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ABSTRACT BOOK

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Plenary Session

Superconducting Magnet Design

Kathleen Amm
Brookhaven National Laboratory, USA

Biography: Dr. Kathleen Amm is currently the head of the Superconducting Magnet Division at Brookhaven National Lab, where she works with her team to deliver innovative accelerator and high field magnet technology. She has more than 25 years of experience in superconductivity and magnet design. Dr. Amm is a member of several professional societies and is a senior member of the Institute of Electrical and Electronics Engineers (IEEE).

Recent Progress on Iron-based Superconductors

Hideo Hosono

Tokyo Institute of Technology, Japan

Biography:

Prof. Hideo Hosono is an Honorary and Institute Professor at Tokyo Institute of Technology, Japan. He is known for the discovery of iron-based superconductors. Prof. Hosono is also a pioneer in developing transparent oxide semiconductors. He is a recipient of various honors including the Japan Prize, von Hippel Prize (MRS) and J.McGroddy Prize (APS), Jan Raychman Prize (SID), Imperial Prize, Japan Academy Prize, Thomson Reuter Citation Laureate, and a foreign fellow of the Royal Society.

Superconducting Power Cable Networks for Electric Aircraft

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Abstract:

Technology advances in electric aircraft have been growing, thanks to the investments by government agencies and the private sector. Superconducting devices are prominent in most of these ongoing technology advances. Superconducting power devices such as generators, motors, and power cables are being considered due to their power density and power capacity ratings. For large scale electric aircraft maximum power loads are envisioned to be between 30-50 MW. NASA has been investing in superconducting electric aircraft both internally and through the University leadership Initiatives (ULI). Recently, a team led by the FAMU-FSU College of Engineering has been selected for a ULI to develop a hybrid-electric propulsion concept that involves hydrogen as the fuel, and superconducting power distribution cable networks to achieve zero emissions. Called Integrated Zero-Emission Aviation (IZEA) this university-industry partnership will establish design requirements for component technologies of a >100 passenger short-range aircraft with a nominal range of 3000 nm. The paper will discuss the plans for the development of a high temperature superconducting (HTS) power cable network, cryogenic cooling concepts, and corresponding subsystem demonstrations in the 20-80 K temperature range. This includes details on HTS cable topology, cryogenic dielectric material selection, and interface design compatible with high altitude environments. The details of the other power system components, including power electronics, fuel cells, switchgear, HTS generators and motors being considered for the IZEA aircraft will also be discussed. To understand the interface challenges of power devices being electrical coupled together whilst having different operating temperatures, a testbed for validating the design concepts of cryogenic thermal management, and the aircraft design will be developed. The IZEA concept will be discussed as a complementary approach to complementary efforts at other organizations to achieve the goal of zero-emission electric aircraft.

Research on the Bi2212 Degradation Phenomenon of Irradiation and Stress for Magnetic Confinement Nuclear Fusion Application

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Abstract:

As a kind of copper oxide high-temperature superconducting (HTS) materials, $Bi_2Sr_2CaCu_2O_{8+x}$ (Bi-2212) was developed to manufacture advanced superconductors for magnetic confinement nuclear fusion application. However, a series of problems need to be solved in the application process, including the irradiation effects, stress effects and so on. In this research, the effects of gamma-ray irradiation on Bi2212 wires, stress on the pre-heat-treated wires and stress introduced by a magnetic field on an 84 wires sub-cable were successively studied. Firstly, the gamma-ray irradiation effects. Critical current (I_c) tests indicated that the normalized I_c first rise to 1.15 then decreased to 0.89 with the increase of gamma-ray irradiation time. Results from XRD, Raman and XPS indicated that defects were produced within the gamma-ray irradiated samples. From the images of HR-TEM, amorphous structure in the irradiated samples is discovered as well. Then the effects of indentation were studied. It was found that the current carrying capacity would decrease rapidly when the indentation depth reached ~18% of the diameter of Bi2212 wires. With the aid of SEM, deformation of the filaments was detected in the wires, which explains the decrease in I_c. Finally, degradation phenomenon with respect to electromagnetic force was researched. With a magnetic field of 5.8 T, an 84-wires-cable carrying 29 kA would be exerted with a force of ~168.2 kN m^{-1}. Moved wires were detected in the central area of the cable by CT. Then I_c data tested by four-probe method indicated that the inner wires of the cable had relatively lower I_c, while cracks were detected in the corresponding wires. The appearance of cracks can be a good explanation of the degradation.

Keywords：*Bi2212; gamma-ray; irradiation; stress; strain; degradation;*

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Development of a New S-shaped Superconducting Hexapole Magnet

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Abstract:

With the increasing demand for high-energy particles in accelerators, it is necessary to develop an ECRIS (electron cyclotron resonance ion source) with compact structure, small volume, and high energy. ECRIS which can produce highly charged particles is a necessary part in heavy ion accelerator and heavy ion therapy. A new structure of S-shaped hexapole was proposed in 2016. The S-shaped hexapole can simplify the distribution of interacting Lorentz forces in ECRIS superconducting magnets and help increase the required axial field in ECRISs. However, the S-shaped coil is difficult to fabricate and there is no article about the fabrication of S-shaped superconducting hexapole published at present. Because the S-shaped coil ends is difficult to apply the preload force, and it needs special support structure to form the S-shape winding route. Based on the design, a superconducting S-shaped hexapole prototype using NbTi was developed in this study. A two-ends slotted skeleton was designed to realize the S-shaped coil winding. The S-shaped hexapole coil used only one cable to realize winding, achieving a continuous uninterrupted winding both the inside to the outside and from the outside to the inside. In the 4.2K cold test, the self-magnetic field reached 1.5T, the current is 480A, and there is no quench. At 8T background field, the current reaches 232A with only one quench, and the load line reaches 98.22%.

Development of A 1.5T Extremity Superconducting Magnet

Riyu Wei

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Abstract:

In this presentation, design and development of a 1.5T superconducting magnet for imaging of human extremities, such as knees, ankles and elbows, etc. are introduced. A passive shimming method is proposed to improve the magnetic field inhomogeneity, with which the magnet has been shimmed successfully to the required specification.

Nanodroplets of Liquid Metal for Flexible Printed Superconducting Circuit

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Abstract:

By enhancing the critical temperature for superconductivity for GaInSn-alloys above 4.2 K, which is the liquid helium critical point, we foresee that these materials can become a practical candidate for micro/nanosuperconducting electronics. Moreover, the nontoxic nature of the alloys allows them to be practically and safely used for flexible, low-cost, and lightweight micro/nanoelectronic devices. Further applications may be energy devices, microelectromechanical systems, NMR, sensors, and display devices.

Reference:

- *Materials Today, 34, 92-11,2020*
- *Advanced Materials, vol. 30, no. 35*
- *Advanced Functional Materials, vol. 26, no. 44, pp. 8111-8118*

Development of Superconducting Magnets for Future Heavy Ion Accelerators

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Abstract:

Superconducting magnets have been a major enabling technology in the development of modern high energy particle accelerators. But for heavy ion accelerators which usually need magnets with larger apertures, smaller bending radius and faster ramping rate, superconducting magnet technology is not widely evolving. In order to meet the demanding needs of future heavy ion accelerators, variety types of superconducting magnets are under development, including high field Nb3Sn magnet for ECRIS (Electron Cyclotron Resonance Ion Source), fast ramping strong focusing solenoid for superconducting Linac, and coil-dominated multiplet and curved dipole with large aperture for fragment separator, spectrometer ring and external-target experiment. The novel coil configurations, field quality optimization technique, quench protection methods, stress and dynamic thermal load management are reported.

Development of On-board Magnets for the First HTS Based EDS-Maglev Test Track in China

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Abstract:

Electrodynamic-suspension (EDS) running of a prototype vehicle with four on-board high temperature superconducting (HTS) magnets has been achieved in December of 2021. The running tests were conducted in a 200-metre test track in CRRC Changchun Railway Vehicles Co., Ltd. with a levitation speed around 40 km/h. Each on-board magnet contains two independent HTS poles which are wound by ReBCO tapes and operated in persistent current mode (PCM) with magnetomotive forces around 320 kA and a decay rate of <1%/day.

Based on the PCM mode operation, on-board magnets are further operated in a so-called off-power mode, which means no power will be supplied not only to HTS coils but also to the cryocooling and vacuum system, and no more cryogen was supplied, like that in permanent magnets. The capability of operation in this mode was proposed to be able to enhance the safety and robustness in future commercial Maglev trains. As far as the authors know, idea of the off-power mode was firstly published by C.-Y. Lee et al. in December of 2018[1] and some groups have been devoting in achieving this mode. In our work, 1-2.5 hours' operation in off-power mode has been realized with <1% decay of magnetomotive forces.

Sufficient operation time with several hours in off-power mode could be attributed to the following key techniques: (1) joints with resistance of several nto achieve good PCM operation with low decay rate; (2) non-insulation winding to provide self-protection ability during potential quench; (3) solid nitrogen which serves as the so-called "thermal battery"; (4) coupled optimization of electromagnetic-mechanical-thermal design and corresponding production of the magnet structure.

Each of the on-board magnets has experienced 2-5 thermal cycles from room temperature to working temperature around 35 K. Two of them suffered a sudden power failure of more than 12 hours in the test track in September of 2021. No damage was detected after recovery. It is also worthy to point out

that the self-protection strategy by non-insulation technique did work in at least two unexpected quench process. However, the turn-to-turn by-pass currents bring more complexity during charging, quench and operation in environmental AC fields, which have been systematically studied by simulation and experiments and are also going to introduced.

Reference

[1] Chang-Young Lee, Overview on Development of KRRI's High-Tc Superconducting Electromagnet for Linear Synchronous Motor, International Workshop on Evacuated Tube Maglev Transport, Chengdu, 2018.12.04-12.06

Acknowledgement

The presented activity of EDS Maglev based on HTS magnets is sponsored by CRRC Changchun Railway Vehicles Co., Ltd, Science and Technology Commission of Shanghai Municipality, Shanghai Superconductor Co., Ltd. and Shanghai Jiao Tong University.

Superconducting our Energy Transition

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Abstract:

In Australia and other parts of the Industrial world, there is great urgency in resolving the dilemma of whether renewables can supply all our energy needs. The agendas of reliability of supply, carbon-sourced generators, the intermittent nature of renewable generation as it is presently configured, the pressure on all Communities to reduce greenhouse gas emissions, do not sit very comfortably together. These agendas do, however, capture the headlines and dominate the thinking of politicians, economists, social commentators and the 24-hour news feed.

A very significant contributor to energy (electrical and gas) transmission and distribution that does not capture many, or any, column inches is superconducting technology with its potential to integrate simultaneously with nation-wide gas distribution networks, such as hydrogen.

This presentation will introduce some of the thinking and planning that is underway in Australia to establish massive solar renewable technology and its likely impact on the National Electricity Market (NEM).

Underpinning the massive investment in renewables that is underway, this presentation will consider what impact the introduction of superconducting technologies could have on all aspects of design, construction, efficiency and operation of these projects. Inherent in a potential transition to superconducting technologies deployed in the power grid is the need for education and training at many levels. The presentation will offer some introductory thoughts on this topic with the intention of stimulating discussion.

On the Passive Shimming of A 7T Whole-body MRI Superconducting Magnet: Implementation with Minimized Ferromagnetic Materials Usage and Operable Magnetic Force Control

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Abstract:

Magnetic field shimming of the magnet is a routine practice in a magnetic resonance imaging (MRI) system. It is generally straightforward to shim clinically-used 1.5T or 3T MRI superconducting magnets; however, it is challenging to compensate for field non-uniformities of ultrahigh field magnets ($\geq$ 7 Tesla). This is because the undesired harmonic components in ultrahigh field MRI superconducting magnets become much more significant in magnitude, requiring a high-sensitivity shimming method, such as using active superconducting shim coils. Still, the complex winding structure and expensive fabrication cost of the superconducting shim coils bring considerable engineering barriers in practice. In this work, we proposed a dedicated passive shimming strategy to improve the field quality of a 7T whole-body MRI superconducting magnet. Compared to lower field systems, passive shimming at 7T requires strict management of the iron usage and magnetic force due to the iron-field interaction. Optimization was conducted to determine the iron piece consumption/layout and control the corresponding magnetic force applied on the shim trays, intending to limit the iron usage and ensure a shim tray insert is operable by manpower (without specially designed tools). According to our calculation, the iron usage was restricted to 3.7kg, and the maximum attractive magnetic force during the insert operation of the shim tray should be around 500N. A shimming experiment was implemented on a 7T/800mm MRI superconducting magnet to validate the proposed shimming strategy. Alternating with the odd and even shim trays in our two-round operation, we successfully corrected the magnetic field inhomogeneity from 85.3ppm to 7.9ppm measured over a 40cm imaging spherical volume, achieving the magnetic field quality elevation of more than one order of magnitude. Also, less use of iron will ensure the future magnetic field stability associated with gradient-switching-induced thermal heating problems. The magnetic field homogeneity is expected to be further enhanced by adding room-temperature shim coils. Through successfully validating the proposed passive shimming scheme on the 7T whole-body MRI superconducting magnet, we demonstrated that our electromagnetic technology is effective for developing high performance-cost ratio ultrahigh field MRI instruments.

