WB1-1-INV

Stable operation characteristics and perspectives of the large-current HTS STARS conductor

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Large-current capacity High-Temperature Superconducting (HTS) conductors have been developed for the helical fusion reactor and the next-generation helical experimental device. Three kinds of HTS conductors, STARS, FAIR, and WISE, have been proposed with different internal structures. For these conductors, the common target is to achieve a high current density of 80 A/mm^2 at a magnetic field of >10 T and a temperature of 20 K. The STARS (Stacked Tapes Assembled in Rigid Structure) conductor was originally developed to be applied to the helical fusion reactor FFHR with a 100-kA current capacity. A prototype conductor sample with a total 3-m length achieved 100 kA, having a 300-mm portion under a 5-T magnetic field with 20-K temperature control by a heater. The STARS conductor uses simply-stacked REBCO HTS tapes embedded in a copper (Cu) stabilizer and stainless-steel (SS) reinforcement jacket. The conductor is mechanically robust without having any deformation in REBCO tapes due to non-twisting and non-transposing. Recently, a 20-kA-class STARS conductor has been developed to apply to the next-generation helical experimental device. A 3-m-long sample was fabricated with laser beam welding in the SS jacket. The sample was tested in the large superconductor testing facility by applying a magnetic field using a split coil over a 300-mm section (like the previous testing). Still, a uniform helium gas cooling was done for the straight sample of 2-m length. A 20-kA current was stably transported at 8 T, 20 K. Then, another STARS conductor sample was fabricated with internal electrical insulation between the Cu stabilizer and SS jacket. The critical current was observed in liquid nitrogen to show the same value as the former sample with no internal insulation. A 6-m long sample of the internally-insulated type STARS conductor was then fabricated with a 600-mm diameter and a coiled structure of 3 turns. It was tested in 8 T, 20 K using a facility equipped with a 13-T, 700-mm bore solenoid coil. This time, a magnetic field was applied uniformly to the whole conductor of 6-m length, and temperature control was also done for the whole sample length with indirect cooling by supplying helium gas in a separate tube mechanically attached to the conductor. A stable operation up to 18 kA was confirmed, together with 100 times of repetitive excitations with a 1 kA/s ramp-up and down rate. For the success of this experiment, the low-resistive mechanical lap joints between the current feeders and the conductor terminals played an important role by ensuring no temperature increase. The measured magnetic field suggests a slight movement of the whole sample due to the electromagnetic force. A residual magnetic field is also observed after the transport current becomes zero, which might be caused by circulating current among the simply-stacked REBCO tapes due to the imbalance of self-inductance among them. Despite the non-uniform current distribution, the STARS conductor with a simple stacking technique is considered promising for fusion magnets.

Keywords: HTS, fusion, STARS, helical

WB1-2-INV

Cable pattern optimizations of low and high temperature superconducting Cable-In-Conduit-Conductors for fusion

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Cable patterns, compaction, electromagnetic load, and reduction of coupling loss are investigated to improve the performance of NbTi, Nb_3Sn, MgB_2 and ReBCO based Cable-In-Conduit Conductors (CICC) for fusion magnets. For round Nb_3Sn and MgB_2 wires, the R&D for full-and sub-size CICC cables was carried out at in a collaboration between ASIPP and University of Twente. Different conductor designs were manufactured at ASIPP based on models developed by Twente. The so-called short twitch pitch "close-to-1-ratio" cable design was eventually selected and experiments on full- and sub-size CICC cables were carried out. For the selected cable pattern in sub-size CICCs; no decrease in critical current was observed from cabling, compaction, and electromagnetic load cycles.

For background magnetic fields in the 20 T range, Conductor on Round Core (CORC®) cables and wires, composed of spiraled high-temperature superconducting (HTS) REBCO tapes, wound in multiple layers, is one of the options in fusion magnet technology. They combine isotropic flexibility and high resilience to electromagnetic and thermal loads. Finite element (FE) and analytical models are developed to predict the performance of CORC® under axial and transverse load. As a basis for the models, extensive REBCO tape characterization has been performed to study the performance under axial, transverse contact and torsional loads. A parametric analysis is carried out by varying winding angle, Poisson's ratio of the CORC® wire core, core diameter, and tape width. The FE model can be used to optimize the cable design for specific application conditions.

The results offer guidelines for the optimization of superconducting materials and cables for application in fusion.

WB1-3-INV

The Importance of Wire Characterization to the Development of Fusion Magnets

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Commonwealth Fusion Systems (CFS) is pursuing a high-field approach to fusion energy, which enables the development of smaller, lower cost tokamaks on a faster timeline. CFS has recently completed the manufacturing and demonstration of a Toroidal Field Model Coil, and is scheduled to demonstrate a net-energy fusion device, SPARC, by 2025 and commercialize fusion with ARC in the 2030s. The key enabling technology for the design of such high-field magnets is 2G REBCO HTS wire, tens of thousands of kilometers of which are required.

Magnets in SPARC and ARC will operate at high field (~ 20 T) and low temperature (~ 20 K) and will be subject to significant mechanical force and neutron flux. HTS wound into magnets will be positioned in varying orientations relative to varying background fields, and will experience additional handling during winding and soldering processes. Therefore detailed characterization of the critical current of HTS wires as a function of field, temperature, and angle are essential for the design and confirmation of conformance of HTS used in high-field fusion magnets. This presentation will further discuss relevant material properties and requirements as well as design-relevant data and testing methods.

WB1-4-INV

The role of temperature in irradiation studies of REBCO tapes

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Fusion energy could become a significant contributor to green energy in the 21st century. Several fusion energy concepts have proposed the use of high field (>20 tesla) superconducting magnets to create high performance plasmas in compact, lower cost devices. Achieving such strong magnetic fields requires the use of Rare Earth Barium Copper Oxide (REBCO) high temperature superconductor; however, the performance evolution of REBCO under fusion-relevant radiation damage and high-fidelity environmental conditions (e.g. temperature, magnetic field, transport current, axial strain, etc.) of an operating superconducting fusion magnet has not been well characterized to date. To directly address this shortcoming, we present the design of a cryogenic proton irradiation facility capable of providing in-situ, in-operando characterization of the critical current of REBCO tapes and initial data from the first experimental campaigns. REBCO samples have been irradiated with 1.2 MeV protons at temperatures ranging from 20 K to 300 K with critical current (Ic) and temperatures (Tc) measured as a function of radiation dose. Importantly, no thermal annealing took place between the cryogenic irradiation and Ic and Tc measurements, thus emulating the microstructural damage sustained at a given temperature and its effects on Ic and Tc as in an operating superconducting magnet. Thermal annealing to recover superconducting performance has been investigated, and we present results showing partial reversal of the radiation damage as a function of annealing temperature and time and confirming the importance of replicating the thermal history of an operating magnet in radiation damage studies.

WB1-5-INV

The role of small and large defects in enhancing and degrading the critical currents of coated conductors for fusion magnets.

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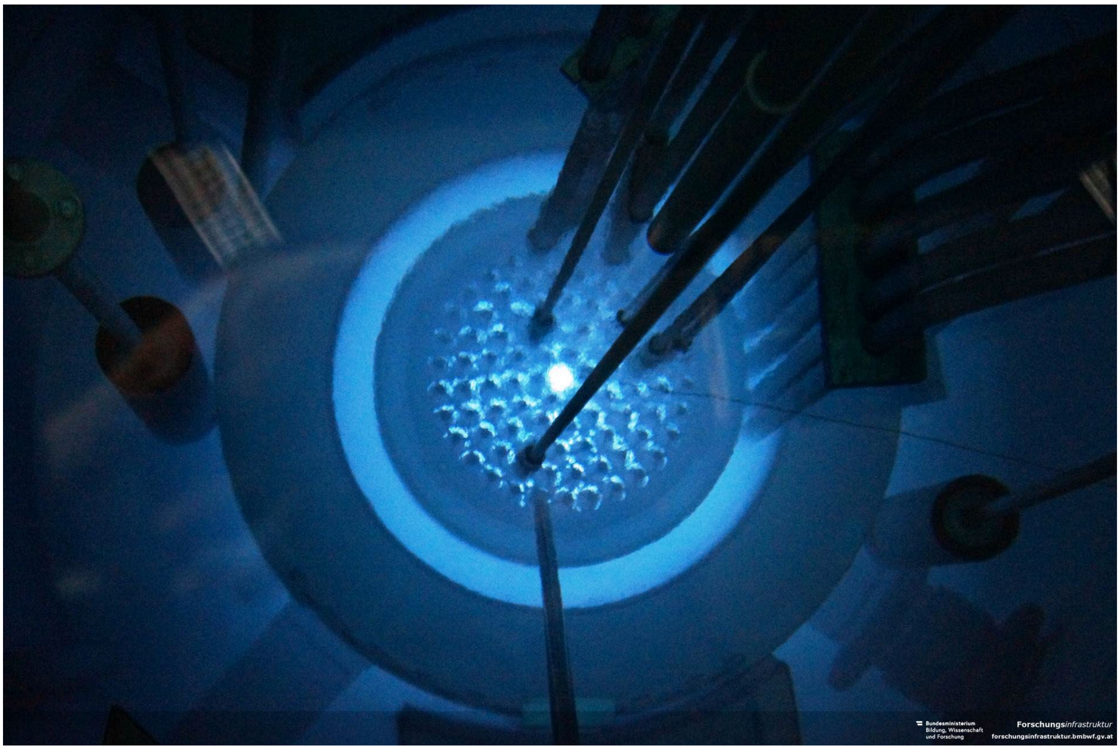
Instable energy markets, global warming and the ever-increasing energy demand lead to a dire need for a new, clean and baseload capable energy source. Though fusion is still a long way to go, it may fill this gap in the foreseeable future, especially if the recent and more compact design proposals prove their feasibility. Two consequences arise from these smaller reactor designs: the necessity to use high temperature superconductors to reach the fields necessary for the containment of the fusion plasma and the increased expected fast neutron flux at the magnets. The latter leads to an accelerated degradation of the critical current and, thus, to a shortening of the expected lifetime of the magnet. Consequently, a better understanding of the influence of radiation induced defects on REBCO high temperature superconductors is mandatory for mitigating degradation processes and increasing the lifetime of future fusion magnets.

In our studies, we irradiated coated conductors with fast neutrons (> 0.1 MeV) and 1.2 MeV protons, to introduce defects into the superconducting layer. The effects of these defects on the superconducting properties were extensively studied with SQUID magnetometry and transport current measurements in order to determine the radiation robustness of coated conductors in fusion applications. However, irradiating samples in fission reactors and with proton beams leads to a broad spectrum of introduced defect sizes. In order to distinguish the influence of small and large defects, (Y,Gd)BCO samples were irradiated with different particles and energies. Gadolinium has a large absorption cross section for thermal neutrons which was exploited to introduce large densities of point-like defects, also called Frenkel Pairs. Irradiating GdBCO based coated conductors with the full neutron spectrum (including thermal neutrons) degrades their transition temperature about 7 times faster than the high energy neutrons alone. The small defects contribute very little to the pinning related increase of the critical current and allow to distinct the influence of large and small defects on the superconducting properties. Furthermore, comparing the behavior of samples that were irradiated with these different irradiation techniques, we aim at a prediction of how quickly a magnet degrades and how this may be mitigated . Moreover, annealing at elevated temperatures seems promising for increasing the lifetime of a future fusion magnet by a factor of up to 2.

Caption: Triga Mark II Fission Reactor

Keywords: Neutron irradiation, Proton irradiation, REBCO,
annealing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WB2-1-INV

High performance REBCO tapes and wires for high magnetic field applications

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Ultra-high magnetic field applications such as compact fusion are driving the demand for REBCO coated conductors. World-wide demand for REBCO tapes far outstrips supply which is limited by the huge expense of establishing REBCO tape manufacturing facilities. One approach to alleviate this bottleneck as well as to significantly reduce the cost (in $/kA-m) of REBCO tapes is to utilize less conductor for the same kA-m requirement using high performance tapes. We have developed an Advanced Metal Organic Chemical Vapor Deposition (A-MOCVD) technology that yields REBCO tapes with 4x critical current than commercial REBCO tapes in a magnetic field of 20 T. The A-MOCVD technology has been successfully scaled up to 50-meter lengths with critical current 3.3x that of commercial tapes at 20 K, 20 T. The high-performance A-MOCVD tapes have also been used to fabricate round REBCO wires – STAR® wires – of 1.5 to 2.5 mm in diameter with excellent isotropic, high-field performance, for use in complex magnets such as those for particle accelerators.

Keywords: superconductor, magnetic field, critical current, MOCVD

WB2-2

Simple-Stacking HTS Solenoid under Non-Uniform Current Distribution Operation

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Simple-stacking (non-twisting) of ReBCO tapes is explored to make a large-current High Temperature Superconducting (HTS) cable for fusion magnet applications [1, 2], to be used especially in DC operation. The simple-stacking approach helps mechanical robustness, simplifies the manufacturing process, and reduces the overall cost of the conductor.

There is experimental evidence that a straight and short (length: 1.3 m) simple-stacked HTS cable can operate stably, under a worst-case non-uniform current distribution feeding [3, 4]. Still, for long-length cables, internal current redistribution and non-uniform current formation (due to inductance variability across the HTS tapes) are concerns for a coil shape, since they may disrupt the stable operation.

An experiment is proposed to explore these features, for a simple-stacked HTS cable wound as a solenoid, including uniform current and worst-case non-uniform current inputs. It considers a conduit with bolts, to vary the mechanical pressure among the HTS tapes, controlling the contact resistance and current redistribution. Manufacture and assembly of the solenoid are in process, and the experimental data is to be compared with a numerical calculation.

Due to the high cryogenic stability of HTS materials and previous experimental results, it is expected that the solenoid can achieve stable operation despite inductance variation. Then, notions of stable operating ranges can be obtained for HTS coil shapes, based on the simple-stacking approach.

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Keywords: HTS, ReBCO, current distribution, fusion magnets

WB2-3

Characteristics of voltage appeared at the current feeder of high-temperature superconducting WISE conductor and its improvement

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The HTS (high-temperature superconducting) conductor is a feasible candidate for constructing magnets for the next-generation fusion devices because of its higher critical current in a high magnetic field. A new concept of the HTS-WISE (Wound and Impregnated Stacked Elastic tapes) conductor has been studied aiming to apply the fusion reactor magnet. Here, the WISE-U conductor is composed of stacked thirty REBCO tapes (10 mm width, 65 μm thickness, I_c = 370 A @77 K, s.f.) wrapped by a stainless-steel coil tube which is inserted into the metal pipe. The 4 m-long REBCO tapes are folded with a radius of curvature of 35 mm in a hairpin-like structure as shown in Fig. 1. A low-melting-point metal U-Alloy 60 whose melting point is 60°C is poured into the pipe for impregnation to make the non-insulation conductor. The REBCO tapes and the current feeder made of oxygen-free copper were also impregnated with the U-Alloy 60 to connect (Fig.2). This fabrication method has the advantage of being easier to fabricate than the technique of connecting each tape using indium foil. The energization test results showed that a maximum current value of 16.9 kA was recorded at B = 5 T and T = 30 K, however, a burnout occurred in the current feeder before the critical current was determined. Then, the modified WISE conductor has been designed and tested which showed a maximum of 19.7kA was reached in the self-field and 20K. However, burnout still occurred in the current feeder section. In those experiments, the superconductor part has not been damaged at all. If this burnout had been avoided, a higher current-carrying capacity could have been obtained. Identifying the cause of burnout and improving the current feeder is required. The voltage behavior of current feeders and improvement ideas will be presented in detail.

