 T in excess of the previous record field obtained by Tomita et al.. Bulk superconductors offer the prospect of convenient, permanent magnet like, fields but of much larger intensity with the very best rare earth magnets achieving little more than 1 T. The utility of such materials is self-evident in spite of the necessity of cryogenic cooling.

The question that immediately arises is as to why it has taken 10 years to achieve a fairly moderate increase on Tomita et al.’s result. To understand this it is important to consider that the limiting factor to the high field performance of such bulks is, unusually in superconductor applications, not the critical current density of the superconductor itself. In fact, it is the tensile strength of the superconductor that limits performance. The strains inside a bulk superconductor during charging to 17 T can reach ~100 MPa with the strain scaling as $B^2$. As the superconductors in question are brittle ceramics featuring a large number of cracks it is clear that this is a challenging problem. Moreover in materials where fracture toughness is important there is often a wide spread of performance since generally it is the one “worst crack” that determines performance.

To achieve high trapped fields, some sort of mechanical reinforcement of the sample is required. Two classes of techniques have been exploited in the literature, steel banding where due to differential thermal contraction a pre-stress is applied to the bulk, and reinforcement with carbon fibre epoxy. We were interested in a quick and easy method which led to our selecting steel banding. We realised, however, that the pre-stress introduced by differential thermal expansion is relatively modest and looked to improve it. We hit upon the simple, and indeed frequently employed in engineering, solution of “shrink fitting”. We carefully machined our bulks to be perfectly cylindrical and prepared slightly under size stainless steel (304L) rings. When heated, these rings expanded and could be slipped over the bulks, as the rings cooled they contracted applying pre-stress to the bulk superconductor. This pre-stress then further increased as the samples were cooled to measurement temperature. In this way we sought to avoid tensile stress sufficient to break them.

**Magnetizing process and trapped field of REBaCuO and MgB$_2$ superconducting bulks**

H Fujishiro, T Naito, T Yoshida and H Mochizuki

Iwate University, Japan

REBaCuO (RE: rare earth element or Y) superconducting bulk magnet with $T_c \approx 90$ K is one of the typical models for practical applications, such as NMR, drug delivery systems (DDSs) and so on. The maximum-trapped field values of the single-grain bulk are $B_z = 3$ T at $T_S = 77$ K and over 17 T below 30 K by field cooled magnetization (FCM) [1, 2], and 5.2 T at 29 K by pulsed field magnetization (PFM) [3]. The mechanical properties as well as thermal stability were greatly improved recently through impregnation of metals and resin, which is highly important for practical engineering applications.

MgB$_2$ superconducting bulk has also promising potential as a quasi permanent magnet, and is attractive in a number of ways as it is low-cost, rare-earth-free and light-weight, and has a homogeneous trapped field distribution. Since the problem of weak links at grain boundaries can be ignored due to their long coherence length $\xi$, better and
larger polycrystalline MgB2 bulk magnets can be achieved below Tc=39 K for magnetically levitated trains (MAGLEVs) and wind power generators in a liquid hydrogen economy in the near future. Several groups have fabricated MgB2 bulks using different techniques and reported the trapped field by FCM and PFM, in which the maximum trapped field of Bz=5.4 T at Ts=12 K was achieved on the bulk surface by FCM [4].

Recently, we achieved Bz=3.2 T at Ts=14 K on a single MgB2 bulk and 4.6 T at 14 K in a bulk pair by FCM as shown in Fig. 1, and Bz=0.8 T at 14 K by PFM [5]. REBaCuO and MgB2 bulks have different superconducting characteristics and are used at different operating temperature Ts, in which thermal and electromagnetic characteristics are quite different. Flux jump frequently takes place for the MgB2 bulk during magnetizing process because of the small specific heat and large critical current density Jc(B, T) at lower temperatures. The avoidance of the flux jump must be technically considered for the practical application.

In this study, we summarize the current status of magnetization process, thermal and electromagnetic properties and trapped field of REBaCuO and MgB2 superconducting bulks. The potential as a quasi-permanent magnet of the superconducting bulk is discussed.


Recent progress in RE-Ba-Cu-O bulk superconductors and applications

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Nippon Steel & Sumitomo Metal Corporation, Japan

We, Nippon Steel & Sumitomo Metal Corporation, have successfully developed high temperature superconducting (HTS) bulk materials of RE-Ba-Cu-O (RE: Y or rare earth elements), which are called QMG. QMG is a single-grained HTS bulk of REBa2Cu3Ox (RE123) with RE2BaCuO5 (RE211) inclusions finely dispersing in the superconducting matrix. Originally QMG stood for “Quench and Melt-Growth" [1], but in the modified QMG process [2] the quench step is eliminated by employing a small amount of Pt or CeO2 addition into the starting materials and thus “Q" means
“Quality” at present instead of “Quench. From the viewpoint of applications, QMG is highly attractive because of their excellent and unique features: 1) extremely high trapped field ability in compact space, 2) large current carrying capacity in the presence of strong magnetic fields and 3) automatically stable levitation without active control systems. Intensive research revealed that the optimal RE element is different for different application requirements. Gd-QMG can trap a very high magnetic field and has been used for almost all bulk magnet applications under development, such as ship propulsion motors, wind or tidal power generators, undulators, magnetic drag delivery systems and so on. However, among bulk magnet applications, NMR/MRI requires extremely homogeneous magnetic fields and Gd ion has a comparatively large paramagnetic moment, resulting in reducing the uniformity of trapped fields. The trapped field capability of Eu-QMG is as large as that of Gd-QMG and a Eu ion has a smaller paramagnetic moment. Therefore, Eu-QMG has been chosen for the development of compact cryogen-free NMR/MRI systems. As for current lead applications, Dy-QMG is an ideal material because Dy-Ba-Cu-O has a small thermal conductivity among various RE elements. QMG current leads have some advantages such as a low heat leak, a large current capacity, a superior field tolerance and a robust structure, and as a result they have been practically utilized in many cryo-cooled superconducting magnet systems.

In the size of HTS bulks, a single-grained QMG as large as 150 mm has been successfully fabricated by using a precursor with RE compositional gradient [3]. This large QMG has been incorporated in the superconducting magnetic bearing of the flywheel energy storage project in Japan. As described above, QMG has been making a steady progress and can be expected to create a new frontier field in superconducting applications.


Materials preparation and magnetization of bulk superconductors

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Abstract not available in a digital format.

Reliable growth of primary and recycled (Sm, Gd, Y)Ba2Cu3O7-δ bulk superconductors

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Single grain (Sm, Gd, Y)Ba2Cu3O7-δ high temperature superconductors are able to generate high magnetic fields. However, the relatively high cost of the raw materials and the low yield of the manufacturing process have impeded the development of practical applications of these materials to date. This presentation firstly summarises recent developments by the Cambridge Group related to the reliable growth of (Sm, Gd, Y)Ba2Cu3O7 single grains, including a better understanding of composition change during growth using SEM, the provision of sufficient liquid to sustain grain growth and relatively new buffering technique, which are the foundations of reliable seeding and the growth of single grains. This presentation will describe a simple, reliable and economical method of recycling failed bulk (Sm, Gd, Y)Ba2Cu3O7-δ samples. Sixty-four failed bulk samples, with diameters up to 31 mm, have been recycled with a yield of approximately 90%. The key innovation in this recycling process involves reintroducing the liquid phase into the melt process, which is normally lost during the primary peritectic processing of these materials. This enables
direct, re-growth of failed samples from solid form without the need for re-grinding into precursor powder. Finally, we demonstrate that the superconducting performance and microstructure of the recycled samples are similar to those of the primary grown samples by top seeded melt growth.

**Bulk superconductivity II / Modelling superconductors**

**Single grain YBa$_2$Cu$_3$O$_{7-x}$ bulk superconductors fabricated by buffer-aided top seeded infiltration and growth process**

N D Kumar, Y Shi, K G Palmer, A R Dennis, J H Dunell and D Cardwell

University of Cambridge, UK

Large, single grain (RE)-Ba-Cu-O bulk high temperature superconductors have significant potential for various engineering applications due to their ability to trap large magnetic fields at technologically achievable temperatures. Top Seeded Melt Growth (TSMG) is a well-established processing technique for fabricating large, single grains of (RE)BCO that exhibit superior superconducting properties. However, this process often results in the presence of defects in the fully processed bulk, including shrinkage and macro-cracks in the sample microstructure. In this context, the so-called seeded infiltration and growth (SIG) process has emerged as a viable alternative to TSMG. However, the growth of large single grains of (RE)BCO by this technique is difficult due to various complexities associated with the growth process itself. The provision of a continuous supply of liquid phase during the growth of RE-123 is one of the crucial parameters in this fabrication technique. In the present communication, we will be describing studies to understand and solve some of these complexities that have resulted in the successful fabrication of single grains of YBCO by the SIG process. Also, we have extended a so-called buffer technique to SIG in order to reliably fabricate single grains of YBCO, as shown in Figure-1.

![Figure-1: Photograph of single grain YBCO fabricated by buffer-aided top seeded infiltration and growth process.](image-url)
Modelling and comparison of trapped fields in (RE)BCO bulk superconductors for activation using pulsed field magnetisation

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The ability to generate a permanent, stable magnetic field unsupported by an electromotive force is fundamental to a variety of engineering applications. Bulk high temperature superconducting (HTS) materials can trap magnetic fields of magnitude over ten times higher than the maximum field produced by conventional magnets, which is limited practically to rather less than 2 T. In this paper, two large c-axis oriented, single-grain YBCO and GdBCO bulk superconductors are magnetised by the pulsed field magnetisation (PFM) technique at temperatures of 40 and 65 K and the characteristics of the resulting trapped field profile are investigated with a view of magnetising such samples as trapped field magnets (TFMs) in-situ inside a trapped flux-type superconducting electric machine. A comparison is made between the temperatures at which the pulsed magnetic field is applied and the results have strong implications for the optimum operating temperature for TFMs in trapped flux-type superconducting electric machines. The effects of inhomogeneities, which occur during the growth process of single-grain bulk superconductors, on the trapped field and maximum temperature rise in the sample are modelled numerically using a 3D finite-element model based on the H-formulation and implemented in Comsol Multiphysics 4.3a. The results agree qualitatively with the observed experimental results, in that inhomogeneities act to distort the trapped field profile and reduce the magnitude of the trapped field due to localised heating within the sample and preferential movement and pinning of flux lines around the growth section regions (GSRs) and growth sector boundaries (GSBs), respectively. The modelling framework will allow further investigation of various inhomogeneities that arise during the processing of (RE)BCO bulk superconductors, including inhomogeneous Jc distributions and the presence of current-limiting grain boundaries and cracks, and it can be used to assist optimisation of processing and PFM techniques for practical bulk superconductor applications.