On Refined Modelling of HTS Pinning Maglev System: Considering the Non-Uniform Electromagnetic Properties of HTS Bulk and the Irregularity Characteristics of Magnet Track

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Abstract:

High-temperature superconducting (HTS) pinning maglev, as one of the important application scenarios of superconducting materials, is attracting more and more attention from researchers and even the government and media. Since the real-scaled HTS pinning maglev engineering prototype vehicle was born in Chengdu, China last January, it is gradually entering the research stage of high-speed engineering application. Besides engineering tests, theoretical and simulation exploration is an indispensable link in researches on complex working conditions. Especially for the high-speed domain of the train, simulating real-world scenarios and predicting potential risks is an important prerequisite to ensure the safe operation of trains, which puts forward higher requirements for the accuracy of the model. In response to this requirement, the concept of "refined modeling of high-temperature superconducting pinning maglev system" is proposed in this paper. It contains, on the one hand, a comprehensive description of the non-uniform features inside the practical HTS bulk, and on the other hand, a reasonable representation of the irregularities of the permanent magnet guideway (PMG). This is the theme of this paper. Firstly, the commonly-used electromagnetic simulation methods on HTS pinning maglev are reviewed. The fast modeling method based on the moving grid proposed by our team is introduced simultaneously. Secondly, the original theoretical description method of the real non-uniform distribution of J_c is emphasized by considering various factors affecting the electromagnetic properties of HTS bulk. On this basis, the ***E-J*** relationship of the HTS bulk was reconstructed into a three-dimensional form, so that it can more realistically simulate the response of the maglev system under the complex external distribution when it runs on the actual line. Thirdly, using the reconstructed 3D model, we calculated and analyzed some typical bulk arrays, and gave the most recommended application scenarios of the 3D model. Fourthly, in terms of track irregularity, we have researched the dynamic performance changes of the maglev system under different damage conditions of PMG's magnet. Evaluation indicators include the levitation force, bulks' temperature and AC loss, etc. It is found that the degree of influence on the levitation performance decreases from the middle magnet to the edge magnet in the track. Finally, we artificially introduced track irregularity by adding small magnets in the experiment and measured the temperature rise of the bulk in real-time. While the accuracy of the models was gradually verified, some instructive conclusions were also obtained. Regarding future plans, three dynamic test platforms are being put into use or under construction, which will provide strong support for the improvement of our refined models and further promote the engineering process of HTS high-speed maglev trains.

Design and Analysis of a Novel Fast Starting Control Method for High-temperature Superconducting Induction/Synchronous Motor with Pulse Injection Technique Equipped in Transportation Applications

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Abstract:

In recent years, there has been a growing drive to develop high-temperature superconducting (HTS) rotating machines with high efficiency and high power density for power-based transportation equipment, including electrical aircraft, ship propulsion, and electric vehicles, where space and weight are at a premium. We have successfully developed a 50 kW-Class high-temperature superconducting induction/synchronous motor (HTS-ISM) with an efficiency of 99.75 % through experimental tests, which has the potential to challenge the highest efficiency of motors in the world.

An HTS-ISM has three modes during operation: startup, asynchronous and synchronous mode. However, the shielding current induced in the HTS squirrel-cage rotor makes the magnetic flux unable to penetrate the superconducting bars to reach the state of flux flow in a short time, affecting the starting speed of the motor. In this work, we propose an innovative variable startup control method, which uses the pulse voltage (V) and frequency (f) to accelerate the HTS-ISM to break through the shielding state of the HTS rotor during startup. Taking 20 kW HTS-ISM as the analysis object, different startup times and currents can be obtained by applying V/f pulse waveform shapes with linear and exponential changes. As a result, the new starting control method with exponential pulse waveform reduces the starting time by about 50% and the starting current by about 20%. This work will further improve the reliability and superiority of the electrified transportation equipment equipped with efficient superconducting motors and accelerate the realization of the goal of energy conservation and emission reduction.

pT-level Highly Sensitive TMR-superconducting Mixed Magnetic Sensor

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Abstract:

Weak magnetic detection has played an increasingly important role in scientific research, industrial production, geological exploration and biomedicine. Among all types of magnetic sensors, tunnel magnetoresistance(TMR) based on magnetoresistance effect are one of the most promising types of magnetic sensors due to their high sensitivity, small size and low power consumption. For improving the sensitivity and reduce the noise, magnetoresistive sensors usually contain magnetic flux concentrator to amplify the external magnetic field. At present, soft magnetic materials with high magnetic permeability are mostly used as magnetic flux concentrators (MCs). In addition, superconductors can also be used as MCs. The Superconducting MC is a closed superconducting loop with constriction of few microns, the TMR is located under the superconducting constriction. When the applied magnetic field passes perpendicularly through the superconducting loop, a shielding current is generated in the loop, and leading to an enhanced in-plane field when shielding current flows through the constriction. With this structure, the local magnetic field amplification of 100 to 1000 times can be achieved.

This article focuses on the preparation and detection performance of the TMR-superconducting mixed magnetic sensors. Aiming at the problem that TMR-YBCO composite film is difficult to prepare, flip-chip method are proposed. As a comparison, TMR-Nb mixed sensors are fabricated by composite thin film process. We studied the influence by the structure of the superconducting MC on the performance of the mixed sensor and optimized it by adding soft magnetic materials. Experimental results showed that the sensitivity of the TMR-superconducting mixed sensor reaches 1510mV/V/Oe, which is over 300 times higher than that of the TMRs, and the magnetic field noise reaches 3 pT/Hz$^{1/2}$@1kHz. The work in this paper contributes to the development of high-performance superconductor/MR composite sensors.

New Binary Rare Earth Oxides as Magnetic and Superconducting Materials

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Abstract:

Binary rare earth oxides (mainly RE_2O_3) are known to be highly insulating dielectrics [1]. However, it is possible to synthesize metastable rocksalt type rare earth monoxides (*RE*O) by utilizing thin film epitaxy, where the rare earth ions are not trivalent but divalent. As a result, *RE*O shows high electrical conduction. YO, YbO, and LuO are narrow gap n-type semiconductors [2-4]. CeO and SmO are heavy fermion metals [5,6]. PrO and NdO are low T_C ferromagnetic metals [7,8]. GdO and HoO are high T_C n-type ferromagnetic semiconductors, where T_C of GdO exceeds 270 K in contrast with T_C of well-known EuO (69 K) [9,10]. Finally, LaO is a superconductor with T_c of about 5 K [11], where LaO/EuO superconductor-ferromagnet heteroepitaxial structure can be fabricated [12]. All of them, except for YbO, are first single crystalline specimens, and YO, HoO, and LuO are first solid phases.

This research is in collaboration with D. Oka, K. Kaminaga, D. Saito, T. Amrillah, Y. Uchida, T. Yamamoto, N. Abe, H. Shimizu, S. Sasaki, N. Kimura, H. Kumigashira, D. Shiga, K. Hayashi, N. Happo, H. Tajiri, J. R. Stellhorn, S. Hosokawa, T. Matsushita, S. Sakamoto, A. Fujimori, and T. Hasegawa. This work is supported by JSPS-KAKENHI (Nos. 18H03872, 18K18935, 19F19347, and 21H05008) and the Mitsubishi Foundation.

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New Strategy for High Critical Current Density: Heavily Electron Doping NdFeAsO

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Abstract:

One of the most important parameters for superconducting power applications is the critical current (or critical current density *J*c), the maximum electrical current without facing any resistance. Obviously, the larger *J*c, the more favourable for applications. Recently, *J*c of the cuprate YBa2Cu3O7-d (YBCO) was increased to more than triple the value of an optimally doped YBCO by over-doping [1]. Over-doping triggered decrease of both the penetration depth and the coherence length, leading to an increase of the condensation energy. With this in mind, we have explored for another superconductor to apply this *J*c-improvement strategy. Our choice of material is electron doped NdFeAsO, since NdFeAsO exhibits a constant high superconducting transition temperature *T*c of around 50 K over a wide range of doping. Electron doping can be realized by a partial substitution of oxygen by fluorine or hydrogen (*Ln*FeAsO1-*x*(F or H)*x*, *Ln*: lanthanide element). The respective solubility limit for F and H are
$x \leq 0.2$ and $x \leq 0.8$. We fabricated NdFeAs(O,H) thin films by a topotactic chemical reaction [2]. NdFeAs(O,H) showed a very high *J*c of over 17 MA/cm2 at 4.2 K, which is almost more than twice as large as our best performed NdFeAs(O,F) [3]. Additionally, the electromagnetic anisotropy of NdFeAs(O,H) was much lower than that of NdFeAs(O,F) [4]. Heavily electron doping benefits the superconducting properties of NdFeAs(O,H) with respect to the critical current and its anisotropy.

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Reaction Proliferation and Microstructure Characterisation of Multifilament MgB_2 Wires

Motasim Billah

The University of Queensland, Australia

Abstract:

Sudden expansion of impurities seen in rapid growth of Satellite Island in a successive number at highly stretched Fe sheathed MgB2 multifilament wire. Ratio between purity and impurity is so surprisingly large that it has been found a very little volume of pure MgB2 is actually carrying immense amount of current (Ic) under 100 µm x 100 µm cross section of single strand. We revealed such behaviour by microstructure analyses and portrait the true Jc within micro cross section of the multifilament wire.

Effect of Gd Addition on the Superconducting Properties of $Nb_{0.6}Ti_{0.4}$ and $Ta_{0.4}Ti_{0.6}$ Alloys

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Abstract:

Our recent work shows that the critical current density (*Jc*) of the body centered cubic (*bcc*) V0.6Ti0.4 alloy enhances significantly after the addition of rare earth element Gd as the latter is immiscible in the matrix [IEEE Trans. Appl. Supercond., vol. 31, no. 5, pp. 8000104, August 2021; Mater. Sci. Eng. B, vol. 274, pp. 115462, December 2021]. The very low solubility of Gd in other *bcc* elements like Ta and Nb is also well known. These facts are utilized to find the effect of adding 1 at.% Gd into the Nb0.6Ti0.4 and Ta0.4Ti0.6 alloys on the superconducting properties e.g., the transition temperature (*Tc*), *Jc*, flux pinning force density (*F*p) and the microstructure. In spite of Gd being ferromagnetic, the *Tc* in these alloys change only marginally (increase by 0.3 K in Ta-Ti and decrease by 0.15 K in Nb-Ti) after Gd addition. The *Jc* (*H* = 1 T, *T* = 4 K) increases by 5 and 1.5 times respectively in the Nb-Ti and Ta-Ti
alloy compositions with Gd addition, which is quite small as compared to the increase observed in the V0.6Ti0.4 (20 times) system. With Gd addition, the grain size reduces approximately by 70% and 17% respectively in the Nb-Ti and Ta-Ti compositions. The present analysis indicates that the grain boundaries are the major flux line pinning centres in these alloys and the role of Gd in increasing the *J*c, depends on the effectiveness of Gd in reducing the grain size. The grain boundary density depends strongly on the distribution of the Gd precipitates, which is found to be quite different from each other in the case of the two alloys under study.

Improved DC Fault Current Limiting Characteristics of Flux-Lock Type SFCL with Series connection of Two Coils using Twice Quench

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Abstract:

In this paper, the improved DC fault current limiting characteristics of the flux-lock type superconducting fault current limiter (SFCL) with series connection of two coils using twice quench were investigated.

The flux-lock type SFCL with series connection of two coils is composed of two windings connected in series and two superconducting modules (SMs) for twice quench. Each SM is connected in with one coil and in series with another coil.

The flux-lock type SFCLs with series connection of two coils in the DC system are thought to perform the similar fault current limiting operation to AC system. However, since the transient period after the resistance in SM approaches into the constant value, its fault current limiting characteristics in the DC system are expected to be different from one in the AC system as well as its recovery characteristics after the DC fault removes.

To analyze its DC fault current limiting and recovery characteristics, DC short circuit tests were performed and the improved operations of the flux-lock type SFCL with series connection of two coils using twice quench in DC system were analyzed from the test results.

Liquid Metal-based Tunable Resistance Electrical Insulation Layers

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Abstract:

Since the discovery of high-temperature superconductors, people have made great efforts to develop electrical insulation layers to improve the stability of the superconducting magnets. Here, a series of core-shell eutectic gallium-indium-tin (EGaInSn) liquid metal (LM) based anisotropic conductive adhesives (ACA) have been successfully employed as electrical insulation layers. EGaInSn nanodroplets (NDs) were used as soft conductive filler micro/nanoparticles for fabricating ACAs, they retain superconducting properties, and the Tc is 6.6K. Furthermore, Ga-based LM can function as an intrinsically deformable conductor that avoids mechanical mismatching with a polymer matrix. Ultrathin passivating oxide skin (~3 nm) of LM NDs offers a layer that can effectively prevent Ga spontaneous penetration from protecting the stability of NDs when pressure is not applied, as well as wetting layers to the polymer matrix. After external stimulation applying in a certain direction, the layer of ND could rupture to penetrate each other to form a conductive path in this direction only, the shell in different directions unaffected. Thus, LM is essential in generating electrically conductive composites with excellent conductivity and good mechanical performance. Through embedding Ga-based LM NDs into a commercial glue matrix at a certain concentration, LM-based electrical insulation layers with satisfactory anisotropic conductivity have been achieved. Besides, the resistance of insulation layers can be adjusted by the ratio of LM NDs and polymer matrix. These insulation layers also demonstrated highly stable performance when applied in a flexible system with significant deformation. The tunable sizes of the LM NDs offer the possibility of packaging super-miniatures for superconductors.

Materials Challenges for High Field Cuprate Magnets

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Abstract:

A central topic in the materials science of high field superconductors is their nanostructure and its influence on vortex pinning and the critical current density, high values of which are essential to high magnetic field applications. Fascinating and important though this is, it is not the only materials challenge facing use of cuprates to build magnets quite impossible with Nb-based materials. Indeed the vortex pinning mechanism in Bi-2212 is still unknown and certainly weak, yet it has become a very viable cuprate conductor technology in the last 5 years. Here I want to contrast some of the lessons we are learning from applying REBCO coated conductors and Bi-2212 round wires to high field magnets in the 30-45 T range. Table I summarizes some of the key properties of each conductor type. Access to industrial REBCO coated conductors has been possible for about 15 years now but few general-purpose user magnets are yet in service, even though it is easy to wind the conductor as delivered.