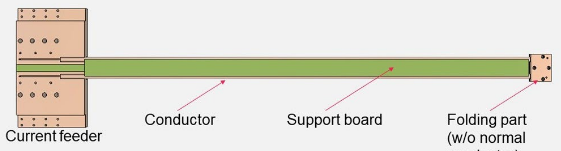

Fig.1 Overview of WISE-U conductor.

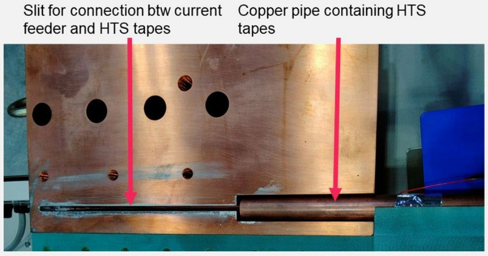

Fig.2 Structure of current feeder

Keywords: HTS, ReBCO, Helical fusion reactor, WISE

WB2-5-INV

Systematic investigation of the effect of the copper layer on the properties of REBCO commercial tape

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The effect of stabilizers on the electrical, thermal and mechanical properties of 20 different commercial REBCO tapes from 8 companies are systematically investigated. The resistivity and thermal conductivity in the radial and circumferential directions were focused on. The charging loss and self-protection ability of 20 different commercial REBCO tapes in the no-insulation coils were evaluated via simulation. The three tapes from Superpower with different Cu layer thicknesses were emphatically investigated. The geometry, size, purity, and quality of the Cu layer were analyzed to explore the possible dominant factors affecting the electrical and thermal properties. It was found that piecemeal Cu grains significantly increase and decrease the circumferential resistivity and thermal conductivity, respectively. The dominant factor in the radial direction was more complex, where the thickness uniformity, side Cu layer thickness, and corner contact quality between the Cu and Ag/REBCO could be important factors. Furthermore, the Cu layer purity may be significantly lower than previously thought. Using the resistivity and thermal conductivity values of pure Cu as the Cu layer in the simulation could result in significant errors. Such an investigation can support abundant data for the design of the REBCO magnet or even the choice of REBCO switch or current lead. Another goal was to help the REBCO manufacturers find a feasible way to adjust the resistivity and thermal conductivity, thereby meeting different requirements of the REBCO magnet.

Keywords: REBCO commercial tape, Cu stabilizer, Resistivity, Thermal conductivity

WB2-6

Cryogenic Magneto-Electrical Properties of an Aluminum-Beryllium Nanocomposite

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Suborbital aerospace, orbital, and lunar power distribution networks are desiring lightweight electrical conductors. Cryogenic hyperconducting aluminum (99.99999%+ pure) is a competitive option to HTS cables at 20 K, but hyperconducting aluminum cables require mechanical reinforcement for many applications, reducing current density, and this strengthening must be compatible with aluminum's annealing schedule to prevent impurity diffusion. AlBeMet 162 is a lightweight Al-Be nanocomposite which can be processed similar to aluminum alloys, and similar to hyperconducting aluminum, does not experience the extreme quench characteristics seen in superconducting composites. In this research, we shall investigate the electrical conductivity of cryogenic AlBeMet 162, and compare its mass specific engineering current carrying capacity with high RRR copper, hyperconducting aluminum composites, and a high current density HTS coated conductor cable. The electrical conductivity will be examined as a function of magnetic field up to 3 T to examine magnetoresistance and possible anomalous magnetoresistance. The possibility of AlBeMet 162 as a lightweight and low AC-loss superconductor composite stabilization will be examined analytically.

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WB2-7

Electromagnetic Thermal Analysis of HTS AC Cable Using T-A Formulation

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High temperature superconducting (HTS) cables have been developed into various products and attracted wide attention in industrial applications due to their high critical temperature, current density, zero resistance and overcurrent strength. Considering the flexibility and economy of materials, triaxial YBCO cables are commonly used in AC applications. In this paper, the transient electromagnetic thermal characteristics of a triaxial HTS cable are analyzed by the T-A formulation and the Thermal-Fluid Coupling Module of the COMSOL software under the condition of alternating current flow. Firstly, the electromagnetic T-A formulation and the basic theory of heat transfer are introduced. Transient magnetic fields, critical current distribution, and magnetization losses are discussed under T-A modeling. To evaluate the thermal behavior of the cable under normal current conditions, liquid nitrogen laminar flow is coupled with the heat transfer module, while the heat source data are obtained from the previous T-A results.

WB3-1-INV

REBCO Coated Conductor Development for Mass Productive Process Using IBAD and Hot-wall PLD

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REBCO coated conductors by IBAD/PLD process have excellent and uniform in-field Jc properties with robust mechanical strain strength. They are suitable to varied field magnets especially for high field applications and implemented in the practical inner magnet coils for high-end NMR systems, which strongly requires good transporting and dimensional uniformity in long piece length. Moreover, tremendous REBCO conductor demands emerged recently for "compact" nuclear fusion prototype research which requires quite high in-field Ic even at 20 K, 20 T, within affordable cost and Ic variations. This talk describes current status and perspectives of REBCO coated conductor by mass productive PLD process at Fujikura Ltd.
Pulsed-laser-deposition (PLD) is a non-equilibrium vapor process characterized to have high growth rate with quite largely supersaturated conditions though it has also excellent controllability of varied deposition conditions for complexed multi-element oxide films as REBCO. It allows to control high density crystalline dislocations and small-size secondary phase particles to a certain extent, dispersed inside good textured REBCO films growing at very high rates. It is so suitable to obtain desired flux pinning centers and in-field transporting current without severe degradation of matrix superconductivity and processing throughput. These PLD advantages should be guaranteed if the most severe parameter of substrate temperature were enough controlled during long length contentious depositions. Fujikura group had designed and developed "Hot-Wall Type" reel-to-reel PLD apparatuses, which realized quite robust and reproducible temperature uniformity by furnace like heating system. We succeeded to commercialization of long length and uniform REBCO wires including BaHfO3 doped artificial pinning type lineups, preserving deposition conditions within narrower windows by Hot wall PLD. It was also important to choose RE elements of Gd, or Eu, that the crystalline growth stability was so excellent that good c-axis aligned high quality thick films were reproducibly obtained by hot-wall PLD. Recent results of high field transporting characteristics for production wires would be presented. There are also some controversy for neutron radiation damage come from very large cross section of low energy (~1 eV) thermal neutron capture of Gd or Eu. But recent simulations suggested it would be not so severe matter because main radiation damage at fusion magnets should come from high energy (> 0.1 MeV) neutron bombardment, though sufficient experimental confirmations are not completed yet [1]. We are currently continuing to develop productivity and quality control of those wires toward large capacity and long piece length industrialization. We also completed line up of tape-width from 2 to 12 mm with commercial level quality, replying to the demand of narrow wide wires for loss reduction or field accuracy, etc.
A part of this work is based on results obtained from a project subsidized by the New Energy and Industrial Technology Development Organization (NEDO). A part of this work was also performed at the High Field Laboratory for Superconducting Materials, IMR, Tohoku University.

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Keywords: BMO Doped REBCO, Coated Conductors, Hot-Wall PLD

WB3-2-INV

REBCO HTS wire production at SuperPower - challenges in manufacturing scale-up to meet increasing demand

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Furukawa Electric Co., Ltd.[2]

Almost immediately after its discovery, people had made a long list of potential applications for the REBCO high temperature superconductors (HTS). For those applications, REBCO was envisioned to be an ideal substitute for the normal conductors and for the low temperature superconductors (LTS). By this time, the substitution has not happened as expected, which is due to many perceivable reasons.

In the recent years, REBCO becomes more attractive and promising in the applications where it is the enabling material rather than a substitute. The recent rapidly increasing demand we have seen is from the technology development of compact fusion reactors for power generation. The successful applications are of the high-field (around 30T) hybrid magnets (including the magnets for the commercial NMR systems). For the first time since the REBCO wires became commercially available, the demand for this material is now outpacing its production.

The adoption of REBCO in high-field magnets and by the compact fusion technology development is attributed mainly to the material's better in-field performance and higher mechanical strength. The improvements in the performance and properties, which is driven by the application requirements, will continue. In the path to achieve a much greater production capacity, we also face the challenges in quality assurance, high-field testing, cost reduction, etc. This presentation summarizes the recent activities for HTS wire production and development at SuperPower Inc.

WB3-3-INV

Recent progress on 2G HTS tape development at Shanghai Superconductor Technology

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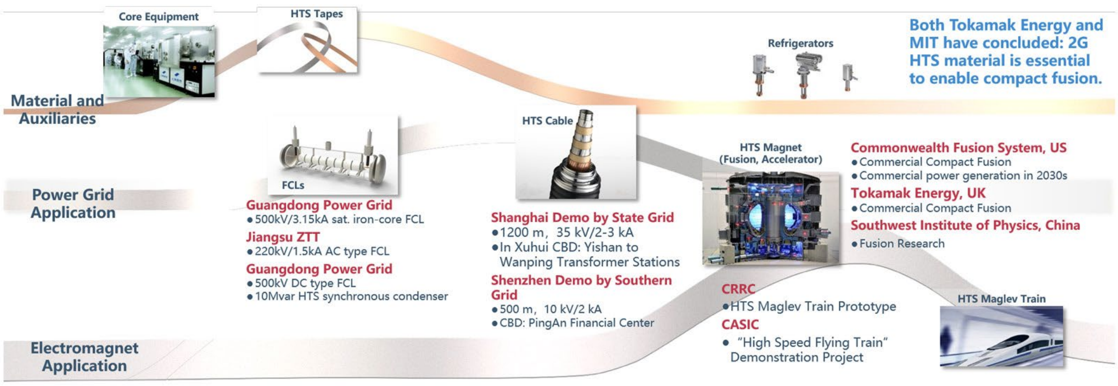
Shanghai Superconductor Technology Co., Ltd. (SST) is a high-tech enterprise developing 2G HTS tapes. After R&D on both process optimization and deposition-equipment manufacturing, km-class 2G HTS tapes have been fabricated and supplied commercially. An advanced pulse laser deposition system was developed to fabricate high performance REBCO layers. A transient liquid was formed and assisted epitaxial growth of REBCO film, which lead to the growth rate up to 100 nm/s. 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, we developed advanced post-processing techniques (lamination and laser slitting) 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. Last but not least, SST will also take the opportunity to provide an update on its latest fundraising, and its work progress towards a 3000 km/yr production capacity target.

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



WB3-4-INV

Title: Production Scale-up and performance enhancement issues at SuNAM

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SuNAM Co., Ltd.[1]

After establishing mass production facilities of Coated Conductors(CC) based on a proprietary evaporation process, SuNAM has been supplying hundreds of kilometers of CC for various applications, including grid use in the domestic market. To keep up with increasing demand from Korean cable installations and high field magnet and fusion applications, we installed the 2nd RCE(Reactive Co-Evaporation) equipment for superconducting layer, about which we reported at the previous ISS, emphasizing critical current enhancements at medium temperature(20~40 K) and mid-field range(

WB3-5

High-temperature superconducting tape optimized to high-field and to AC-based applications

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As the technological readiness of high-temperature superconductors (HTS) coated conductor (CC) tapes is reaching high levels and they become available to more and more applications, THEVA presents recent advances in tape performance. In order to increase the applicability in high field magnets, artificial pinning centres are introduced in the superconducting layer of CC tapes. The latest high-field critical current (I_C) measurements confirm the stabilization of the superconducting state up to extremely high magnetic fields. For some AC applications, the limiting factor is increasingly the AC losses due to induced screening currents in the tape. Therefore, we also present recent progress on reducing tape width while increasing mechanical and electrical stabilization. For highly loss-sensitive applications, even smaller tape widths are required. To maintain mechanical stability and integrity, this is only possible by using filamentized HTS tapes, which are being studied within the Filaments4Fusion project. We are comparing two different filamentization techniques and discuss the possibilities of optimization.

Keywords: high-temperature superconductor, coated conductor, artificial pinning, AC loss

WB3-6

$BaMO_3$ (M = Zr, Hf) doped REBCO tapes fabricated by Fluorine-Free MOD

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Fluorine-free MOD (FF-MOD) is a promising technique for low cost REBCO fabrication because inexpensive easily prepared solutions can be used, there is a nearly 100% material yield and no special energy source is required except for a conventional tube furnace. Moreover, the FF-MOD method can obtain highly textured film at a high growth rate of ~ 100 nm/sec. [1], [2]. However, it has been hard to introduce artificial pinning centers (APCs) needed for magnetic field applications because the addition of dilute metals (M = Hf, Zr, etc.) to the starting solution often disturbed orientation of the REBCO matrix.

During the REBCO growth process, $BaMO_3$ (BMO) formation occurs [3]. The size of the BMO can change depending on the conditions during heating. To avoid the misorientation of REBCO films and a variation in BMO size, we used BMO nanoparticles made using a solvothermal method [4]. By adding BMO nanoparticles to the starting solution, the size of BMO particles can be kept in the nanometer order. Furthermore, we introduced a microcrystallization sintering process for decomposed $BaCO_3$ before making oriented REBCO films, because inhomogeneous decomposition of $BaCO_3$ leads to a disturbance in the homogeneous crystallization of REBCO films.

By utilizing the above techniques, we succeeded in fabricating epitaxial REBCO films which include more than 7 mol% BMO on a clad type tape with buffer layers [5]. The clad type tape consists of textured electro-plated Ni film and rolled Cu foil on a 100 µm thick stainless base tape. 120-m-long APC-added REBCO tapes with I_C exceeding 200 A/4 mm-width at 77 K can be achieved by the FF-MOD method. The highest I_C at 77 K, s.f. is 337 A/4 mm and I_C at 20 K, 20 T (B//c) is 194 A/4 mm with 3.4 mol% $BaZrO_3$. Further improvement of critical current properties at low temperature and with high magnetic fields is expected by optimizing the concentration and size of nanoparticles.

Acknowledgements: A part of this work was performed at High Field Laboratory for Superconducting Materials, Institute for Materials Research, Tohoku University (Project No 202112-HMKPC-0006). We appreciate Dr. Obradors and Prof. Puig of the ICMAB for technical discussions.

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Keywords: coated conductor, REBCO, FF-MOD, APC

WB4-1-INV

Artificial pinning in Nb_3Sn

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The record J_c of Nb_3Sn conductors has been at a plateau since the early 2000s; however, much higher J_c than the state of the art is required for future energy-frontier circular colliders. For example, the non-Cu J_c required by the planned Future Circular Collider (FCC) is ~50% higher than what present Nb_3Sn conductors can deliver. In the past few years a new type of Nb_3Sn conductors with artificial pinning centers (APC) have demonstrated significantly superior performance relative to the state of the art. Such APC wires are based on the internal oxidation method, which generates nano-size oxide particles in Nb_3Sn. It was found that this method improves high-field J_c via four mechanisms: (1) refining Nb_3Sn grain size, (2) the particles directly serving as flux pinning centers, (3) shifting flux pinning force (F_p-B) curve peak to higher field, (4) enhancing B_{irr} and B_{c2}. In 2019 the APC wires we developed first reached the FCC J_c specification. Since then the efforts have been mainly focused on pushing the APC wires toward readiness for practical applications, including improvement of stability. In this talk a comprehensive review of the APC Nb_3Sn conductors will be given, including its opportunities, challenges, current status and future plans.