Multiphysics simulation for YBCO coil using line current magnetic energy minimization

W Yuan, H Zhang and Z Zhang

University of Bath, UK

This paper investigates the modeling of the electromagnetic, thermal and mechanical fully coupled field in superconducting coil and compares the results with experiments. The multiphysic behavior of a stack of 30 YBCO tapes during an AC cycle is modeled. Line current model, combined with the critical state model, is used to calculate the current distribution. The magnetic, thermal and mechanical fields are calculated using 2D asymmetric finite element method and fully coupled with line current model. We applied this model to analyze cylindrical geometries with different radii. AC loss with different critical current dependency models have been calculated. The critical current of the coil is predicted and stress field is compared with copper conductor to investigate the screen current effect. The AC loss and critical current are compared with experimental results and have good agreements.
Multiphysics analysis of a high field HTS insert coil

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Following on from a recent study undertaken by Pes et al (Three-Dimensional Magnetic and Mechanical Finite Element Analysis of the HTS Insert Coil [1]) this paper summarizes the methods employed and results gained from performing a similar study of the same system. In this study (in comparison with the original work) the distribution of the Lorentz forces within the coil geometry which are calculated from JxB within each element are included explicitly in the mechanical simulation along with the distribution of Maxwell stress within the ferromagnetic component. Additionally the effect of the geometric deformation on the magnetic system is considered. Results show a 20% reduction in maximum deformation compared with the original study and demonstrate the benefits of including the deformation within the magnetic field calculations as a reduction in the low order harmonic content of the field of up to 5% is seen purely from the deformation.

A full description of the design, scope and purpose of the HTS insert dipole coil can be found in the original paper [1]. The complete DC dipole (figure 1) constitutes an external LTS coil set with HTS insert coil set. The LTS coil set is not considered in the mechanical simulation and hence only the magnetically active parts are included within the coupled simulation. The HTS insert coil set which itself is made up of six HTS windings each with inner radius of 10 mm, an iron pole, and steel support structures is included in its entirety.

Figure 1: Superconducting dipole magnet a) Complete simulated geometry (Including HTS insert), b) HTS insert including support structures, c) HTS coil set.

The paper will explore the set-up and main considerations for multiphysics modelling of such systems including discussion of coupled physics implementations and the potential benefits of undertaking such a calculation within a single CAE software toolset (in this case utilising the coupled physics options within the Opera Simulation Software Suite [2]).

Results include visual representations of magnetic and structural field quantities including the magnetic B field distribution, field homogeneity in the form of associated Legendre expansions of field harmonics on a sphere located in the central region of the dipole, Lorentz and Maxwell stress distributions in and scaled geometric deformation of the HTS coils and support structures.

[2] OperaFEA.com
In general, intrinsic potential of superconductors are quite huge compared to the achieved critical current properties of the superconducting materials thus far, due to non-ideal microstructure and chemical composition as well as insufficient pinning strength.

On the other hand, superconducting tapes using cuprates or MgB$_2$ have been showing significant advances in these several years in terms of productivity, while their critical current properties are still lower than the ideal levels. In other words, there are large rooms remaining for enhancement of their critical current properties. Applicable conditions of long length tapes and wires of various superconductors are summarized in Figure 1 including 122-type iron-based superconductors.

Many hints for further improvements of critical current properties of cuprates, such as BSCCO, REBCO, MgB$_2$ and iron-based superconductors have been suggested through recent studies. Various strategies to improve critical current performance of HTS materials will be discussed from a viewpoint of chemical composition tuning for controlling condensation energy and pinning force.

![Figure 1](Image)

Applicable conditions of long length superconducting tapes and wires and a short length (Sr,K)Fe$_2$As$_2$ (122) tape$^{[1]}$ (engineering $J_c \sim 10^4$ A cm$^{-2}$). Potential of (Ba,K) Fe$_2$As$_2$ (122) single crystals under $H//c$ are also shown with a criterion of $J_c \sim 10^5$ A cm$^{-2}$.

Recent progress of iron-based layered oxypnictide superconductors

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Iron-based compounds were believed to be little potential for high transition temperature ($T_c$) superconductivity because long range magnetic ordering of itinerant electrons competes with formation of Cooper pair requisite for superconductivity.\(^1\) Since the discovery of superconducting LaFePnO$_{1-x}$F$_x$ (Pn = P, As) in 2006\(^2,3\), a considerable number of iron-based compounds has been reported as exhibiting superconductivity. Maximum $T_c$ of iron-based superconductors are attained at temperatures over 58 K.\(^4\) Several iron-based superconductors, e.g. SmFeAsO$_{1-x}$F$_x$ and Sr$_2$VFeAsO$_{3-d}$ (Fig. 1), exhibit very large upper critical magnetic fields (Hc$_2$) at temperatures below 20 K. Hc$_2$ of iron-based superconductors reaches over 100 Tesla. The Hc$_2$ attracts us to attempt for applications.\(^5,6\) In several iron-based high-$T_c$ superconductors, inhomogeneous magnetic phases, which might be interpreted as phase segregation and/or phase separation, are still confusing broad readers, while relationship between long range magnetic ordering and superconducting phase is established.\(^7-11\) Phase diagrams of LnFeAsO$_{1-x}$F$_x$ indicate long range magnetic ordering of carrier electrons does not coexist with superconducting phase. In this workshop, I will review recent progress of iron-based superconductors and focus on determining F contents in layered oxypnictide.

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**References**

Spectromicroscopy of phase-separated iron-chalcogenide superconductors

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Understanding the interplay between superconductivity and magnetism in iron-based superconductors is likely to provide significant insights into the elusive mechanisms responsible for high temperature superconductivity. The co-existence of magnetic order and superconductivity is a common feature of the iron-based superconductors, raising the question of whether these phases are spatially distinct or whether the same electrons are responsible for both phenomena.

In the case of the $\text{A}_2\text{Fe}_2\text{Se}_2$ compounds, with $T_c$ values of about 30K, the intrinsic phase separation is very extreme, with significant chemical and structural differences associated with the spatially distinct electronic phases. Here we will present recent results on the microstructural development of $\text{A}_2\text{Fe}_2\text{Se}_2$ single crystals upon annealing, and how this influences their superconducting/magnetic properties. In addition to analytic electron microscopy studies, scanning photoemission microscopy (SPEM) has been used to investigate the differences electronic structure between the two phases, enabling direct correlation between the electronic properties and chemistry/structure of each phase. Recent work using Photoemission electron microscopy (PEEM) to carry out spatially resolved core level X-ray Absorption Spectroscopy and linear dichroism experiments will also be reported.

A cryogenic NMR study on superconducting endohedral fullerenes

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Recent success in synthetic methods for the encapsulation of $\text{H}_2\text{O}$¹ and $\text{H}_2$² molecules inside $\text{C}_{60}$ cages has instigated a wide range of studies which use $\text{C}_{60}$ as testing grounds for various phenomena. Examples of this are the ortho-para conversion³ and now superconductivity.

$\text{C}_{60}$ can be made superconducting by doping the cage with rubidium in various stoichiometric ratios, for example $\text{Rb}_3\text{C}_{60}$ or $\text{Rb}_6\text{C}_{60}$. $\text{Rb}_6\text{C}_{60}$ is a type II superconductor, with a transition temperature of 30 K. It follows to a good extent the Bardeen-Cooper-Schrieffer (BCS) theory of superconductivity, and therefore makes a good sample for further analysis using encapsulated molecules. Our principal objective in this study was to investigate how the enclosed $\text{H}_2\text{O}$ or $\text{H}_2$ molecules affect the bulk properties manifested through NMR parameters whilst in the superconducting regime.

NMR has played a key role in the test of various proposed theories of superconductivity, principally because different NMR parameters such as $T_1$ and magnetic shift are expected to behave in certain ways which pertain to either conventional or exotic theories. Previous NMR studies⁴,⁵ on normal $\text{Rb}_3\text{C}_{60}$ have indicated near optimal parameters for conventional superconductivity, from exponential behaviour of $T_1$ at very low

Figure 1: Structure of $\text{Rb}_3\text{C}_{60}$ with encapsulated $\text{H}_2\text{O}$ molecule.
temperatures, a Hebel-Slichter coherence peak just below $T_c$ and the temperature dependence of the Knight shift. These results suggest electrons couple through a phonon mediated mechanism.

Samples of superconducting $\text{Rb}_3\text{C}_{60}$ with encapsulated $\text{H}_2\text{O}$ or $\text{H}_2$ molecules have been synthesized for the first time by our group. We have characterized these new materials using NMR and magnetic susceptibility techniques. Static $^1\text{H}$ and $^{13}\text{C}$ NMR data at 4.7 T and 8.5 T have been obtained under cryogenic conditions on samples of $\text{Rb}_3\text{C}_{60}$ with either $\text{H}_2\text{O}$ or $\text{H}_2$ encapsulated inside, both in the normal and superconducting state. Study of $\text{H}_2@\text{C}_{60}$ allows separation of effects of a host molecule from the effect of the dipolar moment, which is present in $\text{H}_2\text{O}$, allowing us to understand how it contributes to the superconducting properties.


Superconducting materials II

(keynote) Superconductors in fusion energy tokamaks

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The ITER Tokamak currently being built in France is the most important experiment on the planet. If ITER is successful, we expect it to be the last large international experimental reactor built before the commercialisation of fusion.

The talk will review 3 current research areas related to the superconducting strands: i) the European reference laboratory for ITER in Durham ii) superconducting joints enabling demountable magnets in tokamaks and iii) superconductors under strain in high magnetic fields. The work will be placed in the context of this fabulous large-scale $15\text{B}$ tokamak.