Table I. Key issues for REBCO and Bi-2212

Property	REBCO	Bi-2212
Conductor form	Tape ~4mm wide with strong mechanical and electromagnetic anisotropy	Multifilament, isotropic round wire with flexible conductor design
Reaction state	Can be wound as supplied	Must be reacted after winding with insulation and reinforcement capable of exposure to 890 C under 1 bar O_2
Strength	Strong substrate but weak adhesion of REBCO to buffers and vulnerable to out of plane stresses	Dominated by weak silver matrix requiring added strengthening
Vortex pinning	Strong and highly tunable	Weak – but strong enough

The high costs of all cuprates means that use will only occur when Nb-Ti or Nb_3Sn is not possible and cuprates only come into their own for B>>20 T or T>>4 K. The first choice is conductor form: tape or round wire but this also determines the reaction condition. The great advantage of the round, multifilament Bi-2212 is compromised by the need to react it under ~50 bar overpressure at 890°C and to integrate its insulation and strengthening compatible with such reaction. High field use focuses attention on strength and quench protection, both of which have brought unexpected attention to the mechanical and electromagnetic anisotropy of REBCO which is vulnerable to screening current overstress and delamination at the buffer layer-REBCO layer interface at stresses well below the axial conductor strength. To make Bi-2212 viable, internal strengthening to 2-3 times the bare wire breaking stress is highly desirable. These challenges must be well understood and practically mitigated if cuprates are to become a pervasive high field magnet technology. I present my viewpoint on recent work resolving these issues and lay out some challenges for the materials community that could hasten ultra-high field magnet application.

Keywords: *Cuprates, high field magnets, conductors*

Topological Superconductors by Proximity Effects

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Abstract:

Topological superconductors attract lots of attentions recently, since they are predicted to host Majorana zero mode (MZM), who behaves like Majorana fermion and can be used in fault-tolerant quantum computation relying on their non-Abelian braiding statistics. Currently, most topological superconductors are artificially engineered based on a normal superconductor and the exotic properties of the electronic surface states of a topological insulator. As predicted, MZM in the vortex of topological superconductor appears as a zero energy mode with a cone like spatial distribution. Also, MZM can induce spin selective Andreev reflection (SSAR), a novel magnetic property which can be used to detect the MZMs. Here, I will show you that the Bi2Te3/NbSe2 hetero-structure is an ideal artificial topological superconductor and all the three features are observed for the MZMs inside the vortices on the Bi2Te3/NbSe2. Especially, by using spin-polarized scanning tunneling microscopy/spectroscopy (STM/STS), we observed the spin dependent tunneling effect, which is a direct evidence for the SSAR from MZMs, and fully supported by theoretical analyses. More importantly, all evidences are self-consistent. Recently, the segmented Fermi surface induced by the Cooper pair momentum was observed in a Bi2Te3/NbSe2 system. Finally, the strong proximity effect was found in SnTe-Pb heterostructure. The bulk pairing gap and multiple in-gap states induced by topological surface states can be clearly distinguished. The superconductivity of SnTe is consistent with a new type of topological superconductors under the protection of lattice symmetries. Under lattice-symmetry protection, the superconducting SnTe is predicted to possess multiple MZMs in a single vortex. This system provides a platform to study the coupling of multiple MZMs without the need of real space movement of a vortex.

Scanning Hall Probe Microscopy on Magnetically Ordered and Superconducting EuRb-1144 Single Crystals

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Abstract:

The iron-based EuRb-1144 system is an ideal platform for studying the intriguing interplay between magnetic ordering and superconductivity since the superconducting and magnetic transitions are separated by about 20 K. This allows an investigation of the superconducting properties with and without magnetic ordering in the same sample. We exploited Scanning Hall Probe Microscopy at various fields and temperatures with micrometer resolution to map the field profile above the surface of a single crystal in order to resolve the contributions of magnetism and superconductivity. A striking difference in the local magnetization above and below the ferromagnetic transition was observed. We performed measurement in both main field orientations, namely parallel and perpendicular to the ordered magnetic moments (crystallographic ab-planes). In both cases, the Bean-profile heavily distorts near zero field in the magnetic ordered state, which evidences a strong interaction between superconductivity and magnetism.

Nuclear Techniques to Measure and Modify Magnetic and Superconducting Films with Nanoscale Precision

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Abstract:

A challenge in quantum electronics is to precisely control the magnetic or superconducting state of specific components with nanoscale precision. In this talk I will discuss experimental infrastructure available at the Australian Nuclear Science and Technology Organisation to measure and modify magnetic and superconducting elements at the nanoscale. In the first section, I will discuss the application of polarised neutron scattering as a precise technique to provide non-destructive measurements of thin films and heterostructures including magnetic, topological and superconducting materials. As a case-study, I will demonstrate how the nuclear technique of ion beam modification can be used to write topological and magnetic domains to form patterned media.

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Development of Iron-based Superconducting Wires for High-field Applications

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Abstract:

Iron-based superconductors (IBS) are very promising candidates for high-field applications owing to their ultrahigh upper critical field (Hc2) and very small anisotropy. For the practical applications, IBS wires and tapes with high transport critical current density (Jc), high mechanical strength and sufficient length are crucial. In the recent years, high transport Jc up to 2×105 A cm-2 at 4.2 K and 10 T was achieved in highly textured IBS tapes based on a powder-in-tube (PIT) method. Furthermore, the transport Jc of IBS tapes with high-strength composite metal sheath such as Cu/Ag and Stainless steel/Ag was enhanced above 105 A cm-2 at 4.2 K and 10 T as well. On the other hand, with hot isostatic pressing process, the Jc-performance of IBS round wires was also significantly improved. With the achievement of high-performance multifilamentary IBS long-length tapes, the first IBS single pancake coil and double pancake coil were fabricated and tested at 24 T and 30 T background field, respectively. Two IBS racetrack coils using 100-meter long IBS tapes were successfully made and tested in a superconducting dipole magnet which provided a maximum background field of 10 T at 4.2 K. These results demonstrate the great potential of IBS wires in high-field applications in the future.

Enhanced Superconducting and Electronic Properties of Low Activation MgB_2 Superconductor for Fusion Application

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Abstract:

Isotopic magnesium diboride ($Mg^{11}B_2$) superconductors doped with carbon (C) derived from sorghum biomass were synthesized using isotope boron (^{11}B) and magnesium powder via solid-state reaction. The effect of C-doping on the structure and superconducting properties of $Mg^{11}B_2$ bulks were investigated. The DC magnetization measurements revealed a sharp superconducting transition for all samples and a slight reduction in critical temperature (T_c) of the C-doped samples. The critical current density (J_c) of 10 at. % C-doped Mg11B2 bulk synthesized at 650 °C was enhanced to 0.7×10^4 A/cm2 compared with undoped bulk's Jc of 0.4×10^4 A/cm2 in 4.5 T at 5 K. Similar improvement was also observed for the bulks heat-treated at 800 °C. The 10 at. % C-doping induced effective pinning centers and resulted in increased high-field J_c of $Mg^{11}B_2$ bulks. It is likely that the activated porous carbon with a high surface area is beneficial as a dopant compared to other C sources reported in the literature. The flux pinning mechanism of the bulks was investigated using the Dew-Hughes model for pure and C-doped samples. The flux pinning mechanism was understood with a mixture of point pinning and grain boundary pinning for $Mg^{11}B_2$ bulks. This study provides information regarding the enhancement of the J_c of low-activation $Mg^{11}B_2$ superconductors suitable for next-generation fusion magnets.

Characterization of Bi-2223 Superconducting Coils for Compact Cyclotrons in Proton Therapy

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Abstract:

The development of ever smaller medical particle accelerators is motivated by a desire to make proton therapy accessible to more patients. Reducing the footprint of particle accelerators and subsequently proton therapy facilities allow for cheaper and broader usage of proton therapy. By employing superconducting technologies for field shaping, the size of particle accelerators can be reduced further below what is possible with saturated iron. A first-of-its-kind double pancake and a flutter coil assembly, comprising six double pancake coils, designed for a compact isochronous cyclotron for proton therapy, have been fabricated with high-temperature superconducting Bi2Sr2Ca2Cu3Ox (Bi-2223) tape. In a conduction-cooled setup, the critical currents as a function of the temperature of both coils were measured. The coils were mounted under pre-stress within a stainless-steel structure, for maintaining mechanical stability during the experiments. To study the quench and thermal runaway behavior of the coils, additional experiments were performed. The tests showed that the coils were robust and can be well protected against quenches and thermal runaway events. In addition, the critical current of the Bi-2223 tapes was studied under mechanical transverse load in single tape and coil winding package configurations.

The Development and Research Status of HTS CICC for Future Fusion Reactor

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Abstract:

High magnetic field is one of the important conditions required for lots of scientific researches. High temperature superconducting (HTS) materials have the potential to generate a magnetic field beyond the level obtainable with low temperature superconducting (LTS) materials. According to the commercial production technology development of the high temperature superconducting materials, the ReBCO and Bi2212 are the promising candidates. The maximum field of CFETR magnet will be higher than 15T. In order to achieve the magnet field of CFETR, the ReBCO and Bi2212 conductor/coil technology was developed at ASIPP. To maximize their advantages and overcome the shortcomings, concepts of cable design and lots of research activities were proposed and carried out in recent years. Here, the new research results obtained at ASIPP recently were reported.

Firstly, the full size YBCO CICC was designed, and R&D achieves good progress. The first sub-size sample achieves 12kA at 20T back field, and no degradation after about 20 EM cycles with 150kN/m and 10 WUCD cycles. The full size sample for SULTAN is prepared, which was planned to finish in June 2022.

Secondly, the Bi2212 cable obtained good progress. One new sample with pre-high pressure and 5MPa heat treatment was finished, which took 1 year to solve the problem. The testing results shows good performance, and critical current achieves 35.7kA@5.8T, 4.2K. The second one with low void fraction (~32%) is ready for testing in the end of April, which is estimated t o have much higher performance than sample 1.

These results are good reference for development of HTS conductor of high field magnet for CFETR, accelerator, and so on. The future research plan of HTS conductor will be also described.

Development of Superconducting Homopolar Electrodynamical Devices Using Sp^2 Carbon Allotropes-Copper Composites and Their Frictionless Modeling and Simulation in the Presence of up to 20k Amps Direct Current

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Abstract:

In this presentation I report the incorporation sp^2 carbon allotropes such as carbon nanotubes and graphene on the development of superconducting homopolar electrodynamical devices in different parts and its superlubricity modelling and simulation in the presence of up to 20k amps direct current.

The 2020 International Energy Agency (IEA) report[1] summarizes the following highlights to draw a strategic guidance to dramatically scale up clean energy technologies. A major effort to develop and deploy clean energy technologies worldwide is urgently needed to meet to net-zero CO_2 emissions climate goals to 2050. The report finds that transitioning just the power sector to clean energy would get the world only 30%+ of the way to net-zero emissions. But to complete this effort will require devoting more attention to new technologies unthought of until now on transport, heavy industry, and buildings sectors, which today account for about 55% of CO_2 emissions from the energy system. Hydrogen will be the vital solution, alongside electricity. To avoid the worst consequences of climate change, the global energy system must rapidly reduce its emissions:

- To achieve net-zero emissions requires a radical transformation in the way to supply, transform, and use energy,
- Many governments have ambitious plans for reducing emissions from the energy sector, but new brainchild technologies such as this presentation is required,
- Spreading the use of electricity into more parts of the economy is the single largest contributor to reaching net-zero emissions.

The purpose of this R&I work is to generate or power 20k amps of pure direct at about 15-f20 V. This project is based on the work carried out at Guina Energy Tech., Gold Coast, Qld for 12+ years. A paper published in 2016 describes this kind of electrodynamical devices using liquid sodium-potassium alloy (NaK) as current collector.[2] In the present work, sp^2 carbon allotropes-copper composites replace not only NaK as current collector but also the oxygen-free copper on the superconductor homopolar machine described on the paper.

The possible applications of this kind of devices are a) propulsion of aircrafts, ships, trains, trucks b) wind power generators to power electrolyser plants for hydrogen and oxygen productions, c) battery recharger, d) iron ore reduction and copper hydrometallurgy and e) superconducting homopolar electrodynamical devices in conjunction with regenerative fuel cells can be used for space energy[3]

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The Development of High Temperature Superconducting Maglev Transportation in SWJTU

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Abstract:

As a new type of rail transit system, the speed of high-speed (or evacuated tube) maglev transportation will be greater than 600 km/h. The combination of maglev train technology and low-pressure evacuated tube technology can theoretically minimize the aerodynamic and friction resistance of trains running at high speed, which is the inevitable choice for ground rail transit to move towards higher speed in the future. And maglev is one of the core technologies of evacuated tube transportation, its technological maturity restricts the development of the whole system. First of all, we introduce the development of maglev rail transit in the world, and compare the working principle and application of different maglev modes. Then, we discuss the prospect of evacuated tube transportation development under the guidance of maglev technology. The feasibility of ultra-high speed operation of high temperature superconducting (HTS) maglev system in low-pressure evacuated tube environment is demonstrated from three aspects of "low pressure", "high speed" and "heavy load". Then, the research progress of HTS maglev transportation test platform and high speed maglev engineering vehicle and test line are introduced. And a three-step development strategy of low speed, high speed, ultra-high speed is put forward. Finally, the key problems to be solved in the development of HTS high-speed (or evacuated tube) maglev transportation system and the focus of further research are prospected.

Keywords: *high-speed maglev, HTS maglev; evacuated tube transportation, test platform.*

Structural Design of a Large-gap Superconducting Spectrometer Magnet for CEE

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Abstract:

High Density Nuclear Matter Experiment Platform (CEE) magnet is based on Nb-Ti superconducting material with a central field of 0.5 T and an air gap of 1.2 m. In order to reduce the weight of the magnet as much as possible and improve the utilization of space, CEE magnet adopts the coil-dominated magnet scheme. At the same time, the magnet uses a racetrack coil instead of a circular coil, which reduces the height of the magnet while achieving high magnetic field uniformity in a large space. However, the corresponding structural design faces many challenges: due to the heavy weight of the coil, its own deflection is large in the static state; Secondly, due to the large volume of the coil, the cooling and contraction process will produce a large deformation, which will change the distribution of the conductor, affect the magnetic field quality and also produce a large thermal stress on the conductor. In addition, during the operation of the coil, it is affected by the electromagnetic force, and an effective pre-tightening device is needed to ensure that all parts of the conductor are always in a tight state. In addition, the coil surface area is large, the assembly gap between layers is difficult to control, resulting in the preload is difficult to fully apply to the conductor; Due to the racetrack section of the coil, the load-carrying efficiency of the straight section of the coil is lower than that of the arch structure.