Keywords: Nb3Sn, Artificial Pinning Center, APC, Internal Oxidation

WB4-2

Historical Progress of Flux Pinning of (Y,Re)-Ba-Cu-O Thin Film Superconductors with Artificial Pinning Centers

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Artificial pinning centers (APCs) of varying types and nano-scale size have been successfully introduced into (Y,RE)$Ba_2Cu_3O_{7-x}$ (Y,RE-BCO, (Y,RE)BaCuO, YBaCuO or YBCO) thin film superconductors by different processing methods in order to strongly and collectively pin quantized vortices. As a result, the critical current densities (Jcs) of these high-temperature-superconductor (HTS) films have been dramatically improved for a wide range of temperatures (T = 4.2K to ~ 85K) and applied magnetic fields (Happl = 0T to 32T). A number of high quality reviews of this large field have been published that describe progress in the fundamental sciences and pseudo-empirical approaches to improving Jc(H,T) and flux pinning properties. Herein a review is provided that focuses on two specific subtopics: i) plotting historical progress world-wide since 1995 increasing Jc(H,T,Θ) properties, by data-mining the ~ 87 highest cited papers in the field, and ii) presenting how improvements of Jc(H,T,Θ) can have significant impact to improve the performance and capabilities of high power devices and applications. The review plots Jc(H//c,T) values achieved at T = 40K to 77K, and Happl = 0T to 9T, summaries of Jc(H//c,H//ab,min) @65K and 1-3T, and the highest angular Jc(65K, H=1-3T, θ = 0 to 90°). It was found that increases of Jc(H//c,T=40-77K) of 7x to 50x are consistently being achieved by multiple processing methods and nanoparticle additions for the full range of Happl = 0T to 9T. Due to these large increases, it is shown that improving flux pinning at operation temperatures T = 40K to 77K and Happl = 0T to 32T can better enable devices to operate at dramatically increasing higher temperatures, which can significantly reduce system cost-size-weight-and-power (C-SWaP). Reducing C-SWaP can enable operation or completely new capabilities or markets in technology areas such as air or space propulsion.

Keywords: yttrium barium copper oxide, flux pinning, thin films, current density

WB4-3

Improvement of Jc properties of high-entropy RE123 superconducting thin films by introducing BMO_3-type artificial pinning centers

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In this study, high-entropy type RE123 superconducting thin films were fabricated by FF-MOD method and their properties were evaluated. The definition of a high-entropy RE123 superconductor is that the RE sites of the superconductor are substituted with 5 or more elements, and the proportion of each element is 5-35at%. There are few reports of fabrication of high-entropy RE123 superconductors by the FF-MOD method. High-entropy superconductors are expected to have the strong crystal robustness. Therefore, it is thought that artificial pinning centers can be introduced while maintaining the crystallinity, compared to single RE123 such as Gd123. We have fabricated FF-MOD RE123 films in which the RE site was replaced with five elements of Gd, Sm, Nd, Eu, and Y to prepare a thin film. The nominal composition ratio of the elements was $Gd_{0.20}Sm_{0.20}Nd_{0.20}Eu_{0.20}Y_{0.20}Ba_2Cu_3O_y$. The critical current density of the film reached over 2.4 MA / cm^2 at 0 T, 77.3 K. Furthermore, BMO_3-type artificial pinning centers were introduced to improve the critical current density in magnetic fields.

Keywords: RE123, FF-MOD, High-entropy superconductor

WB4-4

Enhanced isotropic pinning at 20K from columnar defects

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Ion irradiation of REBCO thin films and coated conductors is well known to introduce extra pinning centers. These arise as damage tracks from the passage of the ions and can range from point-like defects to discontinuous columns to fully continuous columns depending on the energy-loss profile of the ion. We have explored irradiation with Ag ions with energies from 50 MeV to 150 MeV and have seen that in this range the defects transition from point-like defects at the low energy end to discontinuous columns at the high end. The columnar defects result in strong peaks appearing in the angular dependence of critical currents at temperatures above 40 K, with strong pinning enhancements for field applied parallel to the irradiation direction. Below 40 K there is a transition to the pinning enhancement becoming quite isotropic. We interpret this as arising from an interaction between the columnar pins, intrinsic pins and point pins. The result is an enhancement of up to a factor of 3 for the angular minimum critical current at 20 K.

Keywords: coated conductors, ion irradiation, columnar defects, critical current

WB4-5

Flux pinning dynamics in individual irradiated and multiple irradiated REBCO coated conductors

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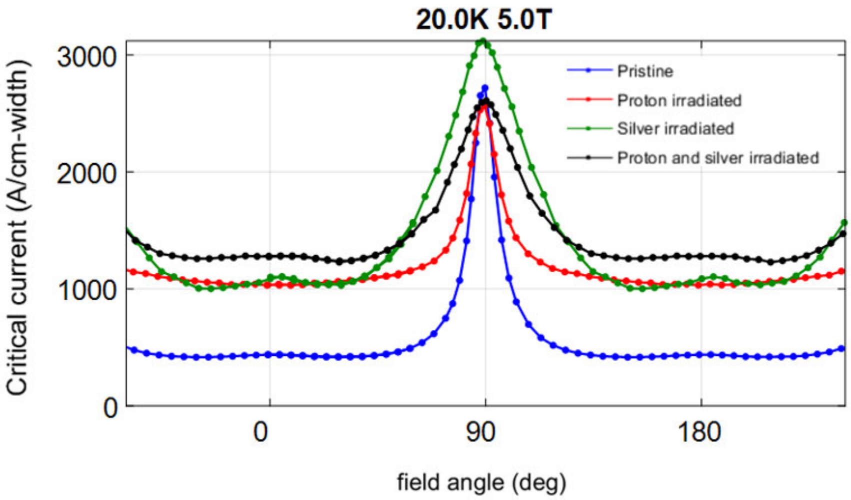
Achieving high critical current density and reduced magnetic field anisotropy in superconductors is of great relevance in designing HTS devices for different applications proposed for sustainable energy production, transport, energy storage as well as medical applications. Incorporating nano-sized non-superconducting secondary phases as additional vortex pinning centers through ion beam technology has proved to be a successful method to achieve high critical current performance in superconductors with minimal disruption to the existing defect landscape, thereby enhancing the critical current in a readily controllable fashion. Previous studies show that irradiation with a single species of ion can enhance the in-field J_c and reduce anisotropy in commercial state-of-the-art CCs. Here we explore the impact of multiple ion irradiation on superconductor performance. We have optimized the critical current for the proton or silver irradiation separately and compared these with the combined irradiation of both on commercially available $(Y,Dy)Ba_2Cu_3O_{7-\delta}$ coated conductors from American Superconductor. The resulting samples were characterized using field angle-dependent transport critical current measurements over a range of temperatures from 20 K to 77.5 K and magnetic fields up to 8 T. The individual irradiation of protons and silver resulted in a similar level of critical current enhancement, a factor 2.4 improvement in the c-axis peak over an already optimized and commercially superconducting tape and combined irradiation with silver and protons results in a further critical current enhancement at 20 K and 5 T. The individual and combined irradiated samples were analyzed in the framework of the maximum entropy model to understand the vortex dynamics providing a broad picture of synergistic and competing interactions among the various types of defects. The knowledge gained will benefit in designing pinning landscape for specific applications which requires optimal concentrations of different defects for maximum critical current.



Keywords: High temperature superconductor, Critical current, Ion irradiation, Vortex pinning

WB4-6

In-field J_c properties for RTR-PLD (Eu,Er)$Ba_2Cu_3O_y$+$BaHfO_3$ CCs with O^{2+} ion irradiated defects

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$REBa_2Cu_3O_y$ (REBCO) grown by reel-to-reel pulsed laser deposition (RTR-PLD) coated conductors (CCs) are expected to be used in magnet application because of their excellent high-field superconducting properties. However, further improvement of the critical current density (J_c) is still required for practical use. The introduction of $BaHfO_3$ nanoparticles (BHO NPs) [1,2] and irradiation-induced defects [3] as flux pinning centers have been reported to improve in-field J_c properties. Recently, S. Eley *et al*. reported the enhancement of J_c for REBCO CCs with oxygen-irradiated defects [4].

In this work, to investigate the effect of coexisting BHO NPs and irradiation-induced defects on the superconducting properties of RTR-PLD (Eu,Er)$Ba_2Cu_3O_y$ CCs, we prepared (Eu,Er)BCO+BHO CCs with various irradiation fluences. Although T_c and J_c decreased immediately after irradiation, they recovered almost all of their original properties after oxygen annealing treatment. The (Eu,Er)BCO+BHO CCs with 1×10^{13} O ion/cm^2 show higher in-field J_c properties compared to that in unirradiated (Eu,Er)BCO+BHO CCs at high temperature (65 - 77 K). To understand these J_c improvements for oxygen-ion irradiated (Eu,Er)BCO+BHO CCs, we used a simple pinning model in the analysis [1]. We see that the calculated J_c using our pinning model is good agreement with the experimental J_c. The pinning model and detailed in-field superconducting properties for (Eu,Er)BCO+BHO CCs with oxygen irradiated defects will be presented.

Acknowledgements:
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Keywords: REBCO, ion iradiation, critical current, PLD

WB4-7

Improvment of thickness uniformity of supercondcting wire using gradient depisition method

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Recently, various high temperature superconducting(HTS) magnets have been developed using a no-insulation technology capable of preventing the quench phenomenon that is one of the major problems of the superconducting magnets. In order to develop a superconducting magnet application using the second-generation(2G) HTS wire, the uniformity of critical current and thickness to the longitudinal direction of 2G HTS wires is very important. Because the non-uniformity of the thickness occurs during wire manufacturing process, it is difficult to accurately control the coil winding and performance by using the 2G HTS wires. In this paper, in order to improve the longitudinal thickness non-uniformity of the 2G HTS wire, first of all, gradient deposition method was used to regulate the total thickness to the width direction of 2G HTS wire. A special designed shield was developed and installed between the target and 2G HTS wire in sputter system for gradient depositing stabilizer. The thickness of deposited stabilizer and total thickness to the width direction were measured to compare the variation of thickness uniformity of 2G wire before and after deposition. It is confirmed that the sputtering process using the gradient shield can improve the thickness uniformity of 2G HTS wires to the width direction.

Keywords: HTS wire, Superconducting magnet, Thickness, Gradient deposition

WB4-8

Growth mechanism of $BaMO_3$-doped $REBa_2Cu_3O_y$ thin films by Vapor-Liquid-Solid technique simulated by Monte Carlo simulation

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Introduction

We have introduced the vapor-liquid-solid (VLS) growth technique to fabricate $REBa_2Cu_3O_y$ (REBCO, RE= rare earth: Y, Sm, etc.) thin films [1]. VLS growth technique is a solution growth method, which can fabricate REBCO thin films with a higher deposition rate and good crystalline orientation than films prepared by conventional pulsed laser deposition (PLD) method, which is a vapor phase epitaxy. To improve J_c in magnetic field, however $BaHfO_3$ (BHO)-doped YBCO films were grown by the VLS growth technique, the films included two regions, one was a region without BHO and the other was a region consisting of segregated BHO [1]. Self-organization process of BMO nanostructures in REBCO films, which were prepared by vapor phase epitaxy, has been investigated by both experimental and computational approaches. [2, 3]. However, there are few reports on a mechanism of BMO self-organization in the VLS growth technique. To understand the mechanism, we have been developing a crystal growth simulation code concerning to VLS growth technique. In this study, we performed the simulations at various substrate temperatures (T_s) and BMO contents to understand the crystal growth of BMO-doped REBCO thin films and the behavior of BMO molecules in a liquid phase in the VLS growth technique.

Simulation

In this study, we used a three-dimensional Monte Carlo simulation for crystal growth. This simulation takes into account solvation energies of REBCO and BMO in a liquid phase, to simulate a solution growth. The simulations were performed at $T\text{-}_s$ = 1113 ~ 1313 K and BMO contents of 0 ~ 5 vol. % to investigate the effects of T_s and BMO contents on BMO nanostructures and growth of REBCO thin films.

Results and discussion

Fig. 1 shows the result at T_s = 1113 K and 0 vol. % BMO. REBCO and BMO unit cells are expressed using simple cubes with the side length of 0.4 nm, and the computational space has 48 nm along *ab*-plane and 20 nm along *c*-axis. The bottom of the space is the substrate made of a single crystalline REBCO, and the top is the surface of liquid phase. From the figure, REBCO unit cells are diffusing in the liquid phase and are growing into 2D islands on the substrate surface. We will report the results of the different T_s and BMO contents, and the difference from vapor phase epitaxy.

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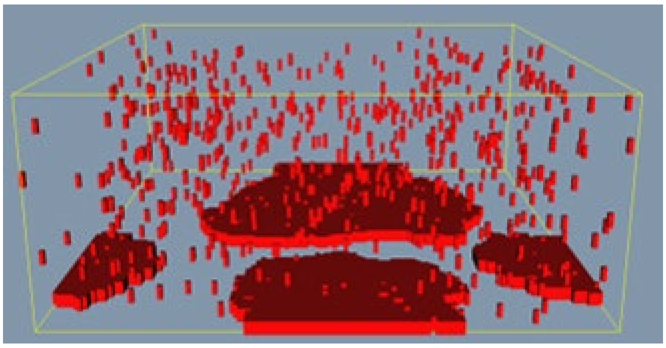
Figure
Fig. Snapshot of VLS-grown REBCO at 1113 K and 0 vol.% BMO using the Monte Carlo simulation.The size of the box is 48×48×20 nm. REBCO unit cells are diffusing in the liquid phase and are growing into 2D islands on the substrate.

Keywords: monte carlo simulation, REBCO, Vapor-Liquid-Solid technique



WB4-9

Geometry measurement of an ablation plasma in the pulsed laser deposition method and effective investigation for using Bayesian optimization

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Introduction

The fabrication of $REBa_2Cu_3O_y$ (REBCO) superconducting thin films by the pulsed laser deposition (PLD) involves many non-quantifiable parameters such as equipment degradation, dirt, and plume shape, in addition to quantifiable parameters such as temperature and pressure. These non-quantifiable parameters also affect the thin film quality and reduce the reproducibility of the superconducting thin films.

The PLD method is a deposition technique in which the target surface is irradiated with a powerful UV pulsed laser to ablate the constituent materials. The ablated materials are then deposited on an opposing substrate. During irradiation of the target, the excited materials form a luminescent column made of plasma called a plume. The geometry of this plume varies depending on quantitative parameters such as ambient oxygen pressure and laser irradiation energy density [1]. In addition, the plume is also affected by various non-quantitative factors such as individual differences in the optics and laser source of each device, dirt on the laser input window, degradation of the laser pumping medium, and surface condition of the target. Therefore, the plume is a parameter that includes the effects of both quantitative and non-quantitative parameters.

To find the optimum fabrication conditions for superconducting thin films, such as temperature and pressure, many samples are prepared by varying these parameters, and the optimum fabrication conditions are searched by evaluating the superconducting properties for each parameter. Currently, the search for optimum fabrication conditions is based on ex-situ evaluations which are X-ray diffraction, superconducting properties and so on, but this process is not efficient. Therefore, a method based on Bayesian optimization [2] is expected to be an efficient method to search for optimal fabrication conditions.

In this study, we are developing a technique to improve the reproducibility of superconducting thin films fabrication in the PLD method by optimizing the in-situ fabrication conditions through obtainment geometric information of the plume including non-quantitative parameters. We are also developing a Bayesian optimization method using the acquired plume information to improve the efficiency of the investigation for the superconducting thin films.

In this presentation, we report on the development of the plume geometry acquisition method and the Bayesian optimization for properties of YBCO films using the plume information.

Experimental method

$YBa_2Cu_3O_y$ thin films were fabricated by PLD method. The substrate temperature was 840°C, the distance between the target and the substrate was 60 mm, the energy (E_L) of the KrF excimer laser (wavelength: 248 nm, repetition rate: 10 Hz, spot size: 1.7×1.2 mm^2) was 30, 50, and 60 mJ, and the oxygen partial pressure (P_{O2}) in the deposition chamber was changed to 100, 400, and 1000 mTorr. Plume images were taken using a depth camera (Intel, Realsense Depth Camera D405) during the fabrication of the nine conditions of the YBCO thin films, plume geometry (height and width) was obtained using the depth camera.