Magnetic levitation between permanent magnets and HTS tape stacks in coil configurations for bearing applications

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Superconducting tape can be cut and arranged into blocks and slabs to form a type of composite bulk capable of sustaining persistent currents. Previous research has shown that the thermal and mechanical properties of the non-superconducting materials in the tape, together with their well-defined and uniform $\text{J}_c$, make it possible to use such stacks as trapped field magnets. The work reported here uses stacks of tape for magnetic levitation by field cooling the stacks in the field of rare-earth permanent magnets. The stacks are in the form of ‘coils’, but without the two ends joined to current leads as shown in Figure 1a, so that there is no net transport current. The purpose of these stacks is
to act as composite bulks providing a stable levitation force for displacement of the permanent magnets, in a geometry designed to be used as a rotary superconducting bearing. Force hysteresis loops for ‘coil’ arrangements like those shown in Figure 1b were measured between 20 – 77 K showing that over 300 N of force can be generated at lower temperatures which is close to the maximum possible force for a plain superconducting cylinder, predicted by using the perfectly trapped flux (PTF) model. The motivation for using HTS tapes for the stator component of a superconducting bearing is primarily the flexibility in geometry. It is easy to wind tape into cylinders, like in this case, as well as creating blocks and slabs. It is perhaps surprising that the ‘coils’ reported can sustain strong levitation forces given that there are no directly circular superconducting current paths. FEM modelling in COMSOL using the H-formulation for the superconducting critical state, will be used to explain what type of current paths are set up and how they result in the forces measured. Measurements of the more complicated dynamic stiffness of the system will also be reported.

![Figure 1: a) Two of the three superconducting tape ‘coils’ wound on the stator to act as composite superconducting bulks. b) Experimental arrangement of a permanent magnet stack coaxially aligned within three tape ‘coils’ for axial levitation force testing.](image)

**Superconducting flux pumped magnets**

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The Electrical Power and Energy Conversion (EPEC) superconductivity group at Cambridge University has been working on the use of flux pumping to activate superconducting magnets. In this paper we report the current status of the flux pumping technology. The paper will show first the fundamental principles of the flux pump, second the performance and finally the potential applications both in the near and the far term. Flux pumping enables the magnetisation of superconducting permanent magnets by the application of time varying magnetic fields. Using this technique means that superconducting coils can be operated in persistent mode without the need for either current leads or a persistent current switch and that magnetisation can be achieved without the need for high current power supplies or external sources of magnetic fields. The research is underpinned by advanced modelling techniques using both pure Critical State models and E-J models to analyse the behaviour of the superconductors.
Experimental analysis on critical current degradation of HTS tape with different impregnation materials

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One challenge in fabricating superconducting magnets is to find the proper encapsulating material to give mechanical integrity to the magnets. This paper analyzes critical current degradation of HTS tape during impregnation process experimentally and numerically. Several different impregnation materials have been implemented, such as GaInSn, Stycast 1266 and Araldite. The experimental results show that the critical current of YBCO short samples varies with different materials. The epoxies, such as Stycast 1266 and Araldite, degrade the critical current, however, the GaInSn shows no degradation. Then the strain and stress of the HTS tapes are measured. It is found that the critical current degradation is highly related to the thermal stress induced by the mismatch of thermal expansion between the HTS tape and the impregnation materials. The degradation is caused by the transversal tensile stress. Finally, a FEM model has been proposed to simulate the thermal stress during the cooling from room temperature to liquid nitrogen. From the simulation results, some recommendations for choosing impregnation material have been suggested.

Superconducting materials III / Charge density waves in cuprates

Soldered lap joints between RE-BCO coated conductors for demountable fusion magnets

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The realization of de-mountable magnet coils would offer significant benefits to the development of commercial nuclear fusion power plants, from improved maintenance to greater design flexibility. This talk describes a programme of work aiming to understand the fundamental properties of jointed superconductors. Jointed high temperature superconductors were fabricated from In₅²Sn₄₈ and Pb₃₈Sn₆₂ soldered joints consisting of a thin layer of solder sandwiched between two Rare-Earth- Ba₂Cu₄O₇ (REBCO) 2G high temperature superconducting (HTS) coated conductors. The electrical and thermal properties of this basic building block in demountable HTS joints are presented together with numerical modelling data, critical current (Ic) and resistivity measurements on the joints from 300 K to 4.2 K in applied magnetic fields up to 12 T, as well as scanning electron microscopy (SEM) studies. Numerical analysis, verified by comparison with analytic calculations, shows that the resistive current density is almost uniform within the solder/copper/silver layers and that the copper/silver layers significantly reduce the effects of heating in the joints to less than a few hundred mK. Resistivity measurements and complementary SEM data show that when the REBCO alone is superconducting, the joint resistivity predominantly has two sources, the solder layer (∼20 - 30 nΩ·cm²) and an interfacial resistivity (Ri) at the REBCO/silver interface which is ∼25 nΩ·cm² in the as-supplied coated conductors. The joint has zero or very weak magnetoresistance in fields up to 12 T which has been confirmed for all angles between the surface of the tapes and the direction of the applied magnetic field and is consistent with the low magnetoresistance measured for the solders and a low magnetoresistance for the interfacial resistance.
Inductive resistance testing by SQUID magnetometry – A novel tool for characterising superconducting joints
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Persistent current joints are critical components of superconducting magnets, and improvements in their properties is widely regarded as imperative for the production of next generation devices. Research into joints is presently constrained by the inability to easily characterise their superconducting properties both quickly and with high precision.

Presented here is a novel inductive resistance testing (IRT) technique performed using a widely available commercial magnetic properties measurement system (MPMS). The technique offers a simple, rapid and highly sensitive means of obtaining the key superconducting properties pertinent to joint performance ($I_c(B,T)$ and $R(I,B,T)$) – a major breakthrough that we believe will accelerate joint development.

(keynote) Spin and charge fluctuations in high temperature superconductors
S Hayden
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It is becoming increasingly clear that the cuprate high temperature superconductors have a tendency to a number of types of competing order. This is particularly clear near $p=1/8$ doping in the pseudogap phase of these materials. In La$_{2-x}$Sr$_x$CuO$_4$, incommensurate spin order was observed near $p=1/8$ by elastic neutron scattering [1]. More recently, in YBa$_2$Cu$_3$O$_{6+x}$, NMR [2] provided evidence for charge density wave (CDW) order which was subsequently observed by x-ray diffraction [3,4]. In this talk, I will discuss our x-ray measurements on YBa$_2$Cu$_3$O$_{6+x}$ and La$_{2-x}$Sr$_x$CuO$_4$ as function of doping [3,5,6]. We have observed CDW order in both materials and have demonstrated the strong competition between superconductivity and the CDW near 1/8 doping. Further we have mapped out the phase diagram of the various competing orders [5,6]. I will also show evidence for intertwined charge/spin order suggesting the microscopic existence of stripes.

Charge density waves in cuprates

Ionic displacements in the charge density waves in YBCO measured in the bulk by X-rays

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Using medium-energy X rays at the XMaS beamline at the ESRF, we have measured the intensity of a large number of Charge Density Wave (CDW) satellites in YBCO. This underdoped High-Tc material has a superconducting Tc of ~58 K and a CDW onset temperature ~ 155 K [1]. The chain oxygens are extremely well-ordered with alternate CuO2 bilayers unoccupied (the ortho-II structure). The CDW measurements were performed at Tc, where the CDW satellites have their maximum intensity. The intensities were fitted using a two rather general models of atomic displacements throughout the unit cell, under three assumptions: (i) that the pattern of ionic displacements is centred on the CuO2 bilayers (this is supported by NMR [2] & resonant X-ray [3] results); (ii) that alternate unit cells in the c-direction are in antiphase [4]; (iii) that the ionic displacements are in the direction of the CDW q vector, and/or in the c-direction. The large number of ions in the unit cell means that the amplitudes of about a dozen ionic displacements contribute to the pattern of weak and strong satellites. We have searched through a complete combination of relative signs of the displacements for both models and iterated to unique fits to the observed intensities for the CDWs modulated along both a & b directions. The ionic motions mandated by our results are more subtle than the simple “bond d-density wave” picture supported by STM measurements [5].


Charge density wave fluctuations in La2−xSnxCuO4 and their competition with superconductivity

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Soon after the discovery of HTS it was postulated the superconductivity might be related to charge or ‘stripe’ correlations [1]. This idea has recently been reinvigorated with the observation of such correlations in YBa2Cu3O6+x by NMR [2] and X-ray scattering [3,4]. Charge density wave (CDW) order appears to onset within the ‘pseudogap’ regime and is suppressed on entering the superconducting state suggesting the two order parameters are strongly coupled and competing. CDW order has also been observed in the La2−xBaxCuO4 system [5] promoting the idea that this order is a generic feature of the cuprates. However, both these systems suffer structural complications (CuO2 bilayers in YBCO and the LTT phase in LBCO) making it difficult to establish whether charge order is inherently linked to the superconductivity in these systems or merely arises due to these structural features.

Here, we report hard (14 keV) X-ray diffraction measurements on three compositions (x = 0.11, 0.12, 0.13) of the high-temperature superconductor La2−xSnxCuO4, a canonical example of HTS with Tc ~ 35 K and a simple crystal structure. All samples show CDW order with onset temperatures in the range 51–80 K and ordering wave vectors.
close to (0.23,0.0.5) [6]. On entering the superconducting state the CDW is suppressed, demonstrating the strong competition between the charge order and superconductivity. CDW order coexists with incommensurate magnetic order and the wave vectors of the two modulations have the simple relationship $\delta_{\text{charge}} = 2\delta_{\text{spin}}$. We present a phase diagram of La$_{2-x}$Sr$_x$CuO$_4$ including the pseudogap phase, CDW, and magnetic order.


Correlation strength and $T_c$: Quantum oscillations in YBa$_2$Cu$_4$O$_8$ under hydrostatic pressure

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The unusual normal state electronic structure of the cuprates is widely believed to be at the heart of understanding high-temperature superconductivity in these materials. Recent quantum oscillation measurements in YBa$_2$Cu$_4$O$_8$ (Y123) have found a strong increase in the quasiparticle effective mass close to two separate critical points in the temperature-doping phase diagram [1]. Here we present a study of quantum oscillations in the double chain cuprate superconductor YBa$_2$Cu$_4$O$_8$ (Y124). Instead of varying the doping by changing $\delta$ (in Y123) we study the evolution of the quantum oscillations under hydrostatic pressure. Pressure increases $T_c$ by around 0.6K/kbar, primarily, it is thought, by increasing charge transfer between the chains and planes. Unlike in Y123, where the increase in $T_c$ close to optimal doping is accompanied by a strong increase in quasiparticle mass, in Y124 we find that the mass decreases. Our results suggest that the mechanism that leads to the mass enhancement in the cuprates (most likely the emergence of a competing charge density wave instability) does not directly lead to an enhancement of the superconducting critical temperature.