Therefore, in the process of coil design, it is necessary to focus on the large deformation of the magnet during operation and ensure that the stress of each part of the conductor is within the safe range. The support structure that can effectively resist thermal stress, electromagnetic force and other complex environment is designed to ensure the long-term reliability of the whole coil.

Key words: *CEE, Superconducting dipole magnet, support structure, mechanical design, large gap*

Origin of Cracks in YBCO Coated Conductors Under Axial Loading and their Interaction with Non-superconducting Phase Particles

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Abstract:

$YBa_2Cu_3O_{7-x}$ coated conductors (YBCO CCs) have been used in many superconducting components of electrical engineering after they were fabricated. New challenge what we face to is how the damages occur in YBCO CCs with multi-layer structure under both mechanical and extreme environment, which also dominates their quality. In particular, damages caused by tensile stress in YBCO CCs, such as cracks, are easy to cause irreversible degradation to their superconducting properties. Therefore, understanding the initiation and propagation modes of cracks can assist in preventing conductor failure and enhancing their mechanical properties in further. In this study, we used a chemical etching method and scanning electron microscopy (SEM) to investigate crack morphology in the YBCO layer of conductors where the protective metal layer had been removed. For YBCO CCs that experienced no deformation, many non-superconducting phase particles were observed and their grain size distribution corresponded to a Gaussian distribution. Energy dispersive x-ray spectroscopy (EDS) identified these as Y-Cu-O particles. For the YBCO CCs that experienced axial tension at 77 K, the cracks did not originate from the YBCO brittle ceramic layer, but originated from the alloy substrate. They propagated into the buffer layer with an increasing strain and penetrated into the superconducting layer along the directions of both the thickness and width when the strain further increases. In addition, different propagation modes of cracks in the YBCO layer, including transgranular fracture, branching, deflection and pinning were observed for the first time. Statistical analysis demonstrated that transgranular fracture occurred in ~95% of the cracks modes. We analysed the reason for this phenomenon considering the thermal stresses stored inside and around the non-superconducting phase particles. The coefficient of thermal expansion of the Y_2Cu_2O5 particles is less than that of the YBCO superconducting matrix, and therefore, the hoop tensile stress generated near the boundary of the Y_2Cu_2O5 particle accelerates the bottom-up propagation of the cracks. The other cracks propagation modes such as crack branching, deflection, pinning and bridging in the YBCO superconducting layer can be considered mechanisms of blocking cracks propagation that can increase the fracture toughness of the YBCO layer. The obtained results reveal the mechanism of cracks formation and provide a potential orientation for improving mechanical quality of YBCO CCs.

Charge Density Wave and Superconductivity in the Kagome Metal CsV_3Sb_5 Around a Pressure-induced Quantum Critical Point

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Abstract:

Using first-principles density-functional theory calculations, we investigate the pressure-induced quantum phase transition (QPT) from the charge density wave (CDW) to the pristine phase in the layered kagome metal CsV3Sb5 consisting of three-atom-thick Sb-V3Sb-Sb and one-atom-thick Cs layers.[1,2] The CDW structure having the formation of trimeric and hexameric V atoms with buckled Sb honeycomb layers features an increase in the lattice parameter along the *c* axis, compared with its counterpart pristine structure having the ideal V3Sb kagome and planar Sb honeycomb layers. Consequently, as pressure increases, the relatively smaller volume of the pristine phase contributes to reducing the enthalpy difference between the CDW and pristine phases, yielding a pressure-induced QPT at a critical pressure *Pc* of ~2 GPa. Furthermore, we find that (i) the superconducting transition temperature *Tc* increases around *Pc* due to a phonon softening associated with the periodic lattice distortion of V trimers and hexamers and that (ii) above *Pc*, optical phonon modes are hardened with increasing pressure, leading to monotonic decreases in the electron-phonon coupling constant and *Tc*. Our findings not only demonstrate that the uniaxial strain along the *c* axis plays an important role in the QPT observed in CsV3Sb5 but also provide an explanation for the observed superconductivity around *Pc* in terms of a phonon-mediated superconducting mechanism.

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Degradation Characteristics of No-insulation REBCO Coils in 20-T HTS Magnet Testing

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Abstract:

A 20-T/17-mm High-Temperature-Superconducting (HTS) magnet, assembled with a 15-T no-insulation REBCO insert (Coil 1) nested in a 5-T metal-insulation REBCO coil (Coil 2), was recently developed and tested. Coil 1 is a stack of 20 no-insulation (NI) double pancake (DP) coils and Coil 2 is a stack of 28 metal-insulation (MI) DPs. The HTS magnet was cooled in liquid helium and charged for five runs, with the maximum power supply current of 228 A. Quench happened during each charging process. The power supply current dropped to zero within 1s. This rapid current variation produced a large induced voltage inside the coil, resulting in damage to Coil 1. After warming, both Coil 1 and Coil 2 were tested in liquid nitrogen. The critical current of Coil 1 was dramatically degraded. Three representative DPs from Coil 1 were chosen to investigate the degradation characteristics. Defects were located by using continuous I_c measurement, and were observed by scanning electron microscope. It was found that most degradation areas consist of a bubble with a current breakdown point, and they were distributed throughout Coil 1. Possible reasons were discussed and protection methods were proposed.

Superlattices, Orbital Character and the Mechanism for Superconductivity

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Abstract:

Our earlier investigations on MgB_2 superconductors using room temperature Raman spectroscopy displayed small peaks that correspond to frequency modes for superlattices in the *c*-direction [1]. More recent experimental results obtained at the THz/Far IR beamline of the Australian Synchrotron have provided further evidence of such superlattices [2] and key peak changes with temperature. For example, THz spectra not only showed additional, low-wavenumber superlattice peaks, but also display an evolution of the spectral density as a function of temperature. After crossing the superconducting transition temperature, low-wavenumber peaks appear and increase in intensity with cooling, indicating a direct connection to superconducting properties of the material. Calculated electronic band structures and the bonding/anti-bonding character of key bands are revisited in light of this new superlattice information. Important phase relations are identified from the variation of the band structure between the reciprocal space G centre point and the Brillouin zone boundaries. Superlattice folding of reciprocal space generates multiple Umklapp processes [3]. Nesting relationships are also apparent on the Fermi surfaces, which will lead to charge density wave formation along perpendicular directions to the nesting vectors [4]. Tight binding equations are compared to expected nesting relationships and corrected accordingly. The results give unprecedented atomistic, mechanistic information on superconductivity, directly from a thorough, systematic analysis of the electronic band structure, when the k-grid resolution of the calculation is adequately fine [5].

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A Compact Giant Inductance Device Based on the Negative Flowing Current Across the Ferromagnetic Josephson Junction for Superconducting Electronics

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Abstract:

Superconducting electronic (SCE) is much more attractive in the post-Moore era, for high operating frequency (sub-THz) and low energy dissipation. However, Different from CMOS technology, the operating principle of superconducting Single Flux Quantum (SFQ) circuits are based on the dispersion and storage of single-flux-quantum (Φ_0=2.067×10^{-15} Wb). There are two parameters should be carefully designed in SFQ circuits, one is the critical current I_c of Josephson junctions (JJs) and the other is the inductance L of superconducting loop ($LI_c \sim 0.5\Phi_0$ for non-storage loop while $LI_c \geq \Phi_0$ for storage loop). Consequently, those inductors will take much of the area in the layout and limit the integration of SFQ circuits, especially when $I_c < 100$ μA. Several development paths for scaling up the SCE circuits have been proposed, like decreasing the feature size [1] or replace geometric inductance with kinetic inductance [2, 3]. However, the latest demonstrated SFQ circuits have one million junctions, and the integration is still ~ 10^4 less than that of CMOS [4]. The basic cell scaling requires further research on inductors for SCE circuits.

In this study, we propose a compact giant inductance device based on novel ferromagnetic π-JJs, which has an abnormal current-phase-relation (CPR) described by $I = I_c \sin(\varphi + \pi) = -I_c sin\varphi$. This giant inductance device can be simplified as a superconducting strip parallelly connected with a π-JJ, or we can call it as π-SQUID (superconducting quantum interference device). We find when the strip inductance L is extremely small ($LI_c < \Phi_0/2\pi$), a negative current can be induced across the π-JJ only when an external excitation is applied. As a nonlinear inductance device, the π-JJ will act as a negative inductor. Due to the parallel effect of positive and negative inductors, the effective inductance can be dozens of times larger than that of the superconducting strip alone in theory and result in a compact giant inductance device. The effective inductance will be simulated and measured by adopting it into DC SQUID and SFQ circuits. We think this compact π-SQUID giant inductance will be a milestone to the development not only for the superconducting digital circuits but also for the quantum computing circuits

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Magnetic Nanocellulose for Waste Water Treatment

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Abstract:

Australia water is essential for the survival of all known forms of life. With population growth and global climate change, the shortage of usable water will become an increasingly geopolitical issue that is no less pressing than the need for clean energy. Currently, over a billion people worldwide lack safe drinking water and waterborne diseases contribute to approximately five million deaths per year.1 Various treatment can be used for water decontamination and desalination, including size separation, adsorption, chemical coagulation, photodegradation, biodegradation, and active sludge treatment. However, the development of sustainable and inexpensive products for water purification will be critical as water usage grows.2,3 In the past few years, we have developed sorbent materials using the cellulose micro and nanofibres derived from sugarcane waste for removing heavy metal4, dye5 and Per and Poly-fluoroalkyl substances (PFAS) from water. In this presentation, cellulose nanofibers are used as a template to synthesise magnetic nanoparticles with a uniform size distribution. Magnetic nanoparticles are grafted on the surface of nanofibers via in situ hydrolyses of metal precursors at room temperature. Effects of different concentrations of nanofibers on the morphology, the crystallite size of magnetic nanoparticles, and the magnetic properties of the membrane produced from the cellulose nanofibers decorated with magnetic nanoparticles are examined. The magnetic membrane was then used as an environmentally friendly, low-cost catalyst in a sulphate radical-based advanced oxidation process and removed 95% Rhodamine B (RhB) from water.

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Spin Dynamics and Magnetoelectric Coupling Mechanisms in $Mn_4Nb_2O_9$

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Abstract:

$Mn_4Nb_2O_9$, being a magnetoelectric compound isostructural with $Co_4Nb_2O_9$, demonstrates magnetoelectric coupling properties below its magnetic phase transition. However, compared to the magnetoelectric coupling coefficient (~18.4ps/m) of $Co_4Nb_2O_9$, the magnetoelectric coefficient (~1.5ps/m) of $Mn_4Nb_2O_9$ is much weaker, even though these two compounds share the same crystal structure in space group $P\bar{3}c_1$. What is the reason for the weak magnetoelectric property in $Mn_4Nb_2O_9$? Neutron powder diffraction on the high-intensity diffractometer, Wombat, at ANSTO and inelastic neutron scattering on the cold-neutron triple axis spectrometer, Sika, at ANSTO were used to study this compound to understand the fundamental mechanism for the weak magnetoelectric coupling mechanism.

It is found that $Mn_4Nb_2O_9$ has a different magnetic structure from $Co_4Nb_2O_9$.[1] The latter was reported to have a non-collinear in-plane magnetic structure with the magnetic moments lying in the *ab* plane with a small canting angle in the plane,[1] while $Mn_4Nb_2O_9$ has a collinear magnetic structure with the magnetic moments all aligning along the *c* axis.[2] Such a strong contrast in the magnetic structure originates from the different spin dynamics of these two compounds.

The inelastic neutron scattering experiment revealed the spin-wave spectrum from $Mn_4Nb_2O_9$. The model analysis of the spin-wave spectrum of $Mn_4Nb_2O_9$ indicates that this compound has a very weak easy-axis magnetic anisotropy with dominating antiferromagnetic interactions in the two MnO_6 networks. This is significantly different from the scenario for $Co_4Nb_2O_9$, where a strong in-plane single-ion anisotropy dominates the spin dynamics of this compound, causing the in-plane magnetic structure, and the Dzyaloshinskii–Moriya interaction induces strong magnetoelectric coupling.[1] The weak magnetoelectric coupling effect in $Mn_4Nb_2O_9$ is attributed to the exchange striction like in Cr_2O_3 but without any orbital contributions due to the $3d^5$ electron configuration. The non-equivalent Mn_I and Mn_{II} play the essential role in the magnetoelectric coupling effect originating from the uncancelled exchange striction.[3]

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Interrelations Among Critical Current Density, Irreversibility Field and pseudogap in Hole Doped High-T_c Cuprates

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Abstract:

The effects of hole content (p) and oxygen deficiency (δ) on the zero-field critical current density, J_{c0}, were investigated for high-quality c-axis oriented $Y_{1-x}Ca_xBa_2Cu_3O_{7-\delta}$ (x = 0, 0.05, 0.10, and 0.20) thin films. Low temperature critical current density of these films above the optimum doping were found to be high and were primarily determined by the hole concentration, reaching a maximum at $p \sim 0.185 \pm 0.005$, irrespective of the level of oxygen deficiency. This implies that oxygen disorder plays only a secondary role and the intrinsic J_{c0} is primarily governed by the carrier concentration in the copper oxide planes. Further support in favor of this was found from the analysis of the in-plane resistive transitions of c-axis oriented crystalline thin films of $YBa_2Cu_3O_{7-\delta}$ under magnetic fields (H) applied along the c-direction, over a wide range of doped holes. The characteristic magnetic field (H_0), linked to the vortex activation energy and the irreversibility field, exhibits similar p-dependence as shown by $J_{c0}(p)$. We have explained these observations in terms of the doping dependent pseudogap (PG) in the low-energy electronic energy density of states. Both the intrinsic critical current density and the irreversibility field depend directly on the superconducting condensation energy, which in turn is largely controlled by the magnitude of the hole concentration dependent PG in the quasiparticle spectral density.