Experimental results and discussion

Figure 1 shows the plume height for different oxygen partial pressures and laser energies. The plume height varied from 0.018 m at E_L =30 mJ and P_{O2} = 1000 mTorr to 0.034 m at E_L = 60 mJ and P_{O2} = 100 mTorr.

From this figure, it can be confirmed that the plume height becomes lower as the oxygen partial pressure increases and the laser energy decreased. From this result, we confirmed that the depth camera could obtain the geometry of the plums because a distance between the camera and the plume can be measured, making it possible to obtain geometric information of the plume independent of a deposition equipment.

Bayesian optimization using the acquired plume information will also be presented.

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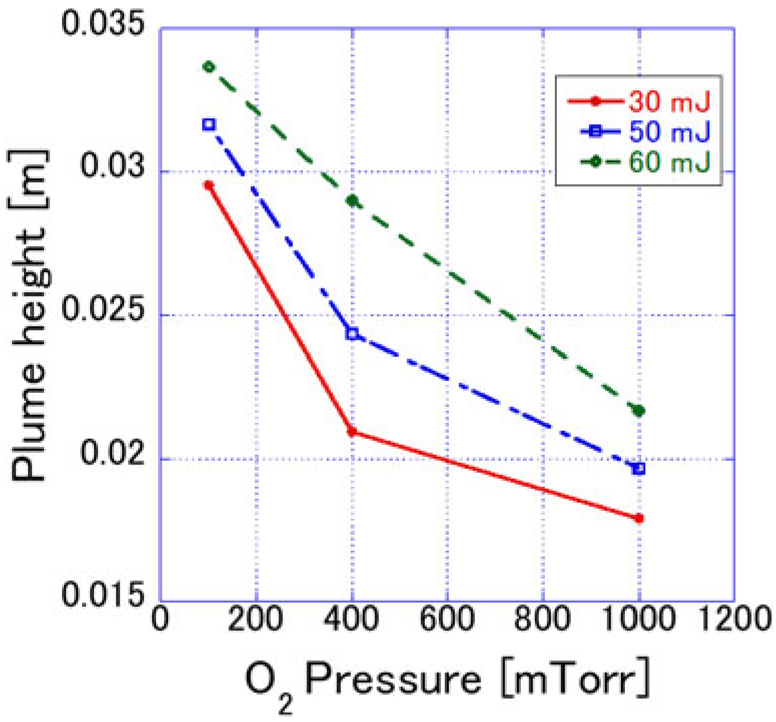
This work was partly supported by JSPS-KAKENHI (20H02682, 21H01872) and NEDO.

Figure

Fig. Plume height of YBCO thin film fabricated by PLD method at different O_2 pressures and laser energies.

Keywords: plume, Pulsed Laser Deposition, REBa2Cu3Oy



WB5-1-INV

Development of DC and AC MgB2 Superconductor Wires and Their Applications

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The use of Magnesium Diboride (MgB2) wires for DC applications has been progressing over the years. In recent years the new development area has been the development of low AC MgB2 for several applications. The desire has been to decrease the filament size, reduce the twist pitch, and remove magnetic materials from the wire matrix, without losing the superconducting current density (Jc). We will be reporting on the successes that has been made to reduce the AC losses. We will also be discussing the benefits of these low AC loss wires for various applications and the potential for developing all superconducting (rotor and stator) rotating machines for wind turbine generators, motors and generators for electric aircraft, ships and trains. The low AC loss wires are also useful for fast charge and discharge superconducting magnetic energy storage(SMES), and utility transformers. We will also update progress on 2nd generation MgB2 wire performance.Acknowledgement This low AC loss MgB2 wire development has been supported by NASA, USA

WB5-2-INV

Development of the ultra-fine MgB_2 superconducting wires and stranded cables

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Facing global environmental problems, such as climate change, global warming, etc., we have to enable a sustainable world as soon as possible. Hydrogen is world-widely garnering attention as a crucial energy resource in achieving carbon neutrality. If liquid hydrogen becomes familiar to our society, superconducting applications operating at 20 K may be able to contribute to saving energy. MgB_2 superconducting wire is promising for a practical conductor at 20 K because it has a high T_c of 39 K, small superconducting anisotropy, no weak-link problem, lightweight, simple chemical composition, possibly to make round wires, expect low production cost, etc. Although MgB_2 multifilamentary wires are already being developed and sold by several companies at present, however, it still remains some R&D issues in order to meet wide practical applications with liquid hydrogen.

We are ongoing R&D of ultra-fine MgB_2 superconducting wires having a very small diameter much less than a human hair. These ultra-fine MgB_2 wires could be bundled and fabricated easily into stranded cables for increasing the current capacity. In principle, the bending strain decreases with decreasing the wire diameter as well as the hysteresis loss. The stranded cables made by these ultra-fine MgB_2 wires would have very flexible mechanical performance and thus react and wind techniques would be applicable. In addition, the coupling loss for the stranded cables is expected to be minimized by increasing the surface and contact resistance, which are relatively easy to be controlled. Therefore, it may be solved both the issues of mechanical brittleness and AC losses at once. Brand-new results for ultra-fine MgB_2 superconducting wires and stranded cables will be presented.

A part of this work is financially supported by NEDO feasibility study program 2022.

Keywords: MgB2, superconducting wire, stranded cable, very small diameter

WB5-3-INV

Strengthened proximity effect at grain boundaries to enhance inter-grain supercurrent in $Ba_{1-x}K_xFe_2As_2$ superconductors

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Iron-based superconductors (IBS) have great potential for high-power applications due to their prominent high-field properties. IBS long wires made by the powder-in-tube (PIT) method have already been made into coils. However, there is still considerable scope for the increase of critical current density, J_c. One of the central issues is to reveal the roles and limitations of grain boundaries in supercurrent transport in IBS. Here, we finely tuned the electronic properties of grain boundaries by doping $Ba_{1-x}K_xFe_2As_2$ superconductors in a wide range ($0.25 \le x \le 0.598$). It is found that the intra-grain J_c^{intra} peaks near x~0.287, while the inter-grain J_c^{inter} has a maximum at about x~0.458. Remarkably, the grain boundary transparency parameter defined as $\varepsilon = J_c^{inter}/J_c^{intra}$ rises monotonically with doping. Through detailed microscopic analysis, we suggest that the FeAs segregation phase commonly existing at grain boundaries and the adjacent grains constitute superconductor-normal metal-superconductor (SNS) Josephson junctions which play a key role in transporting supercurrent. A sandwich model based on the proximity effect and the SNS junction is proposed to well interpret our data. It is found that overdoping in superconducting grains largely strengthens the proximity effect and consequently enhances the intergrain supercurrent. Our results will shed new insights and inspirations for improving the application parameters of iron-based superconductors by grain boundary engineering.

Keywords: Iron-based superconducting wires, Critical current density, Grain boundary engineering

WB5-4

Ic measurement of low AC loss and DC multifilamentray MgB_2 wires over a wide range of temperature and fields

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All-superconducting rotating machines have potentials for meeting the needs of high-power density and high efficiency for electrical aircraft application. However, very high AC loss in superconducting armature windings where superconductors carry AC current and exposed AC magnetic field, hinders its development. Hence, reducing AC loss in superconducting armature windings is one of critical tasks for the application. Considering the achievable filament size of REBCO coated conductors (CC) through laser ablation, critical current degradation due to the laser ablation process, and difficulty in twisting the filaments due to their flat shape, REBCO CCs may not be a suitable conductor choice for the application. On the other hand, multifilamentary MgB_2 wires with filament size lower than 10 mm, and small twist pitches are one of the promising candidates for the stator windings. Therefore, estimating AC loss in multifilamentary MgB_2 wires becomes an urgent task for the aircraft application. As first step, the dependence of critical current on magnetic field and operating temperatures of MgB_2 wires, I_c (*B*, *T*), needs to be measured, because it will be a basic input parameter for AC loss simulation.
In this work, we present J_c (*B*, *T*), J_e(*B*, *T*) measurements in three types of multifilamentary MgB_2 wires. The two non-magnetic low AC loss wires (MgB_2/Nb/CuNi/CuZn) are compared to commercial weakly magnetic sheaths (MgB_2/Nb/Cu/Monel) DC MgB_2 wires. All the MgB_2 wires were manufactured by Hyper Tech Research Inc, USA. A four-probe direct current method is used to measure I_c of the MgB_2 wires at temperatures ranging from 15 K to 35 K with magnetic fields up to 8 T using the SuperCurrent system in Robinson Research Institute, Victoria University of Wellington. The measured J_c (*B, T*), J_e (*B, T*), curves and *n*-values of the MgB_2 wires are compared.

Keywords: AC loss, Ic measurement , MgB2, all-superconducting rotating machines

WB5-5

X-ray Characterizations of Iron-based Superconductor Round Wires with Large Critical Current Density

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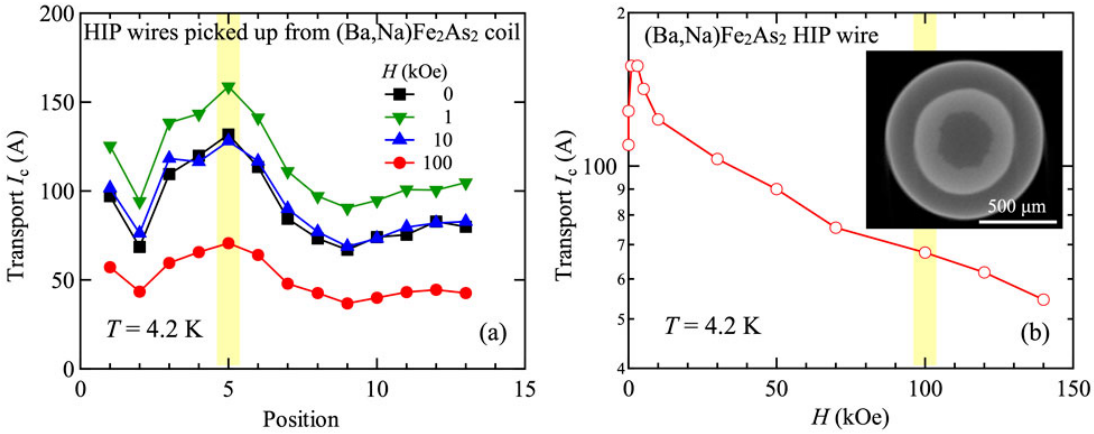
Demands for new generation superconducting wires are growing rapidly. One of good candidates to meet such demands is wires of cuprate superconductors. However, they face several issues such as strong magnetic field of critical current density (J_c) and delamination. In addition, due to complicated fabrication process, fabrication cost of wire continues to be high. In such a situation, wires and tapes of iron-based superconductors (IBSs) attract much attention, since they have sufficiently high T_c and H_{c2}. In addition, IBSs have sufficiently high J_c in single crystals, and it can be enhanced by the introduction of artificial defects [1]. Much effort is devoted to the development of tapes and wires of IBSs, in particular to those based on 122-type IBSs. Actually, J_c over the critical level of $1x10^5$ A/cm^2 under the field of 100 kOe has been achieved in 2014 in tapes [2], and J_c in wires also exceeded a half of that level in 2021 [3].

We have started the preparation of long-length (Ba,Na)Fe_2As_2 wire over 10 m, and constructed small coils to generate magnetic field [3]. Critical current (I_c) of the long wire is much smaller than that in short segments picked up from the long wire, and varies considerably along the length as shown in Fig. 1(a). It is important to know the reason for the suppression of I_c and parameters that affect it most. We have employed X-ray characterizations for such purpose. Magnetic field dependence of I_c for the best segment is shown in Fig. 1(b). The largest value of J_c calculated from the smallest cross section of this segment evaluated using X-ray tomography turn out to be record high, $6.7x10^4$ A/cm^2 at 100 kOe. In addition, X-ray diffraction measurements on the longitudinal and transverse cross sections of the wire has proven that the core of the wire is concentrically textured. It demonstrates the importance of texturing in enhancing J_c.

Fig. 1 (a) Transport *I*c at several magnetic fields for short segments picked up from different positions of the long wire used for a small coil. (b) Magnetic field dependence of transport I_c for the short segment with the largest I_c. The inset shows a representative X-ray tomography image of the transverse cross section

[1] T. Tamegai *et al.*, Supercond. Sci. Technol. 25, 084008 (2012).
[2] X. P. Zhang *et al.*, Appl. Phys. Lett. 104, 202601 (2014).
[3] S. Pyon *et al.*, Supercond. Sci. Technol. 34, 105008 (2021).

Keywords: iron-based superconductor, superconducting wire, critical current density, X-ray tomography


HIP wires picked up from (Ba,Na)Fe2As2 coil
H (kOe)
0
1
10
100
Transport Ic (A)
T = 4.2 K
(a)
Position
(Ba,Na)Fe2As2 HIP wire
500 μm
T = 4.2 K
(b)
H (kOe)

WB6-1-INV

Recent development of high-performance Bi2223 superconducting tapes and joint technologies

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Aoyama Gakuin University[1]

Ag-sheathed Bi2223 multi-filamentary tapes have been extensively used in various practical applications, such as power cables, superconducting magnets and current leads, in these 15 years. High T_c above 110 K, large electromagnetic anisotropy substantially originated in the thick blocking layer, large plate-like crystals with wide *ab*-plane and easy cleavage along the *ab*-plane are well-known characteristic features of Bi2223 superconductors. Since the large electromagnetic anisotropy decreases effective pinning volume and changes vortex state being almost two-dimensional, flux pinning properties of Bi2223 tapes at high temperatures are intrinsically poor, resulting in low J_c compared to the RE123 coated conductors. On the other hand, the porous microstructure spontaneously forms in Bi2223 polycrystalline bulks due to anisotropic crystal growth of Bi2223. Even by applying the rolling in the middle of the fabrication process of Bi2223 tapes, crystal growth easily occurs during sintering which generates pores in the Bi2223 filaments. The over-pressure sintering under controlled oxygen partial pressure (CT-OP) developed by Sumitomo Electric Industries solved this problem and developed DI-BSCCO tapes show high homogeneity in critical current properties because of the highly dense Bi2223 filaments, which enabled us to improve poor flux pinning properties through systematic controls of starting cation compositions and sintering conditions. In addition, enhancement of mechanical strength of the DI-BSCCO tapes achieved by the composite of high strength alloys enlarged their magnet applications to high fields. The latest products of DI-BSCCO, their various physical properties and the recent challenges to increase J_c in magnetic field by an increase in actual lead concentration in Bi2223 crystals of DI-BSCCO will be shown. Moreover, development of superconducting joints connecting DI-BSCCO tapes will be also demonstrated as a hot topic. In this technology, establishment of low angle polishing process less than 1°for DI-BSCCO tape to increase in number of joined filaments of DI-BSCCO tapes was the first milestone. Followed by densification by addition of intermediate pressing process and control of cation composition of intermediate Bi2223 thick film layer resulted in high I_c joint between DI-BSCCO tapes[1]. Even for the superconducting joint connecting reinforced DI-BSCCO (type HT-NX) tapes, high I_c values, ~120 A at 77 K and 300 A at 4.2 K under 3 T, were achieved. Design of a superconducting magnet equipped with the persistent current circuit for the 1.3 GHz NMR system is undergoing under JST-MIRAI project (JPMJMI17A2). The superconducting joints connecting DI-BSCCO tapes will take an important role in the project.