Small-scale / Electronics

(keynote) Ultra-energy-efficient adiabatic superconducting logic: what is the minimum energy limit in computation?

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The recent rapid increase in the energy dissipation of high-performance computers brings about a lot of attention to the energy efficiency in logic devices. The minimum energy limit in the switching operation of logic devices is old but still unsolved question after Landauer predicted that the energy of $k_B T \ln 2$ was dissipated in the irreversible logic operation [1]. We are investigating ultra-energy-efficient adiabatic superconducting logic based on the adiabatic operation of quantum flux parametron (QFP) [2]. In this talk we show our recent research progresses in the adiabatic superconducting logic. It will be shown that adiabatic quantum-flux-parametron (AQFP) logic [3] exhibits extremely
high energy efficiency, whose bit energy approaches the Landauer limit given by \( k_B T \ln 2 \) [4]. We also propose physically and logically reversible AQFP logic and demonstrate its reversible logic operation, where the minimum energy limit in the switching operation is not exist in numerical simulations [5]. In experiments, we confirmed that the switching energy of the AQFP logic is approximately 10 \( zJ/\text{bit} \) at 5 GHz operation frequencies [6], which is five or six orders of magnitude smaller than that of state-of-the-art semiconductor devices. Our recent research activities for realizing large-scale AQFP logic circuits, including 8-bit carry-look-ahead adders and microprocessors will be also shown [7], [8].


**Development of NEMS resonators coupled to a nanoSQUID**

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The growing interest in nanoelectromechanical systems (NEMS) devices is due to vast potential applications in both classical and quantum measurements. At low temperatures, nanoscale mechanical resonators exhibit quantum behavior. Nanoscale Superconducting Quantum Interference Devices (nanoSQUIDs) are capable of detecting this quantum behavior which is subsequently converted into an electrical readout. By coupling the two systems we would be able to convert measurements of the motion of NEMS resonators into an electrical readout given by a SQUID. The eventual aim of this project is to use a graphene membrane as the resonator in a ‘drum’ configuration. The mechanical motion of this conducting membrane will be sensed by a closely coupled nanoSQUID. Graphene, despite being one atom thick, has shown high strength and stiffness. We require that graphene ‘drum resonators’ should also exhibit a high mechanical quality factor.

Graphene has already been transferred onto photolithographically patterned Si/SiO\(_2\) and focussed ion beam milled Si\(_3\)N\(_4\) substrates with a range of supporting structure sizes from 40\(\mu\)m in diameter down to 0.25\(\mu\)m. A possible excitation method of these mechanical resonators uses amplitude modulated or frequency modulated microwaves, incident from a near-field quarter wave coaxial dielectric resonator. The microwave excitation and detection system has been tested using a lead zirconium titanate (PZT) drum and room temperature non-linearity has been observed with graphene drums.

For effective direct coupling the size of the SQUID coil must match the shape and size of the moving parts of the NEMS resonator. Thus the SQUID loop must be sub-micron in size. By fabricating weak link ‘nanobridge’ junctions made by focussed ion beam milling (FIB) we are able to produce junctions approximately 65nm in length and width and SQUID loop dimensions down to 1\(\mu\)m by 100nm (Fig.1). In this poster we will report progress on all of the above elements aimed towards integration into a final coupled system.
Tunable microwave oscillators based on an asymmetric flow of vortices in YBa$_2$Cu$_3$O$_{7-3}$ Josephson-junction arrays and operating at 77K and above

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Josephson flux-flow oscillators based on the unidirectional and viscous flow of magnetic flux quanta in a single long Josephson junction (JJ) have been successfully employed in fully superconducting-integrated submillimeter-wave receivers [1]. Similar magnetic field, B, tunable microwave oscillators based on the flux-flow in parallel arrays of JJs have also been successfully operated by several groups [2-3] and their emitted microwave radiation has been measured too [4]. Such superconducting oscillators made of low temperature superconductors (LTS) and operating below 9K have several advantages over semiconductor ones such as the ability to generate microwaves over a wide range of frequencies (from several GHz up to THz), their wide range B-field tunability and low noise operation. The discovery of cuprate superconductors with transition temperatures well above 77 K immediately enhanced the interest in such devices. This is because of the increasing interest in employing some semiconductor technologies at lower operation temperatures. It looks attractive, therefore, to try and link semiconductor and superconductor technologies to fabricate hybrid devices and improve system level performance. For many years, however, the highly anticipated B-field tunable microwave oscillators made of cuprate JJ arrays and operating at 77K eluded experimental demonstration. Recently, however, this situation changed quite dramatically when the first realization of such microwave oscillators made of parallel arrays of 440 YBa$_2$Cu$_3$O$_7$ bicrystal grain boundary JJs and operating at 77K and above has been reported [5]; significantly the operation of the oscillators appeared to be remarkably stable. We believe this significant progress was possible due to a specially designed parallel array of JJs where an enhanced asymmetric, unidirectional, flow of vortices was achieved through the use of a ratcheting effect. At 77 K we estimate that the device has a B-field tunable power of about 0.1 μW within the frequency range (1.5–25) GHz. Recent investigations have revealed that the B-field tunability is superior when vortices are moving up-hill against the ratchet potential, while microwave generation is more intense in the case vortices are moving down-hill with the ratchet potential. Results of further investigations will be presented [6] on an improved second generation of similar microwave oscillators operating at 77K and above.

We would like to discuss new superconducting materials we recently discovered with emphasis of physics involved. The topics will include the followings.

1. Superconductivity (Tc=3.7K) at Pseudo-gap critical point (Ru,As)P [1].
2. Superconductivity (Tc=5.6 K) in Ta2PdS3 with a high upper critical field violating the Pauli limit [2].
3. Superconductivity at Tc=8.4 K in semi-metallic antiperovskite Sr3PtP [3].
4. Two dimensional superconductivity at the interface between semi-metallic BaPbO3 and charge density wave insulator BaBiO3 [4].


Rectifying a fundamental flaw in BCS theory

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Validity of the BCS theory was questioned recently [1]. We have had associated discomfort for some time [2]. There is a lack of quantitative evidence to support the electron-phonon interaction as the underpinning mechanism of BCS theory. Consistency has not been achieved for this interaction in the superconductive and normal states: either the calculated electron-phonon spectral density, $\alpha^2 F$, is too strong when the electric resistivity, $\rho$, is reasonable or else the resistivity is too weak when $\alpha^2 F$ is reasonable [3, 4]. We identify the flaw as lying in the BCS pairing scheme: the angle of scattering is not supposed to exceed 180°, because electron occupation probability has already been determined by symmetry in the other half of the Fermi surface. However we must recognise that in an umklapp process the scattering angle can exceed 180° resulting in a contradiction [3, 4].

A new pairing scheme is proposed, within it there is mutual normal-umklapp cancellation and superconductivity arises exclusively from residual umklapp electron-phonon interaction [3, 4]. The occupation probability of the paired electron state is no longer doubly defined. Therefore the overly strong $\alpha^2 F$ is duly weakened. To scrutinize the idea we determine the atomic pseudo-potential, $V$, in both the normal and superconductive states via inversion [5]. In the normal state we invert $\rho$ over $0 < T < 295$ K, resulting in $V$ as shown in the figure as the continuous solid curves. In the superconductive state we invert the tunneling current, with the new pairing scheme, resulting in $V$ as shown in
the figure as open circles. With the original BCS pairing scheme we find $V$ as shown by the solid squares. The success of the new scheme is evident.

We use the first principles $V$ for the normal state (solid continuous curves in the figure) to predict $\Delta_0$ (superconductive gap at $T = 0$). We find accurate $\Delta_0$ for Nb, Ta, Pb and Al. We predict $\Delta_0$ for W, Ir and Mo (experimental $\Delta_0$ unavailable) [6]. We also predict $\Delta_0$ for Nb (experimental $\Delta_0$ maybe unreliable). With the new pairing scheme we explain Matthias’ rule that superconductivity favours high valency metals but question the high $T_c$ predicted for metallic hydrogen [7].

The BCS pairing scheme has been widely employed in various theories for exotic high temperature superconductors: they too may have to be rectified to become quantitatively consistent with the effect of their underpinning mechanism in the normal state to become more convincing.
The resonant electromagnetic response of niobium metamaterial shows strong temperature variation near the critical temperature in the visible wavelengths, i.e. above the superconducting bandgap. Plasmonic mechanism of the optical response is discussed.

The low loss and unique electromagnetic properties of superconductors present an opportunity for achieving metamaterials with extreme nonlinearity and tunability. To date all demonstration of these superconducting metamaterials have been reported in microwave, millimetre wave and THz wave regime. The response of such metamaterials has been tuned with incident light, magnetic fields, electrical current and temperature.

Here we report for the first time the response of a tunable superconducting metamaterial operating at visible wavelengths. The metamaterial sample was fabricated by depositing a 300 nm niobium (Nb) film (transition temperature of 9.2 K) on a sapphire substrate (0.5 mm thick). An array of slits (each with length $L=350$ nm and width $w=100$ nm) covering a total area of $100 \mu m \times 100 \mu m$ milled by using a focused ion (FIB) beam to the Nb film. Our metamaterial sample was then placed inside the closed-cycle optical cryostat that provides temperature control range of 4-300 K. The experimental setup is depicted schematically in Fig. 1(a). The scanning electron microscope (SEM) image of the nano-slit is shown in Fig. 1(b). In this study, incident light is polarized in the $y$ direction as defined in Fig. 1(b). Optical spectra were collected as a function of temperature using this optical cryostat. Light from a broadband supercontinuum source was focused to an approximately $50 \mu m$ diameter spot onto the metamaterial.