Keywords: *Superconducting cuprates; Critical current density; Irreversibility field; Vortex dynamics; Pseudogap*

Nucleation and Dynamics of Magnetic Solitons in Topological Materials

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Abstract:

Skyrmions are topologically protected spin textures, which may serve as elements of future spintronic memory and logic devices. Therefore, skyrmion nucleation in topological systems such as topological insulator/ferromagnet is important to study, especially as in these systems the skyrmions are shown to move faster. I will discuss skyrmion nucleation induced by spin-transfer torques specific for a topological insulator interface with a ferromagnetic insulator. Using micromagnetic simulations and energetics, we evaluate properties of the skyrmion nucleation on a surface of topological insulators, such as nucleation time, critical electric field, and skyrmion numbers [1]. I will show that the nucleation time is inversely proportional to the applied electric field and will also identify the Gilbert damping and temperature dependences of the critical nucleation field. Furthermore, I will discuss the effect of the Dzyaloshinskii-Moriya interaction and demonstrate that the temperature dependence can be explained by the reduction of a magnon excitation gap due to the self-energy corrections.

I will also discuss topological solitons in numerous in-plane magnetized materials. These solitons are called bimerons and they are in-plane analogues of skyrmions as they have the same topological charge. I will first describe their stability, static and dynamics properties in ferromagnets [2]. Then I will turn to antiferromagnets, where I will show that in analogy with skyrmions [3], these topological solitons possess no skyrmion Hall effect, and among other interesting properties demonstrate chaotic behavior when driven by ac-currents in low-damping systems.

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Voltage-controlled Magnetic Tunnel Junctions for High-Speed Embedded Memory and Probabilistic Computing

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Abstract:

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

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

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

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Quantum Anomalous Semimetals

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Abstract:

The topological states of matter and topological materials have been attracting extensive interests as one of the frontier topics in condensed matter physics and materials science since the discovery of quantum Hall effect in 1980s. So far all the topological phases such as quantum Hall effect, quantum spin Hall effect and topological insulators and superconductors are characterized by a nonzero integer or Z and Z 2 topological invariant. None is a half-integer or fractional. Here we propose a new type of semimetals which hosts a single cone of Wilson fermions instead of Dirac fermions. The Wilson fermions possess linear dispersion near the energy crossing point, but breaks the chiral or parity symmetry (or time reversal symmetry) such that an unpaired Dirac cone can be realized on a lattice. To avoid the fermion doubling problem, the chiral symmetry or parity symmetry must be broken explicitly if the hermiticity, locality and translational invariance all hold. We find that the system can be classified by the relative homotopy group, and the topological invariant is a half-integer. We term the unexpected and nontrivial quantum phase as "quantum anomalous semimetal". The topological phase is a synergy of topology of band structure in solid and quantum anomaly in quantum field theory. A magnetically-doped topological insulator heterostructure is the first physical system which hosts a parity anomalous semimetal with a half-quantized Hall conductance. The half-quantized Hall effect is attributed to a existence of a single gapless Dirac of electrons.

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Shubnikov de-Haas Oscillations and ARPES Study in Transition Metal Doped Topological Insulators

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Abstract:

Bi_2Te_3, and Bi_2Se_3 are the well known three-dimensional topological insulators whose surface states consist of single Dirac cone at the gamma point. We have performed magneto-transport transport and ARPES experiments to investigate both the bulk and surface state electronic properties of transition metal doped Bi_2Te_3 and Bi_2Se_3 systems. ($Pd_xBi_2Te_3$). We observed Shubnikov de-Haas (SdH) oscillations, weak antilocalisation (WAL) effects that support the presence of topological surface states (TSS), in conformity with the ARPES spectra. Hall measurements revealed change in charge carriers from *n*-type in undoped Bi_2Te_3 to *p*-type in Pd-doped Bi_2Te_3, which is supported with the ARPES results, in which both the Dirac cone and bulk derived valence states are pushed towards the Fermi level upon Pd doping. Besides the energy shift of the Dirac point, the quasi-particles properties such as effective mass and mean-free-path obtainef from the SdH and ARPES experiments were to be found to be quite consistent with each other. Further we will present our results of electronic tranport studies on the noble metals (Pd, Pt, and Au) doped Bi_2Se_3.

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Magnetic Moment Compensated Spin Polarized Semi-metal

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Abstract:

Spintronics devices such as spin transfer torque-based devices require highly spin-polarized materials but with low magnetic moments to prevent the magnetic field generated by them affect the storage and transport of information. Half-metallic ferrimagnetic Heusler alloys, whose magnetic moment scales linearly with the total number of valence electrons per unit cell (Nv) are best suited for such applications as their magnetic moment can be compensated by substituting 3d transition metal elements. While the full-Heusler alloys require 24 valence electrons for magnetic moment compensation, the half- Heusler alloys require only 18 valence electrons to reduce the moment to 0 μB per formula unit. The half-Heusler alloys exhibit a larger half-metallic gap than the full-Heusler systems and are relatively less prone to the anti-site disorder than the latter. According to theoretical calculations, CoMnAl has been predicted to be a ferrimagnet with a magnetic moment of 1 μB per formula unit which corresponds to Nv= 19. Substitution of 50% Mn at the Cobalt site will result in the reduction of Nv to exactly 18 required for total magnetic moment compensation in the system. The material (Co0.5Mn0.5)MnAl was synthesized by Arc-melting under an Argon atmosphere. The analysis of X-ray diffraction data shows the material to have crystallized in a single phase $C1b$ structure. The results of the magnetic measurements indicate that the sample exhibits compensated ferrimagnetic behavior with a sublattice spin crossover. It was found that the curie temperature is 630 K and that a magnetic moment of 0.1 μB per formula unit was observed at 5 K. The system exhibits a unique temperature dependence of resistivity with a negative temperature coefficient in the range of 2-300 K, pointing to the material's semi-metallic nature. The electronic and magnetic properties of (Co0.5Mn0.5)MnAl are theoretically investigated, and it is revealed that the ground-state configuration is a completely compensated ferrimagnet and a semi-metal exhibiting finite spin polarization.

Magnetic Field-induced Peculiar Multiferroic Behavior in L-type Ferrimagnetic $Fe_2(MoO_4)_3$

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Abstract:

$Fe_2(MoO_4)_3$ was synthesized and characterized as a prototype of L-type ferrimagnets (L-FiM) with an ordering temperature TN1 ~ 12 K using magnetic susceptibility (χ), specific heat (Cp), and dielectric (ε') anomaly. Two remarkable findings are magnetic field (H) induced (I) an additional magnetic phase transition at TN2 below TN1; and (II) the emergence of flexible ferroelectric polarization (P) with the tuning parameters H and T below TN2. Thus, the H-T phase diagram for spin-induced type-II multiferroics was established. In contrast to some known multiferroics with a critical field-induced spin-flip P below TN1, the observed multiferroic nature is exotic. The origin of the profound multiferroic nature may be hidden in the complex T-and H-dependent spin and lattice structures. Consequently, the schematic picture of H-induced possible change of lattice symmetry and conical spin structure has been proposed. More experimental and theoretical works providing solid evidence and interpretations have been suggested to explore these peculiar multiferroic phenomena.

Keywords: *$Fe_2(MoO_4)_3$, L-type ferrimagnetism, Magnetic field-induced multiferroic, Ferroelectricpolarization.*

(RE)-Ba-Cu-O Single Grain Bulk Superconductors with Improved Superconducting and Mechanical Properties

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Abstract:

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

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

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

Climate Change and The Need for Emerging Materials and Technologies

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The University of Manchester, UK

Abstract:

The paper examines the fact that climate change will most likely go above the 1.5C limit set as the acceptable limit at the Paris COP 21 in 2015. The fact that man's contribution of greenhouse gases to the atmosphere can be identified now and the emissions over a period of 800,000 years determined show the urgency of action. However, simple projections show that 1.5C will be breached fairly soon. The IPCC AR6 Report does show that socio-cultural mitigation by humans, especially relating to food, can reduce the emissions but the evidence is that humans in developed countries are unlikely to change their lifestyles without legislation and carbon taxes. So new technologies to enhance renewable energy generation and the use of emerging materials is discussed as the central hope for reducing the overshoot of 1.5C to as little as possible. One possibility are supergrids over large distances transporting renewable power using superconducting cables and the use of superconductors in new energy generation and equipment.

Commercial Superconductors and Application Business Opportunities

Michael Tomsic

Hyper Tech Research Inc., USA

Abstract:

This talk will discuss potential commercial applications for superconductors. Some of the applications that will be discussed are all superconducting wind turbine generators to compete against permanent magnet direct drive wind turbine generators. The potential for all superconducting motors and generators for electric aircraft to produce higher power density and high efficiencies than ambient temperature. For the Grid, the potential for superconducting magnetic energy storage to prevent voltage sag, and superconducting fault current limiters to protect from high fault currents. We will also touch on MRI, NMR, Quantum Computing, and RF cavities.

Development of Industrial Grade MgB_2 Superconducting Wires and Magnet at Hyper Tech Research

M. Rindfleisch[1*], M. Tomsic[1], D. Doll[1], C.J. Thong[1], X. Peng[1], K. Kovacs[1], M. Sumption[2], E.W. Collings[2], M. Majoros[2]

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Abstract:

Hyper Tech Research will report on progress that has been made on developing magnesium diboride superconductor wires, coils and magnets for AC and DC applications, with a specific emphasis on the advancements in manufacturing wires and cables with significantly lower AC

We will show that present day MgB_2 conductors are usable for AC applications such SMES, motors and generators. Superconducting and mechanical properties of strands and cables will be discussed in addition to loss values and strand/cable architecture.

Development of Industrial Scale Nb_3Sn Strands at Hyper Tech Research

Xuan Peng

Hyper Tech Research, USA

Recent Progress on 2G HTS Tape Development in China

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Abstract:

In recent years, increasing numbers of universities, research institutes and companies including power utilities in China are carrying out research with superconductors for energy generation, storage and transfer. Second generation high temperature superconducting (2G-HTS) tapes are considered one of the most promising practical superconductors. With the financial support of Chinese central and local government, as well as the input of strategic investors, a 2G-HTS industry circle is forming in the Yangtze River Delta region in China. Three companies, Shanghai Superconductor Technology (SST), Shanghai Creative Superconductor and Suzhou Advanced Materials Research Institute, have been established with the goal of commercializing 2G-HTS tapes, using pulsed laser deposition, metal–organic decomposition and metal–organic chemical vapor deposition, respectively. An average Ic value greater than 800 A/cm at 77 K, s.f. has been achieved on the tapes with high homogeneity. By modulating the composition and microstructure at nano-scale, in-field performance of Ic exceeds 430 A/4mm-width at 4.2 K, 18 T due to the introduction of mixed defect landscape. Moreover, advanced post-processing techniques (lamination and laser slitting) id developed in order to enhance the mechanical (and/or electro-mechanical) properties of the tapes in practical applications. Several typical application cases based on using our products are also briefly mentioned, demonstrating the excellent performance of our 2G HTS tapes for a large variety of potential applications.

Keywords: *2G-HTS tapes, in-field performance, high-field magnet applications, lamination, laser slitting*

Superconductors for Industry

Development of Superconducting MRI Magnet System at Ningbo Jansen

Jianyi Xu & Jie Zheng

Ningbo Jansen Superconducting Technologies Co., Ltd, China

Superconductors: From Fundamentals to Applications-1

Recent Developments on Nb_3Sn Superconducting Undulators

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Abstract:

Nb_3Sn superconductors are a potential candidate to increase the performance of storage ring- and free-electron laser-based light sources beyond the current state-of-the-art. Thus, the Advanced Photon Source (APS) at Argonne National Laboratory has started a project to fabricate a Nb_3Sn superconducting undulator with the goal of validating its performance in a user environment. To accomplish this, first, modeling-driven optimizations were performed to realize the magnetic and mechanical design of the undulator magnets, and several short prototypes (8-cm-long) were fabricated. The design was successfully scaled to 0.5-m-long undulator magnets, confirming the maximum design field at least 20% higher than a NbTi version with the same gap and period length. Then, the final 1.1-m-long undulator magnets were fabricated. In parallel, the design modifications of an existing cryostat to accommodate the 1.1-m-long Nb_3Sn magnets were completed and tested. Further details on the magnet fabrication and cryostat assembly work will be presented.

High-Pressure NMR Studies of $FeSe_{1-x}S_x$: Interrelationships between Nematicity, Antiferromagnetic Spin Fluctuations, and Superconductivity

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Abstract:

The understanding of the interplay between magnetic fluctuations, electronic nematicity, and the nature of superconductivity in unconventional superconductors is one of the central issues in modern condensed matter physics. In iron-based superconductors, antiferromagnetic (AFM) spin fluctuations are believed to play an important role in the appearance of unconventional superconductivity. At the same time, the effects of fluctuations of electronic nematicity are also discussed extensively. However, in most of these systems, the nematic order occurs alongside the antiferromagnetic order, which makes the role of the nematicity on superconductivity unclear.

Recently the sulfur substituted FeSe system, FeSe1-xSx, has attracted much attention for the study of the impact of nematicity or antiferromagnetism on superconductivity independently because it shows nematic and AFM orders separately. In order to understand the effects of AFM spin fluctuations on superconductivity, we have carried out 77Se nuclear magnetic resonance (NMR) measurements at ambient pressure and under high pressure up to 2.0 GPa. From the systematic measurements of temperature (T) and pressure (p) dependences of nuclear spin-relaxation rate ($1/T1$) in FeSe1-xSx, we determined the x- and p-dependence of the strength of AFM sin fluctuations and found that the strength exhibits a strong correlation with superconducting transition temperature Tc [1,2]. In addition, we found that this relationship changes with the presence/absence of nematicity, and that four-fold rotational symmetric AFM spin fluctuations are better in enhancing Tc than two-fold symmetric AFM spin fluctuations [2,3].