[1] Y. Takeda *et al.*, *Appl. Phys. Express* 12 (2019) 023003

Keywords: Bi2223, superconducting joint, DI-BSCCO

WB6-2-INV

Developments of Ag-sheath Bi-2223 HTS wire at SEI

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Sumitomo Electric Industries, Ltd.[1]

Sumitomo Electric Industries, Ltd. (SEI) has developed and commercialized a Bi-2223 high-temperature superconducting wire and named it "Drastically Innovative BSCCO (DI-BSCCO®). After the over-pressure sintering method and the pre-tensioned lamination technique were introduced, critical current and mechanical properties of Ag-sheath Bi-2223 wire have been drastically improved, though further enhancement of their properties is necessary for promoting practical applications such as current lead, cable, magnet and motor applications. For the high field magnet application, reinforced wire partially applied for 25T magnet, which is available as magnet opening to the public at the Institute for Materials Research, Tohoku University. For the high field NMR, MIRAI project is underway to develop a magnet of 1.3 GHz (30.5 T) and reinforced wire partially applied for the magnet. For the current lead application, our low thermal conducting wires have been widely used for liquid helium cooling magnets and implemented the clinical MRI machine magnets. In the International Thermonuclear Experimental Reactor (ITER) project, current lead with current capacity of 68kA using our low thermal conducting wire was developed by the Institute of Plasma Physics, Chinese Academy of Sciences. We have developed a high-strength wire with critical tensile stress of 500MPa at 77K. The Ni reinforced wire was realized by increasing the thickness of the Ni reinforcing tape to 100 μm with the pre-tensioned lamination technique. Furthermore, in order to solve the problem of high splice resistance of wire that use Ni alloys, we developed a method of peeling off the reinforcement tape of the wire. By splicing with this method, we succeeded in reducing the splice resistance of 77K by 75% compared to the normal connection method.
In the presentation, the recent progress of Ag-sheath Bi-2223 wire will present.

WB6-3

Rolling characteristics of Bi-2223 tapes

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Rolling plays a very important role in the preparation of Bi-2223 tape by powder in tube (PIT) process. Through the study of the rolling process of single-filamentary Bi-2223/AgAu tape, it is found that tape width increases with the increasing of the deformation extent, reduction ratio per pass, roll diameter, tape strength and friction coefficient. The deformation of the filaments at different positions of multi-filamentary tape is inhomogeneous. According to the deformation extent of filaments, the cross section of the tape can be divided into thress areas, namely easy deformation zone, difficult deformation zone and free deformation zone. Increasing reduction ration per pass and roll diameter can increase the density and width of cores in different regions. However, the higher reduction ration per pass is, the more rough silver/ superconducting interfaces are. The results show that, using 300 mm rolls, 21-28% reduction ratio per pass not only ensure the full deformation of cores in each deformation zone, but also obtain a smooth silver/ superconducting interface, so a higher J_c is obtained.

Keywords: Bi-2223/AgAu tapes, Filaments width, Different deformation zone, Roller diameter

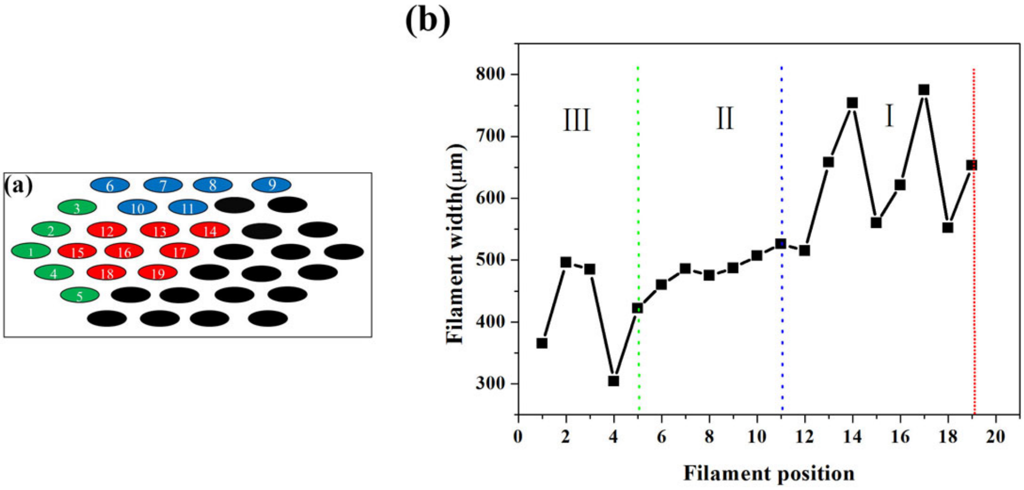

Fig. 1 (a) Filamentary number distribution and (b) filament width at different positions of 37-filament Bi-2223/AgAu tape

WB6-4

High-Speed Spin Testing of Bi-2212 Superconducting Wires for High-Field NMR Magnet Qualification: Final Progress Report

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This paper summarizes an NIH-funded research project designed to study the strength of high temperature superconductors under high circumferential hoop stress, in order to qualify these materials for high-field (> 1 GHz-class NMR magnets. The unique approach presented here is to spin test coils at high rotational speeds, approaching 50,000 rpm, in order to induce the necessary hoop stress. Bi-2212 wires and coils were tested in sub-cooled nitrogen, and additional small sample testing of critical current and magnetic hysteresis was performed to fully characterize these materials.

Keywords: Bi-2212, superconductor, coil, ac loss

WB6-5

Effect of nano ZrO_{-2} doping on the superconducting properties of $Ca_{0.86}Sr_{0.14}CuO_2$ added Bi 2223 composites

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Material science and technology division, NIIST, Thiruvananthapuram, Kerala 695019 INDIA[2]

(Bi,Pb)-Sr-Ca-Cu-O system is one of the multicomponent systems having a very complex phase diagram [1]. Large anisotropy, high flux creep, and poor grain connectivity make it difficult, especially for practical applications close to 77 K [2]. The processing conditions for Bi 2223 superconductors are challenging to optimise, due to the narrow temperature window of phase formation.

Bi 2223 suffers high flux creep as compared to YBCO and hence to make it usable for real applications, one needs to tune it by adding sufficient pinning centers without affecting the superconducting matrix so that enhanced critical current density (J_c) can be achieved at high temperatures and fields. The addition of the secondary phase helps in generating pinning centers of the suitable size to arrest the flux lines such that high J_c is maintained without any dissipation. Some reports in the literature suggest that the secondary phase deteriorates the superconducting properties in lieu of improving [3-4]. But this depends on whether the second phase reacts with the matrix phase.

$Bi_{1.2}Pb_{0.3}Sr_{1.54}Ca_{2.06}Cu_3O_{10+\delta}$ is the superconducting compound obtained from a series series $(Bi,Pb)_2Sr_2(Ca_{0.86}Sr_{0.14})_{n-1}Cu_nO_y$ [5], after normalizing to 3 Cu atoms. In the present work, we report a systematic work on $Ca_{0.86}Sr_{0.14}CuO_2$ (20 mol%) added Bi 2223 composites with x wt.% nano ZrO_2 addition. The concentration (x) of nano ZrO_2 particles is varied as 0, 0.5, 1, and 10 wt.%. From Fig. (a) given below, one can see that the Meissner fraction decreases systematically with the increase of nano ZrO_2 addition. All samples are superconducting as seen from the diamagnetic transitions. The T_c (Onset) for samples BZ 0- BZ 3 are around 105 K, while for the sample BW 4, it is around 80 K. The J_c vs B curves for all samples are shown in Fig. (b). J_{-c} at 20 K is the highest for sample BZ 1 and lowest for sample BZ 4. Results are correlated to the data on phase formation obtained from XRD studies. Detailed analysis of pinning mechanisms will be presented in the light of theoretical models in the literature.

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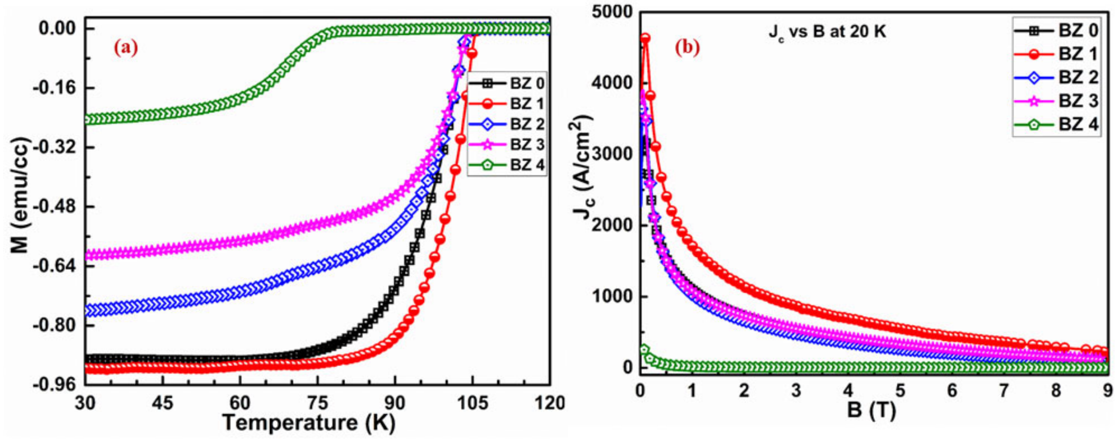
Acknowledgments:
Research funding from DST/SERB/ EMR/2016/006004 and facilities at School of Physics, UOH and at NIIST are acknowledged.

Figure Caption:

Figure: (a) Temperature dependence of magnetization for all samples showing T_c (Onset),
(b) Field dependence of critical current density(J_c) at 20 K showing non zero J_c till 9 T applied field

Keywords: ZrO2 nano particles, Pinning centers, Flux Pinning, Grain connectivity



WB7-1

Dynamic resistance of a REBCO bifilar stack carrying DC currents under perpendicular AC and DC bias fields

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Wuhan National High Magnetic Field Center, Huazhong University of Science and Technology, 430074 Wuhan, People's Republic of China[2]

Dynamic resistance of REBCO coated conductors (CCs) is one of the key parameters in some high-temperature superconductor (HTS) applications, such as field-triggered persistent current switches (PCS), flux pumps, fault current limiters (FCL), and rapid cycling synchrotrons (RCS). In these applications, REBCO CCs carry DC currents under AC and DC bias fields.

In this work, dynamic resistance in a REBCO bifilar stack has been studied at 77 K when carrying DC currents under combined AC and DC bias fields. The bifilar stack is assembled from two serial-connected REBCO coated conductors, cut from 2 – mm wide SuNAM wire. The transport DC currents vary from 10 A to 40 A with amplitudes of AC magnetic fields up to 350 mT and DC bias fields up to 300 mT. The frequency of AC magnetic fields ranges from 10 Hz to 50 Hz. The influences of these parameters on the dynamic resistance have been studied via experiments and coupled electromagnetic-thermal simulations using 2D H-formulation.

Our results show dynamic resistance of the bifilar stack increases with increasing DC bias fields, which we attribute to degradation of the critical current in the stack caused by the DC bias fields.

Keywords: Dynamic resistance, REBCO bifilar stack, REBCO coated conductors

WB7-2 Dec. 1 11:15-11:30 Characterization & Simulation

Abstract Topic : 2) Wires and Bulk (WB)

Study of AC-loss for REBCO coils winded by split wire using magnetic field simulation and magnetization measurement

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Muroran IT[1]

It is known that single-core REBCO-coated conductors has a large screening current induced magnetic field, therefore, a large AC-loss due to the magnetic hysteresis is generated in coils. Recently, we developed multi-core REBCO sprit wires with three methods, as V-bending, pressure concentration, and tearing. In results, magnetization was decreased above 70%, with reducing of area in hysteresis. This indicates that the AC-losses in REBCO-sprit wires were improved largely. Based on these results, we investigated the AC-loss in coil with magnetic field simulation of the coil. For the magnetic field simulation, the maximum magnetic field of each split wire in AC-circuit along vertical direction of tape surface was calculated by using FEM. And then, each AC-loss of turn in coil is obtained by using the magnetization measurement results. Finally, the AC-loss of entire coil was simulated and evaluated.As an example for magnetic field simulation, Fig. 1 shows the results of a maximum magnetic field distribution in a coil. The cross-sections of all sprit wires in a half of coil are shown by a square frame. This model of coil was calculated with an inner diameter of 80 mm, an outer diameter of 111 mm, and 61 turns. The peak current in AC-circuit is 30 A.

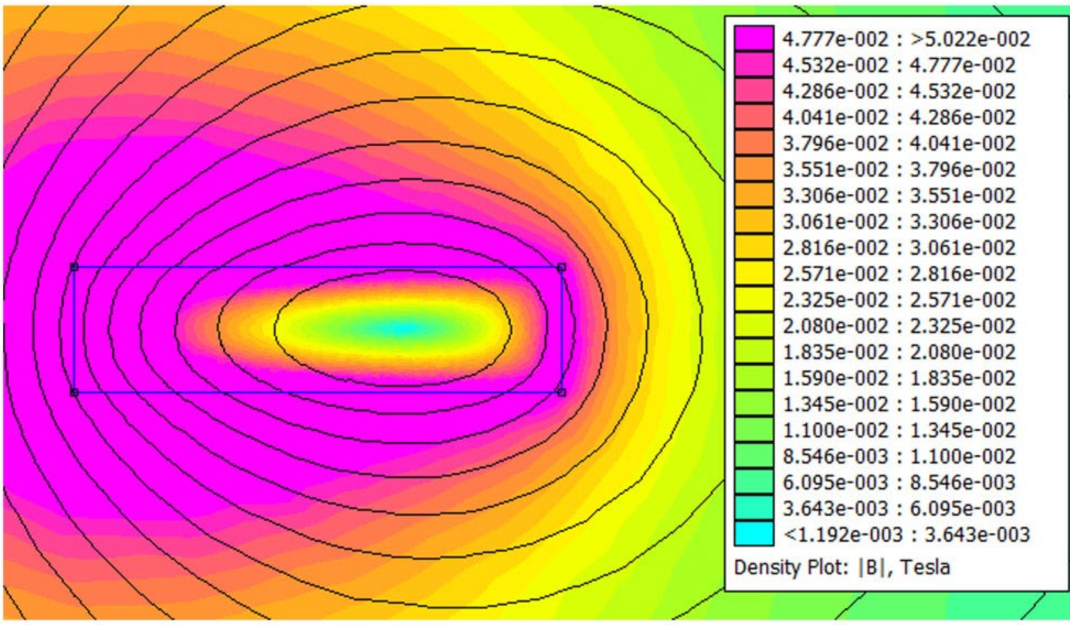

Fig.1 Magnetic field simulation for a coil

WB7-3

Performance evaluation of superconductive-assisted machining (SUAM) with superconducting tapes

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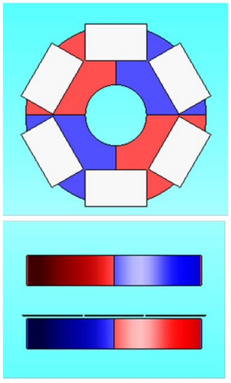
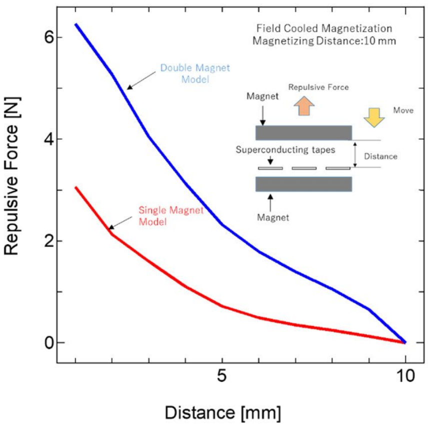
Kyushu Institute of Technology, Japan[1]

There are two types of hollow processing technology, one that processes before molding and the other that processes after molding. However, in hollow processing after molding, it is difficult to internally process an object which has a complicated shape. Therefore, SUAM (Superconductive-Assisted Machine) has been proposed in which a magnetic material is levitated to process an object by utilizing the magnetic flux pinning phenomenon of superconductors. In this study, we evaluated a new type of SUAM using double permanent magnets and superconducting tapes to obtain stronger repulsive force.