Absorption spectrums of the metamaterial at temperatures above and below superconductor transition temperature ($T_c \approx 9.2$ K) as a function of wavelength (450-1050 nm range) are shown in Fig. 1(c). We used relatively low (100 $\mu W$) illumination intensities which are estimated not to affect the superconducting state. Our metamaterial shows temperature dependent resonance strength and spectral features (see wavelengths 651 and 783 nm in Fig. 1(c)). The strongest resonance is occurred at temperature 4.5 K far below Nb film $T_c$ as represented by sharp dip at 651 nm and peak at 783 nm. As the temperature increases both resonances shrink and gradually broadening. The dip in adsorption spectrum at 651 nm vanishes completely when temperature goes above $T_c$. In the presentation we will discuss this physics and show that experimental observations are in good agreement with the simulation results performed by 3D Maxwell equation solver COMSOL modelling package.
Magneto-optical imaging: A tool for fundamental physics and applications of superconductivity

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Magneto-optical imaging (MOI) is the only non-scanning technique that allows directly observing magnetic flux distribution in superconductors (and magnetic materials) as function of temperature, current or external magnetic field [1].

Here we report recent results of the application of MOI in fundamental and applied physics of superconductivity. In particular, MOI reveals new, previously hidden properties of dendritic flux avalanches invading thin superconducting films. It was found that avalanches could be treated as shock electromagnetic waves and similar to them display reflection and refraction on interfaces separating media with different speed of dendrite propagation [2]. We will also report first imaging of surface superconducting state in a bulk Nb single crystal that similar to thin films demonstrates effect of dendritic flux instabilities [3].

On the applied side of research, the unusual blade-like penetration of magnetic flux in melt-grown YBa₂Cu₃Oₓ used for commercial purposes will be discussed [4] together with an unexpected property of nanostructured columnar-grown YBa₂Cu₃Oₓ films that display increase of critical current density with time [5]. A potential of conductive covers for protection of electronic superconducting circuits from dendritic flux avalanches, as it is revealed by MOI, will also be discussed.


High $T_c$ superconductivity

(keynote) Physics of iron-based high temperature superconductors

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The discovery of high-$T_c$ iron pnictide and chalcogenide superconductors has been one of the most exciting recent developments in condensed matter physics. Although there is general consensus on the unconventional pairing state of these superconductors, several central questions remain, including the role of magnetism and orbital degrees of freedom and the resultant superconducting gap structure. The search for universal properties and principles continues. Here I review the recent progress of research on iron-based superconducting materials, highlighting the important questions that remain to be conclusively answered.

Superconducting gap structure and quantum criticality in the iron-pnictide: BaFe$_2$(As$_{1-x}$P$_x$)$_2$

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Amongst the different families of unconventional superconductors, the iron pnictides seem to be unique in that the structure of the superconducting energy gap $\Delta$, i.e., how it varies with momentum $k$ on each Fermi surface sheet, can vary dramatically between different materials. This is despite the fact that the Fermi surfaces of all the iron-pnictides are quite similar, consisting of quasi-two-dimensional electron and hole pockets. It has been proposed theoretically that subtle differences in the Fermi surface topology, the structure of the magnetic interactions and possibly also the effect of orbital order fluctuations can lead to a switch between different gap structures. The structure of $\Delta$ and how this varies between different iron-pnictide compounds therefore provides a strong test to discriminate between candidate microscopic theories of the superconductivity. Unfortunately, experimentally determining the gap structure is not at all straightforward and various different probes have been used with varying levels of success.

Here I will present a study of the superconducting gap structure in the iron-pnictide series BaFe$_2$(As$_{1-x}$P$_x$)$_2$ using specific heat. By measuring the variation of the specific heat as a function of temperature and magnetic field we are able to determine the number and Fermi surface location of the nodes in the superconducting gap. In particular, from measurements of the variation of the specific heat as the magnetic field is rotated in the ab plane of the sample we conclude that the nodes are in the [110] directions. Then from a quantitative analysis of the temperature and field dependence of the specific heat we further conclude that nodes exist on all Fermi surface sheets. Surprisingly this
structure does not seem to vary significantly as a function of $x$ (or $T_c$), however, close to the quantum critical point (QCP) $x=0.3$ the field dependence of the Sommerfeld coefficient becomes anomalous. We argue this may result from field dependence of the mass normalisation and unusual behaviour of $H_{c2}$ close to the QCP.

Work done in collaboration with L. Malone, P. Walmsley, C. Putzke (University of Bristol), S. Kasahara, Y. Matsuda (Kyoto University), Y. Mizukami, T. Shibauchi (Kyoto University and University of Tokyo).

Doping dependence of intrinsic Josephson properties in $Pb_{1-y}Sr_2Y_{1-x}Ca_xCu_{2+y}O_{7+δ}$ epitaxial films

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Recently, we have found that the intrinsic Josephson junctions (IJJs) of $Pb_{1-y}Sr_2Y_{1-x}Ca_xCu_{2+y}O_{7+δ}$ ($Pb1212$) exhibit highly underdamped behavior[1]. Highly underdamped IJJs in low anisotropic cuprate like $Pb1212$ can be suitable for high power and high frequency application, because IJJs in low anisotropic cuprate usually exhibit high Josephson critical current $J_c$ and high plasma frequency $\omega_p$. Blocking layers of $Pb1212$ are composed of chemically dissimilar elements, $Pb$ and $Cu$. This makes superconducting properties of $Pb1212$ different from other cuprates especially in the doping characteristics. For example, the career concentration increases with decreasing the oxygen content $δ$. We consider that single ($Pb,Cu$)-$O$ blocking layers in $Pb1212$ also make the $c$-axis IJJ properties peculiar, thus their doping dependencies include important information.

$Pb1212$ epitaxial films were grown on $SrTiO_3$ (100) substrates by an ex-situ growth technique[2] and small mesa structures ($S = 2-10 \, \mu m^2$) were fabricated on top of a film surface using a standard photolithography and an $Ar$ ion milling technique. It is found that $J_c (4.2 \, K)$ increases with increasing the doping level similar to other cuprates. Meanwhile, Superconducting/Insulating/superconducting (SIS) feature found in $J_c (T)$ was observed even in highly doped samples. This is different from the IJJ characteristics of other cuprates like $YBa_2Cu_3O_7$, in which SIS feature is seen in highly underdoped region while SNS feature is seen in slightly underdoped region.


The electronic structure of superconducting FeSe

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FeSe is structurally the simplest of Fe-based superconductors, and exhibits a tetragonal-to-orthorhombic structural transition at $~90 \, K$ and a superconducting transition at $~8 \, K$ but no long-range magnetism at any temperature. High quality single crystals of FeSe provide a unique possibility to investigate the electronic structure of a Fe-based superconductor below the orthorhombic structural transition in the absence of magnetic reconstruction. Above the structural transition, our angle-resolved photo-emission spectroscopy measurements reveal strong band renormalisations and shrinking of the quasi-2D electron and hole Fermi surfaces compared to density functional theory calculations in the tetragonal phase. However below the structural transition, dramatic symmetry-breaking distortions of the electronic structure near the Fermi level...
results in small, elliptical Fermi surfaces. Our ARPES measurements are consistent with our quantum oscillations studies in high magnetic fields and by combining ARPES, quantum oscillations and transport studies we come to a consistent understanding of the band structure of FeSe.

High magnetic field studies of the vortex lattice structure in Y0.96Ca0.04Ba2Cu3O7

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Small-angle neutron scattering (SANS) measurements of the vortex lattice structure as a function of field and temperature make it possible to extract information such as the penetration depth, coherence length and the superconducting gap structure of a given superconductor. In YBa2Cu3O7-δ (YBCO) SANS can reveal the effective mass anisotropy, the vortex lattice melting, the vortex lattice pinning [1] and the field-induced non-locality [2]. In YBCO the oxygen doping level alters the population of oxygen atoms in the ‘chain’ layers where Cu-O chains lie along the b-axis. Varying the amount of oxygen changes the number of available holes and this tunes the superconductivity. An alternative to oxygen doping in YBa2Cu3O7-δ is doping the yttrium sites with calcium whilst leaving the compound fully oxygenated (δ = 0).

We present a SANS study of Y0.96Ca0.04Ba2Cu3O7 [3] at magnetic fields up to 17 T. The calcium doping increases the hole concentration in the copper-oxide planes beyond that found in YBa2Cu3O6, so this material is overdoped. We find differences between the two compounds in the vortex lattice structure and coordination at base temperature as a function of applied magnetic field that indicate changes in the superconducting order parameter, and we also find that non-local effects become important at high fields. We also investigate the perfection of the vortex lattice and the variation of the SANS signal at higher temperatures. The vortex lattice form factor and structure provide evidence that the inclusion of calcium into YBa2Cu3O7 increases the strength of pinning of the vortices.


The evolution of microwave conductivity in YBa2Cu3O6.5 across the superconducting dome

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The rich phenomenology displayed in the phase diagram of the high-Tc cuprates continues to be an active area of investigation. Recent experimental and theoretical work appears to be converging on a picture of separate spin and charge order phase transitions - well-below and near optimal doping, respectively - along with associated Fermi surface reconstruction. As sensitive probes of the low-energy electrodynamics, microwave spectroscopy techniques are well-suited for characterizing the effects of such changes in electronic structure deep within the superconducting state.
I will present the results of our survey of the complex microwave conductivity of YBa$_2$Cu$_3$O$_{6+x}$ over a wide range of oxygen contents, from 6.49 to 6.998, and discuss their implications for the evolution of electronic structure with doping. In particular, I will highlight the apparent absence of a peak in penetration depth near the proposed $\rho = 0.18$ quantum critical point (QCP), contrasting with its presence near the antiferromagnetic QCP of the pnictide superconductors. I will also discuss the surprising relationship we observed between quasiparticle scattering lifetimes and oxygen ordering, which carries important implications for quantum oscillation measurements.
P:01 The critical current of high field superconductors under strain for fusion applications

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Superconducting magnets are an essential part of achieving the goal of fusion energy generation using a tokamak. The current generation of state of the art fusion tokomak’s use low temperature superconducting magnets. High temperature superconducting tapes show great promise as a possible replacement for low temperature superconductors in future devices. This work aims to assess the suitability of these tapes for use in fusion magnets by looking at the variation in critical current and upper critical field with temperature, field, angle and applied strain.

P:02 Modular superconducting toroidal transformer with cold magnetic core

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Motivation. The results presented in this paper have been obtained in the research being continuation of previous research devoted to superconducting toroidal transformer [1].