This work is supported by the US DOE, Basic Energy Sciences under Contract No. DE-AC02-07CH11358.

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DFT/HSE06 Investigation on Low Index Surfaces of the $TiSe_2$ Material to Analysis New Potential Applications

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Abstract:

Transition metal dichalcogenides (MX_2) can be found in two different space groups, rhombohedral (*P-3m1*) or prismatic trigonal (*P6₃/mmc*) phases. The chemical bond between the transition metal and the chalcogenide in the interlamellar region is majorly covalent, while van der Waals interaction connects lamella at long range. Moreover, as charge density wave (CDW) as topological phenomena have been reported as strong features of the crystalline structure. In particular, the selenites-type dichalcogenides (MSe_2) present superconductivity property at low temperatures, a pristine lamellar structure allows the insertion of transition metals in metallic form, such as Cu, Fe, Ni, performing a doping process to increase the superconductive transition temperature (Tc). With high chemical stability, the $TiSe_2$ has been investigated in doping process because of the charge transfer from doping-metallic atom to Ti atom improving in high level the Tc. This behavior is commented as a charge density waves propagated on the Ti atoms layers because of the Ti 3d orbital half-filling at superconductor state. Atomistic quantum simulation has as approximation the static nucleus movement indicating that the influence of the temperature is null. At the superconductive state, this approximation is an advantage, the electronic state is evidenced through the electronic density on the crystalline structure. Although the $TiSe_2$ is a lamellar material, other surfaces expose different atomic arrangement associated to the advanced chemical properties rebuilding the applications for the same material, a new vision on quantum simulation in surface scale extending the discussion on the impact of the molecular structure of surfaces on properties and chemical activity. The complex computational routine applied was the CRYSTAL17 program, which the crystalline structure from periodic formulation for Hartree-Fock and Density Functional Theory (DFT) approaches simulating high level prevision on the structural and electronic properties. The 86-51(3d)G (gaussian) and m-pVDZ-PP (contracted gaussian) basis sets described the Ti and Se atoms to build the Linear Combination Atomic Orbitals (LCAO) approximation at vacuum and 0K conditions using a 10^{-8} criteria convergence for energy self-consistent field (SCF) and 10^{-7} overall criteria convergence among optimized geometries; an a 4 x 4 x 4 grid for k points according to Mohnkhorst-Pack method with the 10^{-7}, 10^{-7}, 10^{-7}, 10^{-9}, and 10^{-30} values truncating the Coulomb and Exchange integrals. Thus, this work provides a careful DFT/HSE06 investigation of the (001), (100), (101), (110), and (102) low index surfaces of the $TiSe_2$

superconductor to discuss several properties connected to the morphologic changes, such as, the surface thermodynamic stability, electronic structure, charge carriers density and mobility, and morphological features. Our proposition is to simulate crystalline structures to contribute as previous analysis on morphologic control of the $TiSe_2$ properties, focusing on novel or improved applications of the $TiSe_2$ material. For the investigated $TiSe_2$ surfaces, the surface energy increases from (001) to (110), following the order (001) < (102) < (101) < (100) < (110). The formation of the dangling bonds from surface cleavage can be understood as a spontaneous creation process of neutral vacancies (V^x) on the solid surface modulating the surface energy in specific mode. Our research on semiconductors oxide surfaces present this approach indicating a high potential of the quantum simulations on magnetism, photocatalysis, and water splitting applications. Here, we extend this approach on $TiSe_2$ superconductor material to discuss potential morphologies for other applications.

Understanding the Long Length Uniformity and Potential of Bi-2212 Wires by Critical Current Distribution Measurements

Shaon Barua[a]*, Daniel S. Davis[b], Jianyi Jiang[b], Ernesto Bosque[b], Eric E. Hellstrom[b], Ulf P. Trociewitz[b], and David C. Larbalestier[b]

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Abstract:

In composite superconductors, the local critical current can vary along the length due to variable vortex pinning interactions, as well as variations in filament connectivity due to filament shape variation and, especially in high-temperature superconductors (HTS), variations in grain-to-grain connectivity. Today's Bi-2212 wires have a high critical current density (J_c) that can vary by 30–40% for reasons that we ascribe to a still poorly understood convolution of powder quality, filament uniformity, and the conditions of overpressure heat treatment (OPHT). We here report an extensive study of the critical current distributions in ~1.5 m wires made by Bruker-Oxford Superconducting Technology (B-OST) derived from d^2V/dI^2 analyses of the *V-I* curves measured on ITER-like barrels. These transitions can be well fitted by Gaussian distributions and characterized by their relative standard deviations (σ/μ). We find that recent Engi-Mat powder wires have significantly higher J_c and significantly lower σ/μ than found in earlier B-OST wires made with Nexans powder. We also find that the highest J_c values provided by minimum time-in-the-melt (t_{melt}) and lower maximum temperature (T_{max}) during OPHT also correspond to significantly lower σ/μ values. We attribute this property degradation with higher T_{max} to filament connectivity associated with worsening texture due to filament merging during the melt step of the OPHT. Having seen systematic results from the variation of σ/μ as a function of heat treatment conditions, we are now applying the analysis to sections cut from either end of our test magnets containing each about 200 m of wire so as to understand any systematic variations in the ~1 km length wires now being delivered by B-OST.

High-Field Magnets: MIT Magnet Lab Experience

Yukikazu Iwasa

Massachusetts Institute of Technology, USA

Abstract:

The presentation will cover the following topics: 1) a brief history of magnetism till the 1930s when Francis Bitter began developing magnets that generate DC fields well above 2 T, a limit of permanent magnets; 2) basics of the Bitter magnet that led to the National Magnet Lab in the early 1960s at MIT; 3) hybrid magnets; and 4) HTS magnets.

Acknowledgement

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Low-temperature Pulsed Field Magnetization of HTS Bulk Assembly

Difan Zhou[a]*, Yuchen Wang[a], Jingyu He[a], Yibing Zhang[a], Chuanbing Cai[a], Teng Zhang[b], Xueqing Feng[b] and Guanzhong Gao[b]

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Abstract:

Recently, a bulk high temperature superconducting (HTS) motor has been developed by Shanghai University and Wolong [1]. This synchronous motor was equipped with 48 melt-textured YBCO bulk superconductors, 12 pieces for each magnetic pole. It has been found that the magnetization process under a cryogenic environment is the key challenge for the practical application of such a machine. This study focused on the pulsed field magnetization (PFM) of the HTS bulk assembly especially at temperatures lower than 77 K. The presence of neighboring HTS magnets has been found to greatly affect the magnetic flux penetration behaviors. We systematically investigated the PFM of a combination of two HTS magnets. The penetration of the magnetic field was revealed and the resulted trapped field was analyzed.

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Automatic Detection of Local Inhomogeneity in REBCO Coated Conductor by High-Speed Reel-to-Reel Scanning Hall Probe Magnetic Microscopy Coupled with Machine Learning Based Image Analysis

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Abstract:

In our previous study, we have reported that local non-uniformity existing in a tape plane of RECBO coated conductors can be measured nondestructively by using high-speed scanning Hall probe magnetic microscopy, where high-resolution trapped magnetic field image of the magnetized REBCO tape is obtained continuously in liquid-nitrogen by traveling the tape in reel-to-reel manner [1]. However, when it is applied to long wire over several 100s of meters, the analysis of several 1,000s of magnetic images is required. It is essential to establish an automatic analysis method of observed images. In this study, we created an image classification model and object detection model using machine-learning for magnetization current images obtained from magnetic microscopy, and made automatic detection of localized defective parts possible. This allows us to analyze the numbers of defects, positions and their size distributions in the long length tape. Through this method, we have succeeded in obtaining new knowledge such as defect sizes and their statistical information, and also by clarifying the existence of local heterogeneity, which was difficult to detect by the conventional local critical current (I_c) criterion because of the spatial fluctuation of I_c in a commercially available 200 m long REBCO coated conductor.

Acknowledgements: This work was supported by JSPS KAKENHI Grant Number JP19H05617.

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Design Progress of the CFETR Superconducting Magnet

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Abstract:

Tokamak is currently considered as one of the most promising fusion devices to achieve D-T fusion reactions to produce fusion energy. The D-T fusion power of the Tokamak is proportional to the product of the plasma pressure to magnetic pressure ratio and the magnetic field at the plasma center. Therefore, high magnetic field will play a critical role in the R&D of advanced tokamak machine.

The Chinese Fusion Engineering Test Reactor (CFETR), which has the potential to produce a fusion power above 2 GW, is being designed to bridge the gap between the ITER and Demo in China. The maximum magnetic field above 20 T is expected in the CFETR magnet. The state-of-the-art low temperature superconducting (LTS) magnet has a relatively low coil carrying current density under magnetic field above 15 T. Therefore, a high-performance superconducting magnet with high temperature superconductor (HTS) is required to provide superior superconducting property. The REBCO coated tapes, which has the higher critical current density than LTS counterparts in magnetic fields above 15 T and endure a high tensile stress, will be envisaged for the CFETR magnet.

At present, we propose design schemes based on LTS, LTS+HTS, and HTS only to optimize the coil configurations of the CFETR superconducting magnets. This article will introduce the design progress of the CFETR tokamak superconducting magnets.

Magnetization of the Field Pole of a High-temperature Superconducting Motor Constituted of Multiple Bulks

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Abstract:

Due to their ability to trap high magnetic fields, high-temperature superconducting (HTS) bulk materials make excellent candidates for improving electric motors by using them as field poles. Replacing the permanent magnets from a machine field pole with a magnetized HTS bulk would increase the peak magnetic field. In order to increase the total flux of the machine, the size of HTS bulk needs to be increased. Increasing the total magnetic flux will increase its power output, without changing the size or weight. However, the maximum size achievable is constrained by the HTS bulk manufacturing method. It is possible to increase the number of HTS bulks rather than their size. The total magnetic flux can be increased by combining many bulks. Arranging several smaller bulks together is also useful to scale and shape large field poles. The mean of magnetization, however, continues to be a significant issue. The bulks must be magnetized in order to trap strong magnetic fields before use. It can be difficult to quickly and effectively magnetize HTS bulks, especially if the magnetization is carried out in situ. Up until now, field-cooling (FC) magnetization has been the primary method used to experimentally magnetize arrays of bulks. This magnetization technique relies on the generation of strong quasi-static applied magnetic fields. Therefore, large superconducting magnets and a lengthy magnetizing period are needed for this magnetizing method, which limits FC for practical use. Another magnetization technique is known as pulsed-field magnetization (PFM), which works by applying a brief magnetic field pulse. The magnetic field pulse typically lasts several hundred milliseconds and has a peak intensity of several tesla. Copper magnetizing coils are appropriate for applying the pulsed magnetic field due to PFM's speed and don't require the same cryogenic system used for superconducting magnets. Therefore, magnetizing equipment can be more compact and less than 1/10 of the price of FC equipment. There hasn't been much research on the use of a PFM method to magnetize numerous HTS bulks, especially for non-alternate polarity HTS bulk arrays.

In this talk, we exhibit the magnetization of several GdBaCuO bulks using a PFM approach. The internal layout of our radial-gap HTS motor [1] is replicated in this experiment. We compared the performances of PFM of the bulk array using different types and geometry of magnetizing coils. We also tried different magnetization sequences. We compared magnetizing each individual bulk sequentially or all at the same time. It is highlighted how relevant the magnetization order is to the trapped magnetic field. Liquid nitrogen is used to cool the bulks and coils to 77 K during the experiment.

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Electronic and Superconducting Properties of Some FeSe-based Single Crystals and Films Grown Hydrothermally

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Abstract:

Our recent year's studies of the molecule-intercalated iron selenide (Li,Fe)OHFeSe superconductor systems are briefly reviewed here. The single-crystal and film samples were successfully synthesized by our recently developed soft-chemical hydrothermal methods, which are also briefly described. A strong enhancement of the superconducting critical current density has been achieved by doping Mn into (Li,Fe)OHFeSe films. Most recently, the quasi two-dimensional (2D) features of the superconductivity, including the high anisotropy γ = 151 and the associated quasi-2D vortices, are revealed for (Li,Fe)OHFeSe system based on systematic experiments and model fittings. These results have important implications for both the basic and applied research of the high-T_c superconductivity.

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Screening Current Induced Stress in High Field Magnets Using REBCO Coated Conductors

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Abstract:

Rare-earth-based barium copper oxide (REBCO) coated conductors are promising candidates for the development of high field magnets, due to its high in-field performance, engineering current density, tensile strength and commercial availability. However, technological challenges pertaining to the large screening currents still remain. The major issues caused by the screening currents in REBCO conductors in high field applications involve two aspects: the screening current induced magnetic field (SCF), and the screening current induced stress (SCS). With latest advances in the construction and testing of high field magnets, the SCS was identified in recent years and has raised growing concerns. The excessive and highly concentrated Lorentz force, rooted in the high magnetic field and the screening currents, poses threats to the mechanical strength of REBCO coated conductors. In this presentation, we will review recent research efforts in understanding and tackling the SCS related technological issues. We will present recent studies including experimental characterizations, numerical modelling and possible countermeasures. In particular, the discrete-coupled model was developed, coupling the tilting angles of the superconducting tapes and the strain dependency of the critical current. We will also give an example for the design of a 20-T HTS insert coil for a 35-T full superconducting magnet. It is still an open question to precisely predict the SCS in large-scale HTS magnets. How to minimize the influence of SCF and SCS is one of the key technical challenges for the design of future high field magnets.