As shown in Fig. 1, the model of the SUAM has six superconducting tapes placed azimuthal at equal intervals from the center. Then, four layers similar to the upper layer of superconducting tapes were prepared under the superconducting tapes with the distances between the upper and lower layers at intervals of 100 mm. Then two permanent magnets were used. One was magnetized at the magnetizing position of 10 mm above the superconducting tapes. The other permanent magnet was magnetized at the magnetizing position of 1 mm bottom the superconducting tapes. Two permanent magnets are placed in a state of repulsion as shown in Fig. 1. And the repulsive force from the superconducting tapes to the permanent magnet magnetized at the magnetizing position of 10 mm above the superconducting tapes was calculated by using finite element method (FEM), when the permanent magnet was approached perpendicularly to the superconducting tapes. Then, the distance between the permanent magnet and the superconducting tapes was changed from 10 mm to 1 mm, i.e. the upper permanent magnet is approached to the superconducting tapes. Fig. 2 shows the FEM calculation results for a SUAM with double permanent magnets and a SUAM with single permanent magnet only at the above of the superconducting tapes. The results show that when there are double permanent magnets, the repulsive force is much greater than when there is single permanent magnet. This is because a repulsive force is generated between the permanent magnets by placing a permanent magnet with different magnetic poles under the top permanent magnet. Therefore, larger repulsive force by two permanent magnets and stable levitation by the superconducting tapes are achieved.





Keywords: Double permanent Magnet, SUAM(Superconductive-Assisted Machine)

WB7-4

The magnetic levitation of superconducting bulk magnet stacked with HTS tapes

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Cryogenic Apparatus Research Center, Korea Electrotechnology Research Institute, Korea[1]
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Advanced transfer systems have been needed for high-tech industries such as bio, pharmaceutical, semiconductor, etc. that are possible to improve the production yield and get rid of failure by keeping down the dust and vibration during the operation process. To solve this problem, a high-clean, non-contact transfer system has been proposed, but commercialization has been delayed due to lack of levitation force and difficulty in transport control.
In this study, in order to achieve higher levitation force, superconducting bulk magnets fabricated by stacking high temperature superconductor (HTS) coated conductors (CCs) are used instead of the conventional sintered HTS bulk. Because superconducting bulk magnets stacked with HTS CCs have various advantages, such as relatively high and homogeneous levitation performance by using HTS CCs with high critical current density, high mechanical properties by alternative stacking structure with a metal substrate and ceramic superconducting layer, etc.
Details will be presented for the discussion including (1) stacking technology, (2) levitation force measurement, and (3) trapped magnetic field distribution of superconducting bulk magnets.

Keywords: HTS CCs, Bulk magnet, Stacking technology, Levitation force

WB8-1-INV

Unique Magnetic Field Generators of Cryocooled Superconducting Bulk Magnets and Their Industrial Application

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The high-temperature superconducting bulk magnets synthesized by the heat treatment process can trap the applied magnetic field, behave as quasi-permanent magnets. The magnetic properties follow the principle of solenoid coils rather than conventional permanent magnets. Superconductivity is elevated as the temperature decreases, so by using a refrigerator to cool the magnet below the liquid nitrogen temperature, the magnetic field intensity far exceeds that generated by permanent magnets and copper coils, which is comparable to that of superconducting solenoid magnets. Applications of bulk magnets can be classified into passive applications that utilize magnetic levitation force against an external magnetic field and active ones that trap strong magnetic fields by magnetizing them. These are unique applications available only with superconductivity. Magnetic separation and NMR magnets are given as examples of active applications. The application to magnetic separation is characterized by its strong magnetic field gradient, which effectively separate weak magnetic substances without using any filters. In actual, paramagnetic hematite was successfully separated from its suspended water using the magnetic field on the magnetic pole surface. 8kg/day of nickel sulfate powder was separated from the waste liquid of the nickel-plating process, demonstrating the practicality of resource recovery. On the other, we succeeded in detecting NMR signals for the first time in the world in a highly stable magnetic field space on the single pole surface, which experimentally demonstrated that the bulk magnets can be used for NMR analysis instruments.

Keywords: superconductor, cryocooler, magnetic separation, NMR magnet

WB8-2

Pulse field magnetization of multiple high-temperature superconducting bulks

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After magnetization, high-temperature superconducting (HTS) bulk materials can trap strong magnetic fields. Despite the relatively small size of HTS bulks, the peak trapped magnetic field can be stronger even than permanent magnets and electromagnets. Strong magnetic fields are very useful in industrial applications because they can increase the power output of rotating machines for generators and propulsion, or make them smaller. If the field poles of the rotating machine are replaced by magnetized HTS bulk from permanent magnets, the power output of the rotating machine can be increased due to the increased peak magnetic field. In that case, however, the size of HTS bulk is a limitation of the total flux of the machine. Increasing the total magnetic flux will increase its power output, without changing the size or weight. Thus, the use of large HTS bulks would be beneficial but their manufacture is challenging due to the limitations of the single-seed melt-growth process. Alternatively, multi-seeded melt-growth techniques are available. But multi-seeded bulks often have limitations in field trapping capabilities compared to single-seeded bulks. Instead of increasing the size of the HTS bulks, increasing their number is a possibility. Aggregating many bulks together can increase the total magnetic flux. Arranging several smaller bulks together is also useful to scale and shape large field poles. We have previously fabricated a prototype rotating machine with a larger total magnetic flux by integrating multiple HTS bulks in a two-dimensional array and obtained excellent power characteristics [1]. However, the method of magnetizing the bulk is an important issue, since a high magnetic field must be confined to the HTS bulk inside the fully assembled rotating machine before it can be used. The magnetization of an array of bulk is challenging. Until now, the experimental magnetization of arrays of bulks has been mainly done using field-cooling (FC) magnetization. This technique requires large superconducting magnets and a long magnetizing time. FC is consequently limited for practical use because it is structurally and costly impractical to allow for the magnetization of HTS bulks by the large superconducting magnet that individual rotating machines have inside. In contrast, pulsed-field magnetization (PFM) is the magnetization method that can solve the major problems caused by FC. Unlike FC, PFM, which is realized by small and inexpensive devices, relies on the application of a short magnetic field pulse. Due to the rapidity of PFM, with the magnetic field usually reaching several tesla and lasting several hundred milliseconds, copper magnetizing coils are suitable to apply the pulsed magnetic field. Copper coils should be cooled to withstand excessive pulsed currents, however, fundamentally don't need the same cryogenic system as superconducting magnets. So, the magnetizing equipment can be smaller and less than 1/10 of the price of FC equipment. Yet, a major problem subsists, which is the method of magnetization. The use of a PFM technique to magnetize multiple HTS bulks has been little studied, particularly in the case of HTS bulk arrays with non-alternate polarities. In this presentation, we show the experimental results of the magnetization of multiple GdBaCuO bulks using a PFM technique. Three square superconducting bulks have been arranged to reproduce a part of the internal design of our HTS motor [1]. The HTS bulks and coils are cooled to a temperature of 77 K by liquid nitrogen. We show the experimental results of the trapped magnetic flux density in the bulk array by PFM obtained using a prototype of magnetizing coil that we have fabricated for the bulk array. Since the magnetization sequence is important for the trapped magnetic field and the geometry of the coil and bulks, we discuss it based on our experimental results.

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Keywords: Pulsed-field magnetization, Multiple bulk superconductors, High-Temperature superconductor, Rotating machine

WB8-3

Effect of Iron yoke geometry on pulse field magnetization behavior of superconducting jointed Gd-Ba-Cu-O bulk superconductor

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We have fabricated a superconducting jointed Gd-Ba-Cu-O bulk superconductor by employing the local melting method and investigated the effect on pulse field magnetization (PFM) behavior. In this study, we will report the effect of the iron yoke geometry which placed on the coil side during PFM on the magnetization behavior.

It is possible to fabricate a high-quality superconducting jointed Gd-Ba-Cu-O bulk superconductor by employing the local melting method with a Er-Ba-Cu-O superconducting thin plate having a slightly lower melting point. The superconductor joint method enables the fabrication of larger bulk and complex shapes, which have been difficult to achieve in the past.

The PFM method has an advantage that the magnetization in an equipment is possible, compared to the field cooling magnetization method in a magnetic field. However, in case of PFM method, it is difficult to obtain a high trapping magnetic field due to the heat generation caused by rapid magnetic flux motion during PFM. Therefore, we have suggested that controlling the J_c-B property of the superconducting jointed part may disperse the heat generated during PFM and improve the efficiency of pulse magnetization. Here, Yokoyama et al. reported that the possibility of improving the trapped magnetic field of a bulk superconductor with defects by changing the shape of the iron yoke during PFM [IEEE Trans. Appl. Supercond., 2020].

In this study, we apply this technique to a superconducting jointed Gd-Ba-Cu-O bulk superconductor and report the effects of changing the width and orientation of the iron yoke on the magnetizing properties during PFM.

Keywords: Bulk superconductor, Superconductor Joint, Pulse magnetization, Trapped magnetic field

WB8-4

Orientation degrees in Dy123 powders by using Linear-drive type Modulated Rotating Magnetic Field system.

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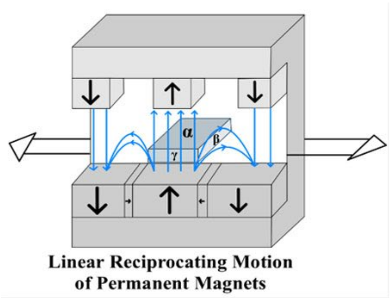
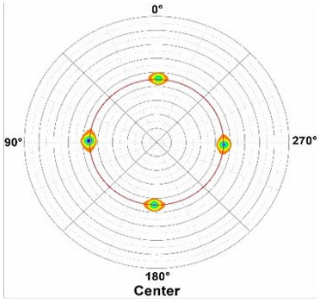
Due to their high critical temperatures (T_cs), rare-earth (RE) based cuprate superconductors are promising candidates for use in liquid-nitrogen-operated superconducting bulk magnets and cables. But their anisotropic crystal structures, which have alternating superconducting CuO_2 layers and stacked layers of Cu-O chains, cause their critical current densities (J_cs) to be anisotropic within the crystal structure, J_c//c < J_c//ab. Furthermore, the inter-grain J_c is drastically reduced even for the c-axis oriented RE123 grains as the misorientation angle between them increases. For RE-based cuprate superconductors, tri-axial grain orientation is a serious issue for increasing the J_c. Thin film growth and melt-solidification processes based on epitaxial growth have been used in practice. Magnetic alignment is a bi-axial or tri-axial alignment process, and it is a non-vacuum process and can be done at ambient temperature. Permanent magnets can be a desirable choice for making the modulated rotating magnetic field (MRF) at a low cost and aligning HTSC in three-dimensional. Fig. (a) shows a schematic figure of a linear drive type modulated rotating magnetic field (MRF). The specimen with the sheet shape in Fig (a) is in the rest position, the permanent magnet array moves in a linear direction over the sample. Although introducing rotating magnetic fields into a linear production process is difficult, the present system that produces an MRF without moving the sample increases the adaptability of magnetic alignment as a material continuous production process. Initially, the sample was placed in the center of the array, α-plane was perpendicular to the linear motion of the unit. In principle, the first and second easy axis and the hard axis of magnetization are normally oriented to the α, β, and γ planes. This equipment employs a permanent magnet array composed of Nd-Fe-B to produce a static magnetic field (SF) and a rotating magnetic field (RF) up to 0.9T. Furthermore, fully oxidized Dy123 powder with a twin microstructure was aligned at ambient temperature in epoxy resin. To investigate the orientation degrees, the α-plane of the magnetically aligned samples of Dy123 was examined by an X-ray pole figure. Before explaining the pole figure results of the aligned sample of Dy123 under the MRF, I would like to explain the size of the sample. As aligned samples have dimension of $10mm^D$ x $2.8mm^W$ x $10mm^H$. To clarify the position-dependent orientation degrees, the aligned sample was cut into 3 different parts; the center part dimension is $4mm^D$ x $2.8mm^W$ x $4mm^H$, while the dimensions of the two different side parts are $3mm^D$ x $2.8mm^W$ x $10mm^H$ in the direction of linear-reciprocating motion of the magnet. The XRD patterns of α, β, and γ of the magnetically aligned sample of Dy123 in epoxy resin under the linear-drive MRF were measured. Before cutting, the XRD pattern at the α-plane indicates that the first easy axis (c-axis) was aligned at ambient temperature. In the XRD patterns of the β and γ planes, the coexistence of the (h00) and (0k0) peaks appeared, which can be understood in terms of the presence of twin-microstructure in the ab-plane of Dy123. In the pole figure of the (103) plane, we observed four different diffraction spots in circumferential symmetry. Figure (b) shows the pole figure result for the magnetically aligned Dy123 sample before cutting. In detail, four-fold symmetric spots are located at 45 degrees. These four distinct diffraction spots are because of the bi-axially oriented twin microstructure. Due to the twin microstructure, the slightly broadened four peaks can be attributed to a loss in magnetic anisotropy. The average FWHM value of these four peaks was ~10 degrees. Figure (c) shows the (103) pole figure of the center part, four-fold symmetric spots are located at 45 degrees, but the four peaks were sharpened and the FWHM value was changed to ~8 degrees. It is strongly suggested that the magnetic flux of the magnetic array is not uniform over the sample. In the current study, we found that the improvement of the spatial distribution of the magnetic flux over the sample was required, for this 3-D simulation work might be useful for analysis of the spatial distribution between the lower and upper arrays as future issues to be overcome. The in-plane orientation degree depends on the position of the sample, which is why the center part shows less broad peaks. Moreover, the side parts of the samples show a more tilted in-plane orientation degree, which verifies the statement of location dependence. The X-ray (103) pole figure of the side parts will be shown in the presentation.

Keywords: Magnetic anisotropy, Triaxial Alignment, Superconductor





(a) (b) (c)

WB8-5

In-situ, low-temperature synthesis and properties of polycrystalline $Ba_{0.6}K_{0.4}Fe_2As_2$ bulk superconductors

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Since the discovery of iron-based (IBS) superconductors in 2008, research has been conducted intensively on fundamental properties for potential applications. Several families such as REFeAsO, $AEFe_2As_2$, AFeAs, $AEAFe_4As_4$ (RE = rare earth, AE = alkali or alkali earth, A = alkali metal) etc., were developed in IBS and optimally doped $(Ba_{0.6}, K_{0.4})Fe_2As_2$ (BaK122) is considered to be superior owing to the high superconducting transition temperature and high critical current density. Meanwhile, there are some difficulties in sample preparation such as unwanted reactions of IBS with various dopants limiting their potential applications. In the present work, we address this problem and developed a novel in-situ and low-temperature synthesis method of polycrystalline BaK122 samples by addition of Sn. Studies of x-ray diffraction indicated the phase formation of BaK122 at 500 °C with the 10 wt. % Sn addition and we have successfully reduced the phase formation temperature of about 250 °C. The microstructural features investigated by the scanning electron microscopy indicated the grain sizes of BaK122 synthesized via our low-temperature method are relatively smaller compared to conventionally produced and are about 1.5 μm. All samples indicated onset of bulk superconductivity up to 37 K. In this presentation we will also address the optimization of synthesis conditions and their influence on the structural, microstructural, composition variations and superconductivity of polycrystalline BaK122 bulks.