The main result in [1] is the transformer that has relative high power density (~700 W/kg - measured) and it depends on frequency (e.g. 1 kW/kg at 70 Hz). The transformer was made of YBCO tape; amorphous material Metglas 2605SA1 was used for magnetic core; the whole transformer was cooled with LN2. The research has been carried out by means of FEM (ANSYS) and also confirmed experimentally. The toroidal transformer offers many advantages over standard transformer. Proposed in this paper transformer is the assembly of single toroidal transformers such as in Fig.2 (resulting turn-to-turn ratio of three module transformer connected as in Fig. 2 is 3:2) [2].
The final version of the paper will contain results of FEM analysis of modular transformer, where distribution of magnetic flux, electrical field and capacitances between turns and voltage distribution over windings and connections between them will be included.

Conclusions:
1. Advantages of modular transformer are similar to single toroidal transformer.
2. Present transformer has higher surface that increases intensity of cooling.
3. Described construction exhibits flexibility, which allows to fit transformer to the rest of electronic device.
4. Modular transformer enables to reach higher nominal power by means of increasing operating voltages.
5. SFCL (Superconducting Fault Current Limiter) will be continuation of presented work.


P:03 DC characterization and 3D modelling of a triangular-shaped, epoxy-impregnated high temperature superconducting (HTS) coil

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The study of DC characterization of high temperature superconducting (HTS) coils is important for HTS applications, such as electric machines, superconducting magnetic energy storage (SMES) and transformers. In this paper, the DC characterization of a triangular-shaped HTS coil made from YBCO coated conductor for a prototype axial flux HTS electric machine is presented. Multiple voltage taps were utilized within the coil during measurement to help provide further detailed information on the DC characterization of the coil. Detailed information on the critical current density’s dependence on the magnitude and orientation of the magnetic flux density, \( J_c(B, \theta) \), determined from measurement of short samples of the coated conductor comprising the coils, allows predictions and analysis of the DC properties by numerical analysis. The \( J_c(B, \theta) \) data is directly included in the numerical model by a two-variable direct interpolation to avoid developing complicated equations for data fitting. Numerical analysis can help predict the performance of practical HTS devices and assist in interpreting experiment results. The coil is simulated by a new 3D HTS coil model that utilizes the real superconducting layer thickness, and this model allows simulation of the actual geometrical layout of the HTS coil structure. Issues related to meshing the finite elements of the 3D real thickness model is discussed in details. Based on the measurement and simulation results, it is found that non-uniformity along the length exists in the coil, which can result in imperfect superconducting properties in the coated conductor, and hence, coil. By evaluating the current-voltage curves using experimental data, it is seen that a decreasing \( n \) value and critical current exists in the non-uniform part of the HTS coils, and the experiment results are finally analysed and verified using the finite-element model.
P:04 Modeling of the current limiting performance of a resistive superconducting fault current limiter prototype
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A finite element model, which couples a 2D superconductor model and an electrical circuit model in COMSOL, is proposed to simulate the performance of a 220V resistive superconducting fault current limiter (SFCL). In the 2D superconductor model, an electromagnetic model and thermal models are coupled together to study both the electrical and thermal characteristics of superconductor during quench. What is more, a new E-J relationship is proposed to describe the electrical characteristics of superconductor in the simulation. Comparison between simulation results and experimental results shows that the proposed model performs well in simulating the current limiting property of resistive SFCL.

P:05 Superconducting solders for the 21st century
T Mousavi, C Aksoy, S Speller and C Grovenor
University of Oxford, UK

Restrictions forbidding the use of Pb alloys in the near future is a serious concern for superconducting magnet manufacturers. We are studying the Sn-In system as a potential substitution for Pb-Bi alloys for superconducting joints between NbTi superconducting wires. SnₓIn₁₋ₓ alloys of various compositions have been fabricated into 2-mm cylindrical bulks and the influence of chemistry and microstructure on the superconducting properties have been investigated. The Sn-In solder bulks were characterized using analytical scanning electron microscopy (SEM), X-ray diffraction (XRD) and SQUID magnetometry. The results show transition temperatures (Tc) above 4.2K for all of our Sn-In studied alloys. Tc decreases with increasing Sn content from the eutectic composition. By quenching the samples, the phase chemistry and microstructure can be manipulated, leading to higher values of Tc, critical current density and critical field.

P:06 The planet’s most important experiment
M Raine, Y Tsui, A Dawson, M McBreen, M Plumb, E Roe and D Hampshire
Durham University, UK

Our usage and reliability on readily accessible energy supplies has placed the human race in a very precarious position. The continued maintenance of our modern day lifestyles has burdened our planet into giving up its energy reserves and our use of these reserves has in return damaged our planet. The need to remedy this situation without disruption has led to a confused reaction in which “green” energy alternatives, such as wind farms, solar power and tidal barrages are being sold as the solution; although there is a growing realisation that they are not. The issue is further compounded by a reluctance to use the nuclear option, which has proved itself to be a reliable form of energy extraction, but has also driven fear into the general public with catastrophic accidents such as the Chernobyl disaster (1986), and more recently, the Fukushima disaster (2011). These and other nuclear-based public fears have stymied awareness of the possibility of a much safer, long term, nuclear solution… fusion.

One of the main benefits of fusion over fission is that it fails safe. Once ignited, fission is difficult to stop. Conversely, fusion is difficult to maintain. The International Thermonuclear Experimental Reactor (ITER) is a €15 billion global attempt at obtaining a net energy gain from sustained nuclear fusion reactions. These reactions occur within a hot plasma that burns at 150-million °C – 10 times the temperature of our Sun. The only feasible means of...
containment is to use large magnetic fields to shape and control the plasma. These strong fields are also used to help heat the plasma to the required temperature. The magnet systems are therefore essential to the success of the project. Furthermore, in order to obtain a net energy gain from fusion, conventional electromagnets cannot be used due to their large energy requirement. Fortunately, superconductors, once cooled to below their transition temperature, enter a resistanceless state that drastically reduces their energy burden. Superconducting magnets are therefore the enabling technology in this profound venture.

The magnet system is comprised of 6 NbTi poloidal field (PF) magnet coils, 6 Nb3Sn central solenoid (CS) coils, and 18 Nb3Sn toroidal field (TF) coils. To provide an idea of scale, the TF coils are 16.5 m high by 9 m wide and they, along with the CS coils, require a total of 95 tons of Nb3Sn superconducting strands that must be qualified for inclusion in the magnet system. It is the role of the Fusion Energy Reference Laboratory in Durham to conduct the verification tests on the Nb3Sn strands earmarked for inclusion in the TF magnets. We will present an overview of the ITER project and Durham’s specific role, in what is, the planet’s most important experiment.

P:07 The architecture of superconducting wires and tapes
F Ridgeon1, M Lakrimi2, A Thomas2 and D Hampshire1
1Durham University, UK, 2Siemens PLC, UK

A better understanding of the architecture of wires and tapes would enable design of higher-stability low-temperature and high-temperature superconducting magnets. Early work on modelling properties of superconducting wires produced 1D analytic equations which are not sensitive to the complex differences in the architecture of modern multifilamentary conductors. The focus of this work is understand on the effect different geometries on the stability of conductors. Using FEA modelling and experimental measurements we aim to establish design guidelines for controlling conductor stability and minimising the deleterious effects of perturbations. Our most recent results will be presented at the JWPAS workshop.

P:08 FEM modelling of levitation forces between bulk superconductor and Halbach PM array
M Stepien and B Grzesik
Silesian University of Technology, Poland

The paper is focused on analysis of forces acting between bulk superconductor and permanent magnet (PM). The analysis is based on numerical modelling of finite element method (FEM) using commercial ANSYS software. Two types of system were taken into consideration. They reflects two types of bulk superconductor operation. The first type is analysis of bulk superconductor with no magnetic field inside (the transition of superconductor from normal to superconducting state with absence of external magnetic field). The magnetic force is only repelling force.
Analysis of forces in both x and y direction has been performed. An example of such system is shown in Fig. 1. Presented results shows how forces varies when distance between superconductor and PM varies. The second type of system and relating analysis is focused on superconductor with trapped magnetic field. Analyzed superconductor is placed at starting position in presence of external magnetic field generated by PM. It is cooled down and turned into superconducting state. The magnetic field is trapped in superconductor. Next the superconductor is moved in both x and y direction and magnetic forces are acting between superconductor and PM. In this situation only attracting forces are present with a trend to move superconductor back to starting position. The result of analysis are characteristics of forces versus dislocation at different starting position and different magnetic field. An example of distribution of magnetic field in the system of superconductor with trapped field dislocated at PM is shown in Fig. 2.
The system of permanent magnet is Halbach array which produces magnetic field enhanced above magnets and reduced below magnets. Arrays with different number of single magnets have been taken into calculations.

Fig. 1. Superconductor without trapped field levitating at Halbach array at central position

Fig. 2. Superconductor with trapped field levitating at Halbach array (moved left)

P:09 Fabrication and characterisation of nanocrystalline high-temperature YBa2Cu3O7-x

G Wang, M Raine and D Hampshire
Durham University, UK

We present our methodology and results from fabricating nanocrystalline high temperature superconducting materials. Mechanical ball milling, hot isostatic pressing and oxygen annealing have been used to fabricate nanocrystalline YBa2Cu3O7-x and nanocrystalline material that is a mixture of YBa2Cu3O7-x, Y2BaCuO5 and CeO2. The materials were characterised using a.c. susceptibility, magnetic hysteresis, SEM, XRD, DSC/TGA and resistivity to study the effects of grain size on critical temperature ($T_c$), upper critical field ($B_{c2}(0)$) and critical current density ($J_c$) in fields up to 8.5 T. We also present computational simulations on the properties and effects of grain boundaries in support of experimental data.

We are looking to find a new paradigm for high field superconductors where the grain size is comparable to the coherence length so that microstructure controls in-field properties. We will present our most recent findings at the conference.
P:10 Intrinsic Josephson junction arrays in the high temperature superconductor $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_8$

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Josephson junctions have the potential to provide a compact solid-state source of terahertz emission for uses in medicine, imaging and communication. However, the emission power from individual junctions is low. By coupling arrays of $N$ junctions together, the emission power increases by $N^2$. Intrinsic Josephson Junctions (IJJs) found in high-temperature superconductors allow large series arrays to be conveniently fabricated due to the high-density atomic-scale layers within the material and their short coherence length.