Challenges of Large Scale Production of 2G Wires for High Field Application at SuperOx Japan

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Abstract:

In 2022 SuperOx Japan reached stable production capacity of the second generation high-Tc superconducting (2G HTS) wires in equivalent of 120,000 kAm/year as a result of the continuous efforts to transform the small R&D company to the full-scale manufacturer of the commercial superconducting wires. During 2022 SuperOx Japan has undergone the change of the company structure, and currently faces the planned increase of the production volume in Japan to reach 500,000 kAm/year by 2023.

Our current manufacturing process relies on the Pulsed Laser Deposition (PLD) of superconducting materials onto the textured buffer substrate fabricated by an Ion Beam Assisted Deposition (IBAD) process using the polished Hastelloy metal tape. In the recent years we achieved a significant progress in development of 2G-HTS wires for high magnetic field applications. The main efforts were focused on the wires suitable for the compact fusion application, which has the most challenging requirements of engineering current density Je(20K, 20T) in the range of 600-1000 A/mm2. Currently the standard 2G-HTS wires produced by SuperOx Japan demonstrate Ic of 170-240A/4mm at 20K and 20T (B//c) and 400-500 A/4mm at 4.2K, 20T, making them suitable for the wide range of practical applications including NMR magnets, motors and etc. Despite rather complicated multistage manufacturing process, we successfully addressed the challenges of production scaling up and reached the consistent production yield approaching 90%.

Our current R&D efforts are aimed at further improving the magnetic field dependence of critical current in two operating conditions ranges: i) 4.2-20K and 20-25T and ii) 65-77K and 1-3 T. Today our state-of-the-art wires demonstrate a record performance of critical current in a high magnetic field ea. Ic =350A/ 4mm at 20K, 20T and 650A at 4.2K, 20T corresponding to the engineering current densities of Je(20K,20T) = 1,760 A/mm2 and Je(4.2K,20T) = 3,300 A/mm2.

E-Poster Presentation

Conceptual Design of an HTS Linear Power Generator for Wave Energy Conversion

Petrus Kambo,[a*] Yuhi Yamanouchi[a], Antomne A. Caunes[a], Kota Yamaguchi[b], Mitsuru Izumia,[c] and Tetsuya Ida[a]

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Abstract:

In this presentation, we show a conceptual structure of a linear power generator with high-temperature superconductor (HTS) bulk field poles for wave energy conversion. A suitable wave energy power generating device should be able to generate practical power from a low speed of ocean waves, and it needs to survive large loads exerted on its power generating mechanism from the large ocean wave forces. The slow vertical motion and large forces of ocean waves are impediments to the practical application of wave energy converter (WEC) because the density of seawater is about 840 times higher than that of air. A buoy is used primarily to capture the kinetic energy from the vertical motion of ocean waves, the translator for power generation connected to the buoy is slowed down by the slow motion of ocean waves. This leads to a reduction in generated power because a driving speed of the translator relative to the armature coils or field pole magnets generate electromotive force, which leads to a production of electric power. We propose a new generator structure aimed at solving two important problems related to ocean power generating devices: 1) output power is reduced due to the slow period of ocean waves. To improve the output power, the size of the power generating device increases, which may make it difficult to install generators and inhibit power generation operation. 2) the structural damage caused by a large loads of ocean waves. It is wasteful to install a damper in parallel with the linear generator to receive the large force generated by the ocean waves, as it would increase the size of the power generation system. For this reason, there is a need to accommodate the slow speed of ocean waves in our proposed linear power generating structure, and still be able to achieve improved output power without the need to increase its size. HTS bulks can trap a high magnetic flux density more than permanent magnets increasing the production of the electromagnetic force, which can be used as a damper. For this reason, we proposed a linear power generator structure that utilizes (Re)$Ba_2Cu_3O_{7-\delta}$ HTS bulks for the field pole.

Another important innovation is to increase the rate of change of the magnetic field through the armature coils by improving the relative speed between the armature coils and the field pole. For this reason, we propose a compact linear power generator with a new concept called dual translator power generation structure and HTS bulk field poles. Unlike more common single translator power generators, where the armature coil is stationary, this new concept moves the armature coils and the

field pole magnets in an opposite oscillatory motion at the same time. The performance of the proposed linear power generator structure has been analyzed using a finite-element method. Its results have been compared with the simulation results of a linear power generator structure with a single translator system, which indicate that electromotive forces, electromagnetic forces, and output power are superior to that of a single translator linear power generator structure. The combination of the dual translator power generation system and the HTS bulk field poles has the potential to help us achieve miniaturization with high output power in a WEC despite low ocean wave speed, which is important to achieve practical application of ocean power generation systems.

Superconducting EIS Coil for 1.5T Whole-body MRI Magnet

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Abstract:

An actively shielded whole-body MRI magnet has minimal intrinsic screening efficiency in its imaging volume against any low-frequency external magnetic field interferences. The external magnetic disturbances significantly affect the homogeneity in the field of view of the MRI magnet. A set of superconducting coils known as B_0 compensation coil or external interference screening(EIS) coil has been designed to minimize the interference of any external magnetic disturbances for a 1.5 T whole-body superconducting MRI magnet through optimization of screening factor, mutual coupling factor, and the overall homogeneity. The screening factor of the best combination is 0.0064, and its self-inductance is 0.064 H. The overall peak-to-peak homogeneity (± 4.8 ppm) at the field of view of the magnet is found to be improved by the induction of current up to 2.5 A in the B_0 compensation coil due to the external magnetic disturbances. The homogeneity starts deteriorating beyond 5 A of current induced in the B_0 compensation coil. The accumulated induced current needs to be quenched periodically by quenching its superconducting switch. The energy released in resetting the accumulated induced current in the B_0-compensation coil is estimated to be less than 1J. The mutual inductance and the coupling factor for the best screening coil combination are respectively 0.58 H and 0.37. During a quench in the main magnet, the EIS coil's PCS is found to be quenched in 0.23s. This paper briefly discussed the optimization methodology to have an efficient shielding efficiency and the construction of the superconducting switches of the EIS coils of a 1.5T superconducting MRI magnet.

E-Poster Presentation

Some Key Issues Related to Development of the Iron-based Superconductor Inserted Coil

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Abstract:

The iron-based superconductor is considered to have a great potential in the field of a high magnetic field due to the advantages of high upper critical field, tiny anisotropy, simple preparation technology, and low material cost. At present, China is at the world-leading level in the physical and application research of iron-based superconducting materials, and the performance of the iron-based superconducting wire has been continuously improved to meet the practical application requirements, and the development of high field inserted coil based on high performance iron-based superconducting wire is now gradually carried out. The design and fabrication of the iron-based superconductor inserted coil involve some key technology issues, such as: design options, stress and strain characteristics, winding and insulation processes, joint manufacturing method, quench behaviors investigation, experiment and measurements, and so on. This paper introduces some research progress and critical issues from the high field inserted coil development program in detail. Meanwhile, some testing results of the inserted coil, which were realized by serious research and development(R&D) activities, in the high background field are also addressed briefly in the paper

Keywords: *Iron-based superconductor; Development; Inserted coil; key issues*

Analysis on Mechanical Properties of 10 MJ HTS SMES Magnet Wound by Q-ISs and STCs

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Abstract:

The quasi－isotropic(QIS) high temperature superconductor witch is the quasi-isotropic strand, consisting of tapes stacked with symmetric structure and sheathed outside by superiorly thermal and electrical conventional conductor with round or square configurations.This paper designs and optimizes a HTS Magnet for a 10 MJ class Superconducting Magnetic Energy Storage (SMES) magnet base on configuration of QIS and directly stacked tape conductor (STC) by particle swarm optimization. The high temperature superconducting materials have much lower structural strength than low temperature superconducting materials. In order to ensure the stable operation of SMES systems, it is necessary to evaluate the mechanical properties of the stresses caused by Lorentz forces. Therefore, This paper analyses the magnetic strain caused by Lorentz force by using finite element method(FEM).

Index Terms*—FEM,Lorentz force,QIS high temperature superconductor, SMES magnet, Screen current.*

Analysis on Distribution of Critical Current and Thermal Stability of 10 MJ HTS SMES Magnet Wound by Q-ISs and STCs

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Abstract;

This paper presents an high-temperature super-conducting (HTS) energy storage (SMES) magnet with 10 MJ in 20K used to power grid for compensating the power fluctuations and wound by quasi-isotropic strand (Q-IS) and directly stacked tape conductor (STC). Firstly,we calculated the critical current of two kinds of magnets and obtained the critical current density distribution, then analyzed on the thermal stability performance, such as minimum quench energy (MQE) and the quenching propagation velocity (QPV) in the adiabatic approximation. The results show that the critical current density distribution of the SMES made from Q-IS is more uniform,the critical current of the SMES wound by STC is higher. the MQE of the SMES made from Q-IS is higher and the QPV is lower.

Index Terms—high-temperature superconducting (HTS) energy storage magnet(SMES), quasi-isotropic strand (Q-IS), stacked tape conductor (STC)minimum quench energy (MQE), quenching propagation velocity(QPV).

Influence of the Wire Diameter, Filament Size and Interval Ag Space on the Processing Window of Bi2212 Wires

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Abstract:

Four Bi2212 wires with four different mass loading percent were machined respectively to three different diameters of 1.18mm, 1.00mm and 0.81 mm. The processing window of these Bi2212 wires was then compared and discovered to be influenced by the wire diameter, the filament size and the interval Ag space. The processing window difference for these Bi2212 wires was mainly related to the difference of the heat transfer and the oxygen transfer caused by their structure difference. Wires holding the largest filament diameter with diameter of 1.18 mm, 1.00 mm and 0.81 mm respectively lost their low processing window, which was mainly caused by their lowest heat transfer. But wires with different mass loading percent with diameter of 0.81mm all lost their high temperature window, which was mainly caused by both the much higher percentage of 1:2 AEC phase and the severe filament coupling existed in the wires. The slower oxygen transfer rate and the larger heat transfer rate resulted in the lower oxygen concentration and the higher temperature in wires with diameter of 0.81 mm, which led to their larger percentage of 1:2 AEC. What's more, the severe filament coupling was found to be mainly caused by the small interval Ag space between each filament. To guarantee a higher processing window, the interval Ag space was suggested to be above ~ 6 µm. All in all, the relative smaller filament diameter, the relative larger wire diameter and the relative larger interval Ag space in Bi2212 wires contribute to a larger processing window.

Superconducting Properties and Vortex Avalanches of High Entropy and Medium Entropy Alloys Synthesized by Melting and Powder Metallurgical Processes

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Abstract:

High-entropy alloys (HEA) are the compounds with multi-component mixing of elements with high symmetry crystalline structures such as cubic (FCC and BCC) or hexagonal close packed (HCP) phase. HEAs possess outstanding structural and physical properties including high thermal stability with excellent hardness and high corrosion and wear resistances. HEA superconductors are known to be conventional type-II s−wave superconductors. We investigated the superconducting properties of high entropy and medium entropy alloys with various synthesis methods such as arc-melting, hot press, and spark plasma sintering methods. The superconducting properties are significantly different depending on the synthesis methods. Here we overview the superconducting properties of high entropy and medium entropy alloys such as strong and weak coupling, vortex avalanches, strong flux pinning, and unconventional vortex dynamics with synthesis methods.

Hybrid Energy Transfer with Superconductivity - What is Going on

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All-Russian Scientific Research Institute of the Cable Industry, Russia

Abstract:

The transfer of high-power flows over long distances will be the one of the principal tasks for the energetics in this century. Increasing energy flows could be achieved by the use of hybrid energy lines, where energy is transferred by chemical and electrical carriers simultaneously in single channel. Common choice is the liquid natural gas. Liquid hydrogen is also quite attractive choice. Both chemical agents in liquid state have rather low temperature and could be used as a cryogen for superconductivity. The usage of "gratis" cold to cool a superconducting cable made of proper superconductor permits to deliver extra electrical power with the same line. In this presentation, the research activities of LH2 energy pipeline and LNG energy pipelines are reviewed, and their development trends are discussed. Results of recent developments of hybrid transmission lines in Russia and China are presented.

ReBCO High-Temperature Superconductors for Future High-field Accelerator Magnets

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Abstract:

Higher particle collision energies in circular accelerators can only be realized by using superconducting magnets. The Large Hadron Collider (LHC) at CERN is using NbTi magnets, some Nb3Sn magnets are already built for the High-Luminosity upgrade of LHC, and in the Future Circular Collider project Nb3Sn 16 T magnets are taken into consideration. To exceed 16 T, High-Temperature Superconductors (HTS) as ReBCO or BSCCO need to be used [1].

HTS materials are reaching maturity from a material point of view, in superconductor critical current density and fabrication of the suitable lengths of the conductor. Currently, the record field for an HTS magnet application is 45.5 T [2].The majority of demonstrators are using solenoid or pancake architecture [3], however, for guiding the particle beam in a circular accelerator, dipoles providing a field transverse to the particle beam are required.

In this work, we will address the most common and recent challenges for HTS – ReBCO accelerator type magnets. We will show impregnation issues that result from a combination of material properties, the high geometry aspect ratio of the conductor itself and the availability of the impregnation materials. We will discuss the technology of non-insulating coils and their ramping properties and the applicability of these types of coils in accelerators. Finally, we will present experimental results of the first small-scale accelerator magnet demonstrator in the shape of a cloverleaf. This coil design is unique in that it takes into account the mechanical properties of the ReBCO flat tape structure, which do not allow for hard-way bending in the coil geometry. Perspectives based on literature review and in-house experience on future high field accelerator magnets will be presented.

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Vortex Commensurability and Ordered Bose Glass Phenomena in $YBa_2Cu_3O_{7-\delta}$ Thin Films with Ultradense Pinning Landscapes Fabricated by Focused Helium Ion Beam Irradiation

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Abstract:

Patterning copper-oxide superconductors with nanoscale resolution is challenging due to their complex atomic structure and environmental susceptibility, imposing severe constraints on conventional lithographic techniques. An alternative route is to leave the crystallographic framework of the material intact and tailor the superconducting properties by introducing controlled point defects [1].