Keywords: IBS, Phase formation, Critical tempreture, X-ray diffraction

WB8-6

Trapping Magnetic Field in a Bulk Iron-based Superconductor Sintered under High Pressure

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Superconductors with a large critical current density (J_c) can trap a high magnetic field when their powders are pressed into bulk and sintered, which could be used as superconducting magnets. In this work, we attempted to improve the J_c characteristics and trapped field of bulk iron-based superconductors by increasing the pressure used in the manufacturing process. In this work, we attempted to improve the J_c and the trapped field of bulk iron-based superconductors by increasing the pressure used in the manufacturing process. In the present study, we prepared a cylindrical bulk polycrystalline $Ba_{0.6}Na_{0.4}Fe_2As_2$ superconductor with a diameter of 3.9 mm and 2.06 mm in thickness. Polycrystalline powder was synthesized by the mechanochemical method as described in Ref. [1] and was sealed in a silver tube with an inner diameter of 4 mm. A cold press process was performed in the glove box to texture the grains along *c*-axis. The sample was then put into a cubic press and sintered under a pressure of ~2.2 GPa at ~850 ℃ for 1 hour. The critical temperature of this bulk is ~33 K. A Hall probe was set at the position *z* ~0.38 mm from the bottom surface of the bulk to measure the trapped field as shown in the inset of Fig. 1(a). Measured magnetic induction at 4.2 K as a function of the applied field is shown in Fig.1 (a). In the remanent state, measured magnetic induction is ~3,718 G. J_c under the self-field is estimated by Biot-Savart approximation [2] to be ~65.9 kA/cm^2, which is larger than that in the previous work [3] but lower than the value in high-quality wires [1]. The trapped field on the surface of the bulk was finally calculated by the same approximation to be ~7,200 G. From XRD result measured on the top surface of the bulk (Fig. 1(b)), it can be seen that the ratio between the intensity of (002) peak and that of (103) peak increased from ~1/5 in random powder to ~1/3 in the bulk, suggesting that grains are textured along *c*-axis. However, this ratio is still much lower compared with the result in well-textured tapes [4]. We will next try to use higher pressure for the cold pressing to enhance the texturing and to further improve J_c and trapped field.

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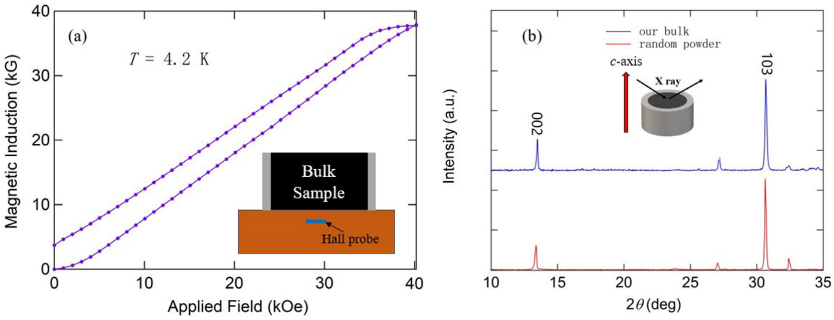
Figure 1 (a) Magnetic induction close to the surface of the $Ba_{0.6}Na_{0.4}Fe_2As_2Ba_{0.6}Na_{0.4}Fe_2As_2$ bulk sample measured by a Hall probe as a function of applied field at 4.2 K. (b) X-ray diffraction patterns of the bulk sample and reference randomly-oriented powder.



Keywords: iron-based superconductor, bulk magnet, high-pressure sintering

WB8-7

Bulk (Y, Gd)$Ba_2Cu_3O_{7-?}$ single-grain superconductors growth by the addition of sharp-edged Gd_2BaCuO_5 particles

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RE$Ba_2Cu_3O_{7-\delta}$ (*RE*BCO/*RE*123, *RE* = rare earth elements) superconductors have a wide range of applications due to their high superconducting transition temperature (T_c) of ~92 K and excellent field trapping capabilities. This is very important for developing next-generation high-magnetic field applications, which depends on the magnitude of critical current density (J_c) and how well the magnetic flux motion due to the Lorentz force is suppressed. This can be achieved by dispersing pins such as RE_2BaCuO_5 (*RE*211) particles or other nanometer-sized defects in the superconducting *RE*123 matrix. Recently, we have demonstrated that high-energy ultrasound irradiation effectively controls the initial *RE*211 ($RE211_{Ultra}$) particle size. By employing the $RE211_{Ultra}$ particles, the J_c and trapped fields of various REBCO single-grain bulk superconductors were improved.

In this study, for improving the 123-matrix pinning, (Y_{1-x}, Gd_x)$Ba_2Cu_3O_{7-d}$ (YGdBCO) superconductors were synthesized via top-seeded melt growth method by the addition of 20 mol% of ultrasonically pre-treated (with 450 W for 30 min) Gd211 particles. *S*ystematic isothermal experiments were conducted at various constant temperatures (from 1020 °C – 990 °C) indicating that a safe growth window for fabricating large YGdBCO bulk single grains is 1015 °C – 990 °C. The microstructural and composition studies (mapping, line scan and point scans) performed via electron microscopy and energy dispersive spectroscopy on YGdBCO samples indicated that the inclusion of the Y211 phases wrapped in Gd211 particles. All YGdBCO samples exhibited superconductivity above 92.5 K. A maximum of 74.1 kA/cm^2 at 77 K and self-field was achieved in the YGdBCO sample grown at 1000 °C. Further, we will outline the relation of the developed microstructure and superconducting properties dependence on the isothermal growth temperature.

Keywords: (Y, Gd)Ba2Cu3O7-?, single-grain, ultra sonication, microstructure

WB8-8

Critical current densities in multiple positions in a commercial YBaCuO bulk

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The progress of the melt growth synthesis technique for preparing superconducting REBaCuO bulks allows the production and commercialization of a single crystal with a diameter of 10 cm. This is in good agreement with the development of new applications such as electrical motors where superconducting bulks are used as trapped field magnets or magnetic shields [1], [2].

It is then crucial to determine the superconducting properties such as the critical temperature, critical current density and irreversible magnetic field which is commonly done with the help of an MPMS-SQUID on a millimeter-size sample. However, the inhomogeneity of performances has been reported on a bulk [3], which highlights the necessity to measure the critical properties in multiple positions along the sample radius either in a grain sector or along a grain sector boundary.

We propose a simial work with a characterization carried out on a 10 cm wide commercial bulk after machining for use as magnetic shields [1]. 24 rectangular samples have been extracted in a different position from the bulk's center, prepared and measured on a 14 T MPMS with a VSM head. Then a comparison of the superconducting properties of each sample will be presented along with trapped field measurement done on 10 other wide YBaCuO bulks. Finally, this will allow a discussion on the readiness of this technology and its possible future development and it will point out the necessity to measure the superconducting properties in different positions.

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[3] V. Antal *et al.*, « Relationship between local microstructure and superconducting properties of commercial YBa2Cu3O7- δ bulk », *Supercond. Sci. Technol.*, Feb. 2020.

Keywords: Superconducting Bulks, Magnetic Characterization, YBaCuO, Critical current density

WB8-9-INV

Large bulk superconductors – is jointing the solution?

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TSMG bulk superconductors have the singular advantage over conventional permanent magnet material that the maximum trapped field scales linearly with sample diameter. Unfortunately, there are a number of challenges to growing large samples including the relatively slow growth rate and deterioration in texture, and thus critical current, far from the seed. As the potential range of applications of bulk superconductors as pseudo-permanent magnets increases the importance of being able to create larger samples has become progressively more apparent.

In the coated conductor area of research joints are now seen as a key technology. In this talk I will discuss the potential for superconducting joints in superconducting bulks. I will review work in this area since the inception of the field and discuss recent work carried out in this area by the Cambridge group and collaborators in jointing bulk superconductors.

Keywords: Jointing, Bulk Supercondutors, Cuprate

WB9-1-INV

Transient Liquid Assisted growth (TLAG): a novel method to increase Coated Conductors throughput

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$REBa_2Cu_3O_7$ (REBCO CC) coated conductors are a unique opportunity to achieve high currents at high magnetic fields where other materials cannot compete, especially in the emerging sectors for energy transition, including fusion, and high energy physics with high field magnets. Much effort has been devoted in recent years to increase yield, high-throughput, and overall decrease cost/performance ratio of REBCO CC manufacturing processes. We believe that our novel growth approach, entitled "Transient Liquid Assisted Growth (TLAG)" [1,2], which utilizes chemical solution deposition (CSD), can become a very competitive high-throughput and cost-effective fabrication method, because ultra-fast growth rates, beyond 1000 nm/s, are reachable by tuning the non-equilibrium transient liquid [3]. We have proven that TLAG has a wide working window compatible with the growth of nanocomposites and coated conductors with critical current densities of 3 MA/cm^2 at 77K. Besides, very reproducible thick pyrolyzed layers showing nanocrystalline and very homogeneous microstructure can be fully decarbonated, at least up to 3 μm.

TLAG is a very non-equilibrium process where kinetic parameters have a strong influence on nucleation and growth, which implies that very solid and reproducible conditions are desired. Consequently, we developed a robust, facile and very reproducible colloidal ink [4] to control the supersaturation degree during growth, and we determined the correlation of the kinetic parameters of the process with epitaxy and growth rate. The use of fast acquisition in situ XRD imaging (<100 ms/frame) under synchrotron radiation, transmission electron microscopy, in situ resistivity experiments, and angular transport measurements have been crucial for this study.

In this presentation, I will discuss the current understanding of the TLAG process, relevant process parameters for growth of CC, and the relevance of the kinetic phase diagrams to guide us through the extreme non-equilibrium TLAG mechanisms [3]. Advances in growth rates, correlation between growth and properties, and richness of vortex pinning capabilities of films and nanocomposites will be discussed.

We acknowledge funding from EU-ERC_AdG-2014-669504 ULTRASUPERTAPE, EU-ERC-PoC-2020-IMPACT, EU-ERC-PoC-2022-SMS-INKS, CSIC-TRANSENER-PTI+, MICIN-SUPERENERTECH

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Keywords: Growth , critical current, REBCO, nanocomposite

WB9-2

The influence of large quantities of nanoparticles on J_c for TFA-MOD $(Y_{0.77}Gd_{0.23})Ba_2Cu_3O_y$ CCs

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For high critical current density (J_c) in a magnetic field, we have improved the J_c of trifluoroacetate metal organic deposition (TFA-MOD) $(Y_{0.77}Gd_{0.23})Ba_2Cu_3O_y$ by introducing various incoherent $BaMO_3$ (BMO: M = Sn, Zr, Hf) nanoparticles (NPs) [1-4]. Especially, 12vol.% BHO doped (Y,Gd)BCO coated conductors (CCs) show the highest self-field and in-field J_c compared to that of other CCs [3]. However, the influence of large quantities of BHO NPs on the superconducting properties of (Y,Gd)BCO+BHO CCs has not been clarified.
In this work, to study of the influence of large quantities of BHO NPs on the superconducting properties over a wide temperatures range (26 - 77 K), we fabricated (Y,Gd)BCO CCs with different BHO nanoparticle additions. (Y,Gd)BCO CCs doped with over 16 vol.% BHO have slightly lower crystallinity and self-field J_c compared to the other CCs. As a result, the in-field J_c for CCs doped with large quantities of BHO is lower than that of 12 vol.% doped CC. Detailed microstructural and superconducting properties will be presented.

Acknowledgements: This work was supported by JST-FOREST (Grant Number JPMJFR202G, Japan). A part of this work was supported by JSPS KAKENHI (18KK0414 and 20H02184).

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WB9-3

Film thickness dependence of J_c for $(Y_{0.77}Gd_{0.23})Ba_2Cu_3O_y$+$BaHfO_3$ CCs

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Practical applications, such as MRI, generators and motors, require high critical current (I_c) in a magnetic field. For this reason, increasing the film thickness *d* and enhancing flux pinning are extremely important. So far, we have succeeded in obtaining high in-field I_c by controlling the *crystal growth rate and* introducing $BaZrO_3$ nanoparticles (BZO NPs) into trifluoroacetate metal organic deposition (TFA-MOD) grown $(Y_{0.77}Gd_{0.23})Ba_2Cu_3O_y$ ((Y,Gd)BCO) coated conductors (CCs) [1]. Recently, we have reported more improvement of the in-field critical current density (J_c) by introducing $BaHfO_3$ (BHO) NPs instead of BZO NPs [2-4]. However, the influence of the film thickness dependence of the in-field J_c and of the microstructure of (Y,Gd)BCO +BHO CCs is not clear.

In this work, to investigate the film thickness dependence of J_c at various temperatures (85, 77 and 65 K), we prepared standard (Y,Gd)BCO and 12 vol.% BHO-doped (Y,Gd)BCO CCs with various thicknesses. For all thicknesses, films and temperatures, (Y,Gd)BCO+BHO CCs show a higher J_c compared to that of YGdBCO CCs. Despite the fact that for thinner films J_c decays rapidly with increasing thickness (), for thicker films the J_c value is almost constant. This thickness dependence of J_c may be caused by the change of depensation of pinning (2-dimensional pinning in thinner films and 3-dimensional pinning in thicker films). Detailed experimental results for nanocomposite (Y,Gd)BCO CCs will be presented.

Acknowledgements:
This work was supported by JST-FOREST (Grant Number JPMJFR202G). A part of this work at Seikei University was supported by JSPS KAKENHI (20H02184).

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WB9-4

Enhancement of critical current densities by co-doping with Ce and Zr for Gd123 thin films fabricated by fluorine-free MOD method

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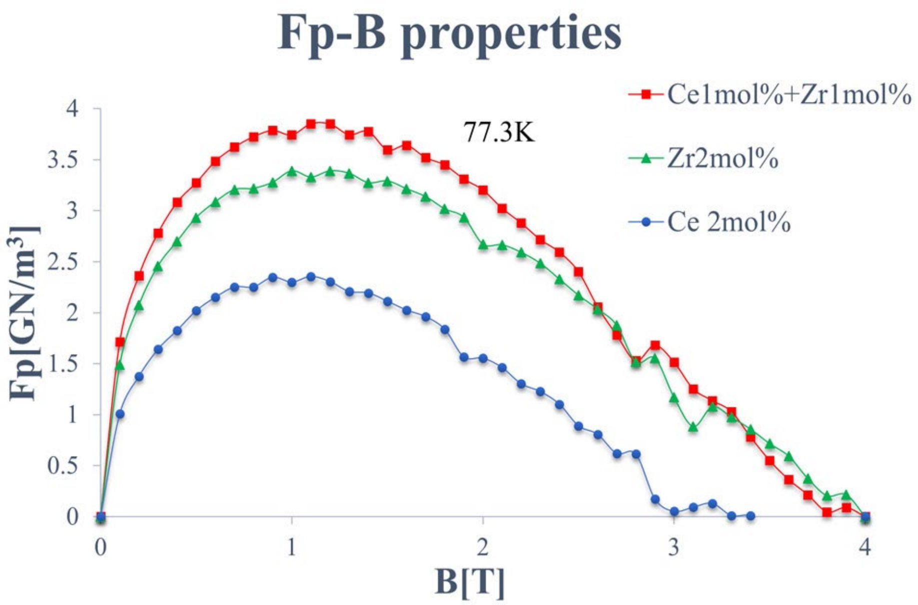
We have fabricated Gd123 thin films with Ce and Zr added at the same time by the fluorine free metal organic deposition method. When different BMO_3-type artificial pinning centers (APCs) are generated simultaneously, they considered to share the Ba used for APC growth. Therefore, it is expected that APCs size is more decreased. In this study, we selected Ce and Zr as doping elements, and fabricated three samples with the same amount of APCs added. As a result, the maximum pinning force density of the co-added sample was 1.6 times higher than that of the single BMO_3 sample at 1T under77.3K.