It has been shown by Benseman et al. using Bi$_2$Sr$_2$CaCu$_2$O$_{8+\delta}$ (BSCCO) mesas, that by coupling multiple stacks of IJJs together, terahertz emission powers of 0.6 mW can be achieved$^1$. However, mesa devices suffer from Joule heating due to the high bias required for emission. Thermal management is a significant factor limiting emission. By orienting the ab-planes perpendicular to the substrate surface, self-heating is reduced$^2$ and it may be possible to achieve higher emission power$^3$. In this context, a-axis oriented cuprate thin films would be ideal. No one has yet grown an a-axis oriented BSCCO or Tl$_2$Ba$_2$CaCu$_2$O$_8$ (TBCCO) films. TBCCO films have however been grown on vicinally cut substrates$^4$. Here the cuprate planes are at an angle to the substrate surface. These films may therefore provide an advantageous geometry for thermal management.

We have fabricated stacks of IJJs in TBCCO thin films grown either on a 20° vicinally cut LaAlO$_3$ substrate or on regular c-axis LaAlO$_3$ substrates. The TBCCO film is grown by first r.f. sputtering from a Ba-Ca-Cu-O ceramic target and then annealing in a closed crucible with thallium powder. Device patterning was performed using a gallium focused ion beam (FIB). The stacks have been fabricated in series and parallel arrangements and we have measured the current-voltage characteristics. We have also fabricated junction stacks using c-axis oriented samples using a neon FIB, which may result in less sample poisoning.

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P:11 A novel measurement method of current distribution for a multi-layer DC HTS superconductor cable

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The developments of DC power cables have been carried out for long distance power transmission worldwide. The HTS DC cable has been proven to be a competitive technology due to its high power density and negligible transmission losses. For higher power capacity, a multi-layer HTS structure is typical for HTS DC cables. Uniform current distribution of each HTS layer is important for maximum transmission efficiency and safety. Hence the configuration of the DC HTS cable needs to be optimised to make sure the same amount of current flows through each HTS layer. As the contact resistances dominate the total current spreading from cable terminals into each HTS layer, it can also be used as a constant factor of determining the magnitude of the current for each HTS layer. This paper reports a novel method to measure the current distribution based on the contact resistances of each HTS layer. To verify the measurement theory, a one meter long prototype DC HTS cable consisted of two HTS layers has been constructed. The results show a good current determination of each HTS layer and the method can be applied to DC HTS cable with any number of HTS layers.
P:12 Doping effects in superconducting SmBa$_2$Cu$_3$O$_{7-\delta}$ bulk materials
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In this work, we reported and compared the effects of adding 1 mol% ZrO$_2$, 1 mol% BaZrO$_3$ and 1 mol% TiO$_2$ as dopants into Sm-Ba-Cu-O (SmBCO). The potential of SmBCO, which is a member of the (LRE) BCO (where LRE = light rare earth element such as Nd, Sm, Gd, etc.) family of bulk, melt processed high temperature superconductors (HTS), for practical applications is greater than Y-Ba-Cu-O (YBCO) (which has been investigated in a wide range since it was discovered) because of SmBCO’s higher critical transition temperature, $T_c$, and “peak effect” characteristics in high field. However, due primarily to the high melting temperature of SmBCO precursor powders, characteristically rapid growth rate and the substitution of Sm on the Ba site in the superconducting SmBa$_2$Cu$_3$O$_{7-\delta}$ (Sm-123) phase, it is extremely difficult to grow large SmBCO single grains in air with good superconducting properties even without any dopants. As a result, a limited amount of research has been performed on this material.

In our work, the top-seeded melt growth (TSMG) process was used to fabricate SmBCO single grains containing 1 mol% ZrO$_2$, 1 mol% BaZrO$_3$ and 1 mol% TiO$_2$ as dopants. The superconducting properties, $T_c$ and the critical current density, $J_c$ of each sample are investigated, then the effects of these different dopants are discussed.

P:13 Numerical simulation and analysis of single grain YBCO processed from graded precursor powders
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Large single-grain bulk high-temperature superconducting (HTS) materials can trap high magnetic fields in comparison with conventional permanent magnets, making them ideal candidates to develop more compact and efficient devices, such as actuators, magnetic levitation systems, flywheel energy storage systems and electric machines. However, macro-segregation of Y-211 inclusions in melt processed YBCO limits the macroscopic critical current density $J_c$ of such bulk superconductors, and hence, the potential trapped field. Recently, a new fabrication technique with graded precursor powders has been developed, which results in a more uniform distribution of Y-211 particles, in order to further improve the superconducting properties of such materials. In order to develop this graded fabrication technique further, a 3D finite-element numerical simulation based on the $H$-formulation is performed in this paper. The trapped field characteristics of a graded YBCO sample magnetized by the field cooling (FC) method are simulated to validate the model, and the simulation results are consistent with the experimental measurements. In addition, the influence of the graded technique and various graded $J_c$ distributions for pulsed field magnetization (PFM), recognised widely as a practical route for magnetising samples in bulk superconductor applications, is also investigated, with respect to the trapped field and temperature profiles of graded samples. This modelling framework provides a new technique for assessing the performance of various sizes and geometries of graded bulk superconductors, and by adjusting the Y-211, and hence $J_c$, distribution, samples can be fabricated based on this concept to provide application-specific trapped field profiles, such as the generation of either a high magnetic field gradient or a high level of uniformity for the traditionally conical, trapped field profile.
First-principles investigation has been carried out in order to analyze structural, electronic and magnetic properties of $\text{RESn}_3$ compounds thereby exploiting specific properties for better understanding of their magnetic structure. The generalized gradient approximation $+U$ formalism has been used to account for the strong on-site Coulomb repulsion among the localized $\text{RE}^{4f}$ electrons. By varying the Hubbard $U$ parameter from 0 eV to 8 eV, a detailed study of magnetism of these compounds via the density of states DOS and charge densities, is presented.
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Figure 2: Contour of the charge density of valence (a) NM-LaSn₃

Figure 3: The Fermi surfaces of the compounds RESn₃ (RE = Tb,Sm).


P:15 Broken time-reversal symmetry probed by muon spin relaxation in the caged type superconductor Lu₆Rh₆Sn₁₈

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It is a major theoretical challenge in strongly correlated electron systems to understand the pairing mechanism in unconventional superconductors [1, 2]. In conventional ‘s–wave’ superconductors, only gauge symmetry is broken. If the pairing is not conventional then some other symmetries of the Hamiltonian may be broken below the superconducting transition. Symmetries which might be broken include lattice point and translation group operations and spin rotation symmetries, in addition to the global gauge symmetry that is responsible for the Meissner effect, flux quantization, and the Josephson effects. The nature of the broken symmetry in the pairing state is reflected in the symmetry properties of the order parameter. Superconductors whose crystal structure features a
center of inversion, can be classified via the parity of Cooper pair state: the spin-singlet pair state \( S = 0 \)
corresponds to an orbital pair wave function \( \psi(k) \sim \psi(-k) \) with even parity [i.e., \( \Delta(k) = \Delta(-k) \)]; The spin-triplet
state (total spin \( S = 1 \)) has a superconducting order parameter with odd parity \( \psi(k) \sim -\psi(-k) \) [3]. A few
compounds have been reported to be spin-triplet superconductors, for example the 4d-electron system \( \text{Sr}_2\text{RuO}_4 \),
and the 5f-electron systems \( \text{UPt}_3 \) and \( \text{UNi}_2\text{Al}_3 \).

Caged type structures have received considerable attention due to their fascinating properties [4]. Three cage
compounds have been comprehensively studied over the past decade as “rattling-good” materials: \( \text{Ge/Si} \)
clathrates, filled skutterudites (\( \text{RT}_4\text{X}_{12} \)), and \( \beta \)-pyrochlore oxides \( \text{AOS}_2\text{O}_6 \) [4]. Usually they possess three
dimensional skeletons encompassing large atomic cages, inside of which moderately small atoms are positioned
and can “rattle” with large atomic excursions owing to the virtual size discrepancy, weak structural coupling, and
strong electron–phonon (rattler) coupling, leading to a substantial anharmonicity for rattling vibration. For instance,
rattling of the A atoms in the \( \text{OsO}_6 \) cages induce extremely strong-coupling superconductivity in \( \text{AOS}_2\text{O}_6 \). A strong
interplay between quadrupolar moment and superconductivity has been pointed out in \( \text{RT}_4\text{X}_{12} \) and \( \text{RT}_2\text{X}_{20} \). \( \text{R}_5\text{Rh}_6\text{Sn}_{18} \)
(\( \text{R} = \text{Sc}, \text{Y}, \text{Lu} \)), which can also be categorized as the cage compounds, exhibit superconductivity with the transition
temperature \( T_c = 5 \, \text{K} \) (Sc), 3 K (Y), and 4 K (Lu). These compounds have a tetragonal structure with the space group
\( \text{I4}1/\text{acd} \) and \( Z = 8 \), where \( \text{R} \) occupies two sites of different symmetry.

The superconducting state of the caged type compound \( \text{Lu}_5\text{Rh}_6\text{Sn}_{18} \) has been investigated by using magnetization,
heat capacity, and muon-spin relaxation or rotation (\( \mu \)SR) measurements [5]. Our zero-field \( \mu \)SR measurements
clearly reveal the spontaneous appearance of an internal magnetic field below the transition temperature, which
indicates that the superconducting state in this material is characterized by the broken time-reversal symmetry.
Further the analysis of temperature dependence of the magnetic penetration depth measured using the transverse
field \( \mu \)SR measurements suggest an isotropic s-wave character for the superconducting gap. This is in agreement
with the heat capacity behavior and we show that it can be interpreted as in terms of an non unitary triplet state
with point nodes and an open Fermi surface.