To this end, the focused beam of a helium ion microscope (HIM) is used to fabricate narrowly spaced nanopillars in thin films of the prototypical copper-oxide superconductor $YBa_2Cu_3O_{7-\delta}$ (YBCO). In these nanopillars, the critical temperature T_c is reduced or entirely suppressed due to pair-breaking by numerous point defects. Simulations of the He^+ ion-target interactions calibrated by experimental data [2] anticipate that well-defined columns of non-superconducting material can be created in the superconducting matrix by focused 30 keV He^+ ion irradiation.

Indeed, measurements of vortex commensurability effects show pronounced maxima of the critical current and corresponding resistance minima at an unprecedented high magnetic field of 6 T in a hexagonal nanopillar lattice with 20 nm spacings. In contrast to previous observations, matching phenomena persist at a temperature of 2 K, far below T_c. These results establish the HIM as a versatile platform for also creating complex pinning landscapes [3] in copper-oxide superconductors.

The disordered intrinsic strong pinning in YBCO demands further investigation of its interaction with the periodic engineered pinning sites. When the pinning at the engineered hexagonal defect nanopillars overcomes the uncorrelated pinning, we observe a novel behavior in voltage-current isotherms. We attribute it to an ordered Bose glass phase that predominates at the matching field where every columnar defect can be filled by one flux quantum [4]. Furthermore, critical scaling relations of the voltage-current isotherms in constant magnetic fields yield parameters that distinguish between vortex glass and ordered Bose glass behavior. The latter can emerge from a vortex Mott insulator when thermal energy and disorder weaken the vortex correlations.

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Intelligent and Sustainable Processing of Innovative Rare-Earth Magnets

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Abstract:

The future of renewable energy and smart mobility depends upon permanent magnets (PMs), and those magnets depend upon Rare Earth Elements (REEs). From wind turbines and hydroelectric generators to electromotors in next-generation hybrid and electric vehicles, magnets are critical to Europe's future. The essential Critical Raw Materials (CRM) used in NdFeB PMs are REEs and non-REEs niobium and gallium. Although CRMs from China have been the primary source for Europe, supplies are uncertain, and the Chinese production chain is generally unsustainable. At the same time, the demand for REEs to make new PMs is projected to double in 15 years and the global market will increase to 34 billion $ by 2025.
This work focuses on sustainable recycling and reproducing PM from sources of end-of-life (EOL) PMs focusing on the most common and readily available source of economically recyclable electric motors: home appliances. We are developing new dismantling and recovery procedures for PMs on highly available scrap and reproduction lines. We use an already well-established method of hydrogen in HPMS1 (Hydrogen Processing of Magnetic Scrap), followed by milling, degassing and coating of sensitive powders.

These powders are the basic material for bonded magnets and densely sintered bulk magnets using radiation spark plasma sintering. Characterization along the whole production chain is performed using advanced analytical electron microscopy and mechanical and magnetic properties measurements.

The first pilot experiments in producing bonded magnets out of recycled magnets confirm the no-waste circle economy processing and future independence from the unstable sources of REE.

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Influence of Annealing Conditions on the Structure and Critical Parameters of MgB_2 Superconducting Wires with Nano ^{11}B made by CTFF Method and Future Approach for the PIT Technique

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Abstract:

The MgB_2 wires made by the powder-in-tube (PIT) method have many advantages, such as: high critical temperature (T_c), low anisotropy, high upper critical field, low weight, cheap (components, technology, method of colling). This indicates their high application potential, e.g. in superconducting coils, or power lines.

The MgB_2 superconductors wires are more favorable for fusion reactor applications compared with Nb-based superconductors, since the former have higher T_c (39 K). In addition, the MgB_2 wires have low activation energy and shorter decay time in comparison to Nb-based ones. It is demonstrated that ^{11}B isotope is stable under neutron irradiation and therefore MgB_2 containing ^{11}B could be beneficial for fusion reactor applications [1,2].

The monofilament isotopic $Mg^{11}B_2$ wires with Nb barrier were made by Hyper Tech Research Inc. using continuous tube forming and filling (CTFF) method. We investigated samples that were additionally heated under high isostatic pressure, i.e. underwent HIP process. We concluded that the HIP process is very effective for increase of high-field pinning centers density in MgB_2 wires with nano ^{11}B [1,2,3].

Our studies suggest that the iron based superconductors (IBS) may be the future candidate to use in PIT method. Especially two families of IBS with possible use in the powder in tube technology (PIT) should be pointed out: AFe_2As_2 (A= Ba, Ca, Sr, Eu) [4] and AFeAs2 (A= La, Eu) [5]. Beside manifesting higher critical temperatures and critical fields [4] than MgB_2, these IBS have rather small magnetic anisotropy of T_c among other high temperatures superconductors.

Moreover compounds with Eu (where $EuFe_2As_2$, $EuFeAs_2$ are the parent compounds) can simultaneously exhibit superconductivity – associated with the Fe-sublattice – and localized magnetism on the Eu-sublattice[6]. The existing interplay between the magnetism and superconductivity in these compounds possibly give us the potential to control these materials with a magnetic field, in example to use them as non-mechanic switches.

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Modification of Superconducting Properties in Nb Using Laser Technologies

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Abstract:

The use of short and ultra-short pulse lasers opens new possibilities in the control of surface properties in different materials. The interaction of these lasers with different materials generates different types of nanostructures, whose characteristics depend mainly on the laser parameters but also on the physical sample properties. Nb is one of the materials where the surface properties can be modified by an adequate laser treatment. Recently [1, 2] we have demonstrated that these nanostructures generated with ps and fs lasers can modify the superconducting properties in bulk and foil samples. In particular, we observe the effect on the surface superconducting layer that persists at magnetic fields between H_{c2}, the upper critical magnetic field, and H_{c3}, the surface critical strength field, when the magnetic field is applied parallel to the superconductor surface. The associated surface critical current depends on the surface characteristics, as for instance, roughness and morphology. In consequence, laser nanostructuring can be considered an alternative to different mechanical and chemical polishing procedures or ion irradiation surface modifications that are frequently used in several applications, as for instance in superconducting radiofrequency cavities. Another advantage of laser induced nanostructures is that the process can be scaled to process large areas.

The formed nanostructures on the surface of bulk materials reach depths of approximately 200 nm. Thus, a new issue appears when these laser treatments are performed on thin films because the generated structures can affect the superconducting connectivity across the film. Nevertheless, by generating new controlled junctions between superconducting and non-superconducting regions, new phenomenologies and physical properties may appear. Special care has been taken in order to identify the laser conditions that are able to generate different surface nanostructures maintaining the integrity of the film and to control the level of damage that the laser treatment can cause in the superconducting thin film. The obtained results demonstrate that laser treatments can also be useful in controlling the superconducting properties of these materials.

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Laser based 3D Technologies to Texture Large Size Bi-2212 Superconducting Materials with different Geometries

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Abstract:

The laser furnace technology has been proposed as a new alternative to process ceramic materials using a 3D approach. The combination of a roller furnace and a CO_2 laser enables processing of dense ceramics minimizing the thermal stresses that can be generated in these materials during laser treatments and facilitates obtaining dense ceramic structures. In this work, we present the combination of the laser furnace process and the use of femtosecond (fs) lasers to machine the obtained 3D ceramic in order to fabricate superconducting samples with sizes up to 8 cm x 8 cm with a multilayer structure and generate electrical circuits with several geometries. The developed process combines these technologies and require different optimization depending on the objectives in each step. In the first one, a green fs laser was used to machine the surface and modify the wetting properties of an Al_2O_3 plate employed as main substrate to facilitate the uniform integration of the first printed molten layer. On top of the substrate, different Al_2O_3-ZrO_2 layers were deposited using the 3D laser furnace technology. The maximum layer thickness that can be treated in each laser step was determined, along with the developed microstructure found at the interface between the different layers. The temperature of the furnace was set in order to minimize the thermal stresses induced during the laser treatment, avoiding crack generation. Finally, the superconductor layer has been integrated in the structure. By adjusting the laser parameters, it is possible to improve the texture of the superconducting phase and the thickness of the textured region. Critical current values above 100 A/cm-width were achieved after adequate thermal annealing. Finally, the fs laser was used again to machine the superconducting layer geometries that allow designing several electrical circuits on the sample. In this last step, laser parameters have been optimized to avoid crack generation and minimize the volume of superconducting material that it is affected during the machining process.

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Resonant Photoelectron Spectroscopy Unravels Out-of-plane, s-type Electronic Contributions in Bi-cuprates

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Abstract:

In high-temperature superconductors with a layered crystal structure out-of-plane contributions are often neglected, while the copper-oxygen planes are commonly considered to dominate the electronic properties around the Fermi energy. In this contribution we report on a resonant photoemission study of (Pb,Bi)2201 and (Pb,Bi)2212 single crystals to unravel the resonant decay mechanisms at the Cu 2p absorption edge. Unlike direct photoemission this method is capable of detecting s-type contributions. We observed a pronounced polarization dependence and ascribed them to two different Auger processes for in-plane and out-of-plane orientations. We deduce that the lowest energy valence state being involved in the two Auger processes, consists of three-dimensional contributions by admixed out-of-plane Sr, Bi, and O 2p states. It also suggests that the doping-induced charge density is dynamic, fluctuating within the Cu-O plane, and spills out perpendicular to it /1/.

Anisotropic Flux Pinning Mechanism in Fe(Se,Te) and YBCO Superconducting Films

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Abstract:

A deep knowledge of the vortex pinning mechanisms in iron-based (IBS) as well as in high-temperature (HTS) superconductors is still highly desirable to successfully implementing them in real-world applications. An insight into pinning mechanisms working in IBS in comparison with HTS is provided by angular measurements of the flux pinning energy U(H,θ) as a function of the applied magnetic field orientation. Magneto-resistivity measurements were taken at various angles between the field and sample surface of both FeSe0.5Te0.5 and YBCO thin films. We observed that the flux pinning energy is much larger for a magnetic field applied parallel to the ab-plane orientation as compared to all the other orientations in the case of FeSe0.5Te0.5 [1]. On the contrary, in YBCO a double peak in the U(θ) dependence is found. Moreover, we analyzed the effect of the angular dependence on the H-T phase diagram, and surprisingly we unveiled a common anisotropic behavior depending on the chosen threshold criteria from 90% to 50% of the normal state resistance [2]. Such an approach allowed distinguishing between materials and pinning anisotropy. The combined effects of the material's layered structure and the presence of correlated nanoscale defects [3] parallel to the layer's orientation can explain all these findings.

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Overcoming the Challenges Associated with Joining RE-Ba-Cu-O Bulk Superconductors

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Abstract:

High-strength permanent magnets are essential for a wide range of technologies, including motors, generators and magnetic separators. Replacing permanent magnets with bulk superconductors will enable a step change in the performance of these technologies by providing an order-of-magnitude increase in magnetic field. However, there remain many key challenges to the practical implementation of bulk superconductors. The most fundamental is geometry.

Our work on joining aims to address the current limits to the size and geometry of (RE)BCO bulk superconductors. Smaller bulk superconductors are quicker to fabricate and are generally of significantly better quality than larger samples. As a result, bulk (RE)BCO superconductors are rarely fabricated with diameters larger than 60 mm. Provided the microstructure is of suitable quality, then the larger the single grain, the greater the maximum trapped field a (RE)BCO bulk can support. The obvious solution is hence to join small bulks into a larger aggregate structure. We report advances in our previous research of joints between YBCO bulk superconductors by demonstrating the joining of the industrially favoured GdBCO-Ag bulk superconductors and compare the challenges associated with the joining of these two materials. The ability to join small bulk superconductors to form fully superconducting hybrid structures is revolutionary.

In order for joined grains to be viable for use in practical applications they must fulfil a number of criteria, the most important being that the interfaces should be capable of supporting a value of critical current (J_c) comparable to that of the single grain material. The joints must therefore behave in a similar way to a low-angle grain boundary. To achieve this, the joint should be free of defects and the interface should show a continuity of the grain orientation. These factors aid the mechanical properties of the joint which in turn will also increase the maximum achievable trapped field.

Here we discuss and compare the challenges associated with joining YBCO and GdBCO-Ag bulk superconductors. We report the superconducting properties of a range of joints fabricated using a YBCO-Ag intermediate joining material. The microstructure around the joints is also compared. The joints are mechanically robust and provide promising superconducting properties.

The Connection between Porosity and Superconducting Properties in YBCO Single Grains

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Abstract:

Single grain RE-Ba-Cu-O [(RE)BCO where RE = Y, Gd, Eu, Sm, Nd] bulk superconductors can be considered as strong magnets. As the trapped field increases with increasing sample diameter, these technologically important materials can trap a magnetic field up to ten times higher than that achievable with conventional ferromagnets. Therefore, bulk (RE)BCO can potentially be used as magnetic bearings in flywheel energy storage devices, electric aircraft motors, maglev trains, and low-cost MRI systems.

A fundamental problem of these ceramic-like materials is their poor mechanical properties, which causes them to fracture or break under exposure to high magnetic fields or high mechanical stress. Pores created by the generation of oxygen gas during peritectic solidification within the bulk microstructure are a primary cause of the poor mechanical properties in single grain bulk (RE)BCO superconductors. The porosity generally scales with the diameter of the bulk material, with an increasing number of pores reducing proportionately the effective superconducting volume. As a result, the circulating supercurrent, and subsequently the trapped field, can be significantly lower than that of an "ideal" sample due to the presence of pores.

Statistical analysis of the porosity of YBCO samples of diameter between 13 mm and 42 mm will be presented, and the influence of porosity on the critical current density and, subsequently, the trapped field will be discussed. A better understanding of porosity could significantly improve the processing of superconducting (RE)BaCuO bulk single grains and lead to even higher trapped fields in bulk samples with larger diameters.

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