Keywords: FF-MOD, Re123, APC co-dope



WB9-6

Transmission Electron Microscopy Analysis of High Current Density REBCO Superconducting Thin Films and Coated Conductors Grown by Ultrafast Transient Liquid Assisted Growth (TLAG)

*Kapil Gupta[1], Lavinia Saltarelli[1], Albert Queraltó[1], Roger Guzmán[1], Laia Soler[1], Júlia Jareño[1], Juri Banchewski[1], Silvia Rasi[1], Diana Garcia[1], Valentina Roxana Vlad[1], Aiswarya Kethamkuzhi[1], Joffre Gutierrez[1], Susagna Ricart[1], Cristian Mocuta[2], Xavier Obradors[1], Teresa Puig[1]

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Among high temperature superconductors (HTS), cuprate superconductors ($REBa_2Cu_3O_{7-\delta}$ (REBCO, RE = rare earth)) have garnered most research efforts in large-scale superconducting power applications and high field magnets due to their high critical temperature (~ 92 K) and outstanding ability to carry high critical currents at high magnetic fields owing to the high irreversibility line. A limiting factor in its implementation is the need of high performance/low-cost manufacturing of epitaxial films, for which, chemical-solution deposition (CSD) has become a very competitive cost-effective and scalable methodology [1]. However, slow growth rates (0.5-1 nm/s) are one of the main obstacles for CSD to become a high through-put process. For this purpose, we have developed a novel fluorine-free growth approach, entitled, Transient Liquid Assisted Growth (TLAG) [2,3], which is able to combine CSD methodologies with ultra-fast growth rates (100-1000 nm/s) by facilitating a non-equilibrium liquid-mediated approach. Critical current densities up to 5 MA/cm^2 at 77K are already realized in TLAG-CSD grown thin films, but in order to further improve the current carrying properties, understanding of initial nano precursor phases in the pyrolysis process and fine tuning of growth parameters are essential to define a robust process and thicker REBCO layers [4]. Therefore, the microstructure of multi-deposited pyrolyzed and grown YBCO films, investigated via high-resolution transmission electron microscopy (HR-TEM), scanning transmission electron microscopy (STEM), electron-energy loss spectroscopy (EELS) and energy-dispersive X-ray spectroscopy (EDX), will be presented. In addition, a phenomenon of re-orientation of homogeneous to *c*-axis heterogeneous epitaxial growth of YBCO, observed during TLAG, will also be discussed.

Furthermore, the control over the YBCO film microstructure is essential to enhance the critical current-density capabilities. This can be achieved by the presence of well-controlled nano-defects inside the epitaxial superconducting matrix acting as vortex-pinning-centers. We found that the microstructure of pristine YBCO films could be tuned significantly via TLAG-CSD by optimizing different growth parameters. Besides, the addition of secondary phase nano-inclusions can also increase flux-pinning at high fields by incorporating pre-formed nanoparticles to the metal-organic inks [2]. Therefore, the detailed microstructure of REBCO films, REBCO nanocomposites, and coated conductors with varying growth parameters on different substrates investigated via HR-TEM, EELS, and using aberration-corrected STEM combined with high-angle annular dark field (HAADF), will be discussed in detail. Additionally, the capability of TLAG to augment other physical growth processes (e.g, pulsed laser deposition, PLD) and provide growth rates of more than two orders of magnitude higher than standard PLD growth of REBCO films has been attained [5], so, its microstructural study will also be discussed.

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[2] L. Soler et al, Nat. Commun., 11, 344 (2020)

[3] S. Rasi et al, Adv Sci, 2203834 (2022)
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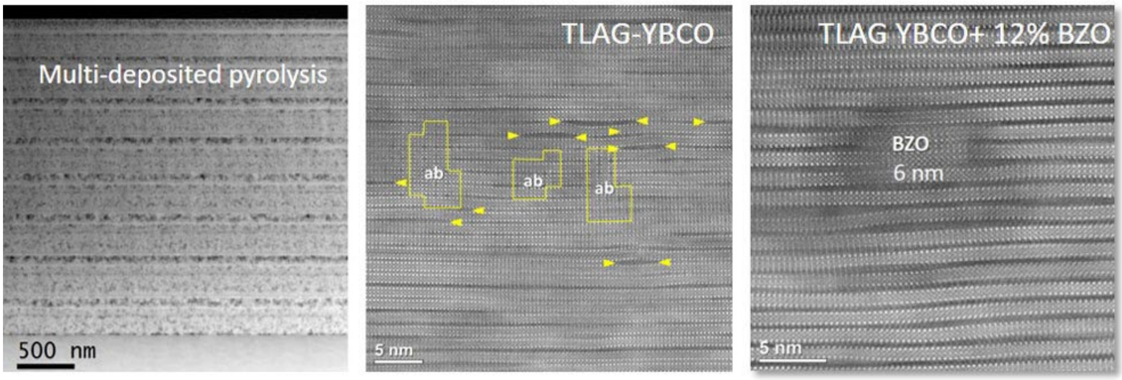
[5] A. Queralto et al (submitted)

Keywords: REBCO, TLAG-CSD, TEM, Superconductivity



WB9-7

Superconducting $YBa_2Cu_3O_{7-\delta}$ nanocomposite films grown by TLAG-CSD from functional colloidal inks

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The growth of Chemical Solution Deposition (CSD) nanocomposites from precursor solutions containing metal preformed nanoparticles has recently proven to be a very good pathway developing low cost $YBa_2Cu_3O_{7-\delta}$ (YBCO) superconducting layers carrying high currents at high magnetic fields by pinning vortices at none superconducting nanoscale defects [1][2].

In our work, we are able to synthesize binary metal oxide NPs using a 2 steps process called hybrid hydrolytic-solvothermal synthesis (H2S2). In the presence of a polyol as surfactant, we have synthesized small-sized, crystalline, monodisperse and stable $BaMO_3$ NPs (M= Zr, Hf). We are able to tune their size in a range of 4 - 20 nm, controlling the hydrolysis step involved in the reaction mechanism [3]. On the other hand, combine H2S2 process with a post-synthetic surface functionalization we have obtained, for the first time, small-sized (4-6 nm) and agglomeration-free BaM_2O_6 NPs (M= Nb, Ta).

These NPs are being used for the preparation of superconducting nanocomposites using the non-equilibrium ultrafast Transient Liquid Assisted Growth (TLAG-CSD) process. We have developed a fluorine-free functional colloidal ink adapted to TLAG-CSD nanocomposites able to achieve very homogenous and reproducible multideposited films. We have demonstrated the compatibility and stabilization of the colloidal ink, obtaining homogenous pyrolyzed films with crystalline NPs, homogenously distributed without coarsening. Finally, we have further proved the compatibility and chemical/thermal stability of NPs with the TLAG approach [4] and through In-situ synchrotron X-ray diffraction we determined the kinetic process parameters strongly influencing the TLAG growth process. The kinetic phase diagrams developed from In-situ XRD experiments [5] have allowed us to achieve epitaxial YBCO multideposited TLAG nanocomposites obtaining Jc results of 2-2.5 MA/cm^2 at 77 k for 400 nm of thickness with smooth Jc(H) curves provided by NP pinning at the fast growth rates of even 1300 nm s^{-1}.

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Keywords: Superconducting Nanocomposite Films , Colloidal Inks , Chemical Solution Deposition,

Transient Liquid Assisted Growth

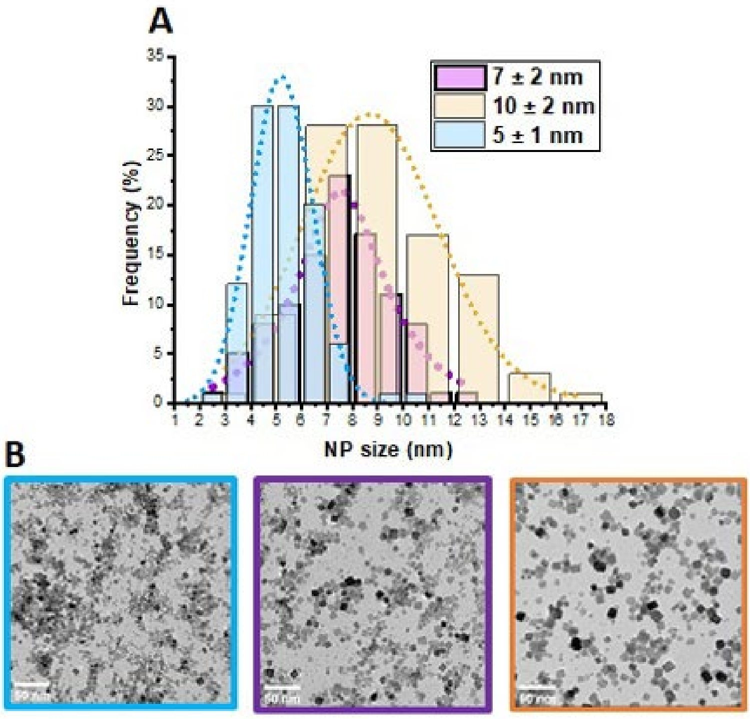

Figure 1. A) Size distribution (histograms) of $BaZrO_3$ nanoparticle solutions of different sizes from B) transmission electron microscopy (TEM) images to show the tuning of NC size

WB9-8

Novel class of metalorganic fluorine-free solutions for tunable liquid composition in the Transient Liquid Assisted Growth of high performance superconducting $YBa_2Cu_3O_{7-x}$ films

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High temperature superconductors (HTS) are unique materials to transport high electrical currents without losses up to liquid nitrogen temperatures and/or at high magnetic fields. Therefore, substantial research was promoted to demonstrate their opportunities towards efficient electrical transport and high field magnets applications. However, the high production costs of the existing technology refrain their market out-breaking. Chemical solution deposition (CSD) techniques have decisively opened possibilities for the manufacturing of low-cost nanostructured epitaxial HTS superconductors with high performances, successfully employing trifluoroacetate metal-organic precursors (TFA-route). We have developed a high-throughput growth method, the Transient Liquid Assisted Growth (TLAG), that enables to reach growth rates up to 1000 nm/s [1,2] compatible with a CSD methodology. Additionally, since it uses a fluorine-free solution approach, it follows the global need for greener chemical processes to grow epitaxial $YBa_2Cu_3O_7$ (YBCO) superconducting films. We designed a robust environmentally friendly propionate-based metalorganic solution using a facile low cost synthetic method which ensures a 50% higher metal concentration and very high stabilization, starting from low-cost commercial precursors [3]. This solution facilitates the preparation of highly homogeneous nanocrystalline pyrolysis layers with very low porosity (1-2 %) at least up to a thickness of 2.7 µm, resulting in the ultrafast growth of reproducible YBCO epitaxial layers of 2.5-3 MA/cm^2 at 77 K. Solution rheological characterization together with EPR, TGA and TEM analysis were key to obtain thick films without compromising their homogeneity [3]. Moreover, this novel preparation method is compatible with the possibility of varying the Ba/Cu molar ratio in solutions, allowing us to optimize solutions of various compositions with desired features for TLAG. The use of various liquid compositions results in a modification of the supersaturation conditions and characteristics of the transient liquid in the TLAG process, through which we can evince the differences in nucleation, epitaxy and physical properties. Employing in-situ XRD synchrotron radiation and HRTEM/STEM, we could reach a wide understanding of the TLAG mechanism by identifying the relevance of the kinetic behavior, the influence of the transient liquid composition and the correlation with the superconducting properties.

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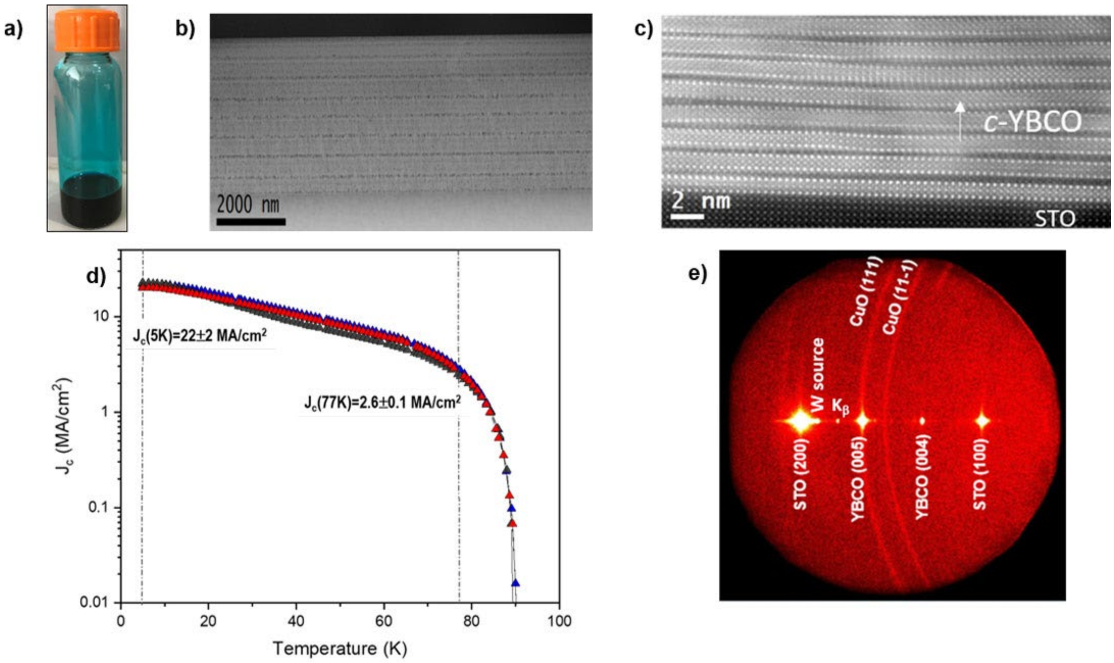
Keywords: YBCO superconducting films, chemical solution deposition, transient liquid assisted growth, in-situ XRD synchrotron characterization



WB9-9

The influence of the Ba content on the superconducting properties of TFA-MOD $La_{2-x}Ba_xCuO_4$ films

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The enhancement of the in-field critical current density (J_c) has been one of the most important topics for magnet applications of superconductors. The addition of artificial flux pinning centers is an effective way to increase the in-field J_c and reduce the flux creep rate (S) for most superconducting materials [1-3]. Moreover, it is reported that S is almost proportional to $G_i^{1/2}$, where G_i is the Ginzburg number, in REBCO and $BaFe_2(As_{1-x}P_x)_2$ (Ba122) films [2]. However, the region between REBCO ($G_i^{1/2}$~0.1) and Ba122 ($G_i^{1/2}$~0.02) has not yet been investigated. To clarify the relationship between S and $G_i^{1/2}$ in this unstudied region, $La_{2-x}Ba_xCuO_4$ (LBCO) is an interesting superconducting material because it has a maximal critical temperature (T_c) up to 30 K near optimal doping and a different anisotropy than REBCO and iron pnictide superconductors. In this work, to investigate the superconducting properties of LBCO films, we fabricated LBCO films with x=0.13, 0.14, 0.15, 0.165 and 0.18 on $LaAlO_3$ substrates using the Trifluoroacetate Metal Organic Deposition (TFA-MOD) method. The LBCO films with optimized fabrication conditions have high crystallinity and grow epitaxially on the $LaAlO_3$ substrates. The x=0.15 film shows a T_c^{onset}~24 K and it is the highest of all the Ba content films studied. To investigate the coherence length (x_{ab}) and mass anisotropy (g_H) for the LBCO films with different Ba content, we measured the r-T properties, where r is the resistivity, for various T, m_0H and field angles. The calculated x_{ab} and g_H are dependent on the Ba content of the LBCO films. Detailed microstructural and in-field superconducting properties for the LBCO films with different Ba content will be presented.

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