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P:16 Transport characterisation of phase-slips in superconducting constrictons

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Coherent quantum phase-slip (CQPS) is a very promising physical phenomenon, which was predicted and observed
in superconducting nanowires [3]. The quantum phase slip is a well-known process: in a thin nanowire, quantum
fluctuations of the order parameter \( \Psi = \abs{\Psi} e^{i\phi} \) become significant, hence the phase \( \phi \) may suddenly change by
\( \pm 2\pi \), and it is accompanied by the change of single magnetic flux quantum \( \Phi_0 \) in the loop. Very recently the first
experimental evidence of the process of coherent flux tunneling was demonstrated in phase-slip qubits [1, 6]. What
is also interesting, CQPS is expected to be exactly dual to the Josephson effect [5] with respect to the exchange of
conjugated variables in superconducting system — charge \( q \) and phase \( \phi \). Since the latter effect is very well studied,
we can expect some similar manifestations for CQPS, literally the same as for Josephson effect, but dual. For
Example, voltage blockade which is dual to supercurrent, was predicted [4] and claimed [8]. But the blockade itself may be ordinary Coulomb blockade and hence does not confirm neither the presence of phase-slip processes nor the coherence of such processes. The proof of CQPS may be the observation of so-called inverse Shapiro steps — the plateaus at IV-characteristic of nanowire which occur in the presence of microwave radiation. The values of current on these plateaus are given by $I = 2en \cdot v$, where $v$ is the frequency of the signal. Consequently, such steps are probably the most interesting application of CQPS, which may lead to the realisation of the quantum current standart, analogous to the voltage standart developed on ordinary Shapiro steps. Hence CQPS is very promising for quantum metrology and for other applications.

In our work, we investigate not a wire but a narrow constriction which is formed from TiN films with thickness of 2-3 nm and $T_c = 1.3$ K by e-beam lithography and plasmochemical etching. The background for that is the following. It was theoretically shown [2] that inhomogeneities (namely, constrictions) in nanowires lead to the formation of single phase-slip centers. Since the tunnelling amplitude of phase-slip depends exponentially from the width of the constriction, the effect is well-defined by the narrowest one. We fabricated several constrictions with different geometrical parameters. Each constriction was put in series with the large inductance $L \approx 10^{-6}$ H, which provides decoupling from the environment. The dc-measurements of each circuit showed the supercurrent $I_s$ for widest samples and voltage blockade $V_b$ for narrowest ones, moreover, intermediate constrictions demonstrate both types of behaviour simultaneously, with smooth transition from blockade regime at low voltages to supercurrent regime at higher ones. We also measured temperature dependencies of $I_s$ and $V_b$. $\Delta(T)$ coincides very well with well-known AmbegaokarBaratoff formula, which is in accordance with the BCS-type dependence of $\Delta(T)$ for similar TiN films [7], so wide structures behave as weak-links with sinusoidal current-phase relation. $V_b(T)$ is also in good correspondence with $\Delta(T)$ from the BCS-theory. Hence we consider our structures as very appropriate for the further investigation of CQPS and for inverse Shapiro steps detection.


P:17 Flux line lattice in $\text{KFe}_2\text{As}_2$ under $H//c$

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Iron-based superconductors have raised much interest, because of their high maximum $T_c$. The pairing state has been proposed to be probably mainly s$_{\pm}$ and pairing mechanism is probably magnetic. Previously we succeeded in observing the flux line lattice (FLL) of the Iron-based superconductors for the first time, in the clean stoichiometric material $\text{KFe}_2\text{As}_2$, which is strongly overdoped and has $T_c \sim 3.6$ K, and therefore accessible values of $B_{c2}$ [1-2]. We
also investigated the field direction dependence of the FLL (at low fields) and found an anisotropy factor between in-plane and out-of-plane $\gamma_{ac} \sim 3.8[3]$.

Recently Pauli paramagnetic effects of the conduction electrons were suggested to appear on KFA with the field direction parallel to the basal plane[4]. Just as in CeCoIn$_5$[5], we may expect an unconventional field-dependence of the spatially varying field in the mixed state, arising from magnetisation of the depaired electrons in the flux lines. We have performed FLL measurements by small angle neutron scattering technique under the field almost parallel to the in-plane direction and at high fields. In the concefence, we would like to focus to report the possibility of Paramagnetic behavior in KFe$_2$As$_2$.


Interaction between ferromagnetism and superconductivity in hybrid nanostructures

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Two phenomena with antagonistic-nature can have very different properties when brought together in a hybrid system. One example is a hybrid of superconductivity and ferromagnetism in which many new phenomena can be observed [1-2]. Here we report a superconducting-ferromagnetic hybrid system consisting of a Nb layer (200 nm) between two layers of ferromagnetic Ni nanoparticles (NPs), which have been prepared by pulsed laser deposition (PLD) with Ar or O$_2$ as ambient gases. The Ni NPs are in direct contact with the Nb layer and as a result, a proximity effect is present in the system. Microstructural studies show that the NPs made in Ar and O$_2$ gases have very different shapes and properties: one (prepare in Ar) is cubic with a mean diameter of ~5nm presenting an agglomerated distribution consisting of metallic Ni, and the other (prepared in O$_2$) is spherical with a mean diameter of ~4.5nm uniformly distributed and composed of NiO.

The different shapes and properties of the Ni NPs have very different influences on the superconducting properties of the Nb layer; the sample with Ni (Ar) NPs does not show a vortex glass transition and exhibits a more ordered profile of vortex organization. The sample with Ni (O$_2$) NPs shows a very clear vortex glass state [3] without any external magnetic field indicating a more disordered (entangled) state of spontaneously generated vortices, as demonstrated by the $V(I)$ measurements in Fig.2.
The orientation of magnetic moments in the Ni NPs plays an important role in the vortex generation and behavior, where a random alignment is obtained from the spherical Ni (O₂) NPs, in contrast to the cubic Ni (Ar) NPs whose magnetic moments are aligned along one of the geometric sides. Measurements of electrical transport and magnetotransport have been carried out in order to characterize the hybrid systems.


P:19 First-principles prediction of the magnetic ordering and the superconducting state in rare earth iron pnictides
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The discovery of new superconductors based iron has opened a new horizon for high temperature superconductivity. Iron is usually associated to the magnetism, which is actually an antagonist element to the superconductivity. Recent studies show that the magnetism and superconductivity can coexist in these compounds that present an ideal platform for studying the relationship between these two electronic orders. A considerable number of magnetic superconductors has been examined in the past two decades [Cava et al., 1994; Eisaki et al., 1994; Lynn et al., 1997; Shiratori et al., 1997; Namiki et al., 2007; Wu et al., 1987; Hor et al., 1987; Yang et al., 1989; Tokura et al., 1989; Lynn et al., 1990; Sumarlin et al., 1992]. Keywords: protein folding, nanoporous sol-gel glasses, silica-based biomaterials, circular dichroism spectroscopy, surface hydration, crowding effects, micropatterning, biomedical applications. Recently, iron-based superconductors RTPnO type (R = La [Kamihara et al., 2006, 2008; Ren et al., 2008], Ce [Ren et al., 2008; Chen et al., 2008; Zhao et al., 2008], Pr [Ren et al., 2008; Baumbach et al., 2009], Bhoi et al., 2008; Zhao et al., 2008; Kimber et al., 2008], Nd [Ren et al., 2008; Baumbach et al., 2009; Kito et al., 2008; Qiu et al., 2008], Sm [Ren et al., 2008; Kamihara et al., 2008; Chen et al., 2008; Fratin et al., 2008; Tropeano et al., 2008], Gd [Cheng et al., 2008; Yang et al., 2008], Tb, Dy [Bos et al., 2008; Yang et al., 2009], Ho [Yang et al., 2009]; T = Fe; Pn = P, As [Lee et al., 2008, 2009]) have been studied by several research groups. The parents of the superconducting compounds crystallize in a tetragonal structure formed by layers T–Pn and R-O alternately arranged. It was observed in LaFePO compounds [Kamihara et al., 2006] and LaNiPO [Watanabe et al., 2007,2008] that T–Pn layers play a major role in the appearance of high critical temperatures. This observation was confirmed by a theoretical analysis of the energy band structure based on the theory of density functional (DFT), revealing that the hybridization of Fe 3d orbitals with 4p orbitals of Pn contributes to the Fermi surface [Lu with experimental lattice parameters. et al., 2008]. With the change of T element, the electronic and magnetic properties of RTPnO compounds vary such that one finds an anti-ferromagnetic (AFM) insulator for T = Mn [Watanabe et al., 2007], a superconductor for T = Fe and Ni [Kamihara et al., 2006, 2008; Watanabe et al., 2008; Lu et al., 2008] and a metal ferromagnetic for T = Co [Yanagi et al., 2008]. The SmFePO compound with the...
ZrCuSiAs structure was reported by [Kamihara et al., 2008] using different experimental methods. This compound was identified as a superconductor with a critical temperature below 3K and shows an AFM order below a Néel temperature of 5K, which confirms the possibility of the coexistence of magnetism and superconductivity. The main objective of this work is to identify the microscopic origin of superconductivity in the iron pnictides by providing the key parameters of this property and to discuss the possibility of the coexistence of magnetism and superconductivity in those systems. The study of the electronic structure, in particular the nature of the Fermi surface, is a fundamental step to obtain details on the mechanism of this phenomenon. In addition, understanding the influence of the 4f orbitals of the rare earth element on the magnetic structure is also a major objective in this work. The superconductivity and magnetic phenomena of the rare earth iron pnictides $RFePO$ ($R =$ rare earth) are analyzed using ab initio density functional theory in the local density approximation (LDA) with the on-site Hubbard $U_{eff}$ parameter.

Figure 1: The calculated band structures of the paramagnetic tetragonal compounds $RFePO$ ($R =$ La, Sm)

### P:20 N-values of 2G HTS tapes and coils

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The n-values of different 2nd generation of high temperature superconducting (2G HTS) tapes and coils were investigated in this work. N-value is an important superconducting parameter, which represents the homogeneity of characterized superconductor as well as thermally activated depinning. n-values are crucial input parameters for the numerical simulations of superconducting tapes, coils and other complicated superconducting applications where E-J power law applies. N-values measured for 2 G HTS racetrack coils are reflecting possibility of usage these coils in superconducting machines. Very low n-values are causing early resistive behaviour of the coil and on the other hand too high n-values are associated with unstable behaviour which can cause premature quenching. In this work, complex measurement data of n-values from different 2G HTS tapes and coils are presented. In addition, some of the 2G HTS tapes were step-by-step irradiated by fast neutron fluences up to $1 \times 10^{22}$ m$^{-2}$. N-values of the irradiated tapes, containing additional randomly distributed pinning centres, are presented, analysed and compared with unirradiated samples. Special attention is placed on the underlying physics resulting in the power-law part of the I–V curve and on the correlation between critical currents and n-values.
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