

PL-1-INV

30 years of superconductivity in molecular solids

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Following the discovery of C₆₀ (a quasi-spherical molecule with dimensions of ~1 nm) in 1985, the subsequent isolation and preparation of bulk crystalline samples of fullerenes—a set of hollow, closed-cage molecules consisting purely of carbon—from arc-processed carbon in 1990 sparked off a remarkable interdisciplinary research activity, encompassing diverse fields of chemistry, physics and materials science. The early research activity quickly culminated in 1991 in the synthesis of superconductors with stoichiometry A₃C₆₀ (A = alkali metal) and considerably enhanced superconducting transition temperatures, T_c , when compared with any other molecular system. This was followed by a long period during which the established fulleride chemistry failed to deliver new materials. Therefore the physical picture of fullerene superconductivity remained unaltered until 2008 when the discovery of Cs₃C₆₀ led to their rebirth and demonstrated their commonality with other classes of unconventional superconductors such as the cuprates and the iron chalcogenide/pnictide systems. C₆₀-based solids with stoichiometry A₃C₆₀ are now established as archetypal examples of molecular superconductors with the highest superconducting transition temperatures ($T_c = 38$ K) among all molecular systems known. In addition, they also display the highest upper critical magnetic field ($H_{c2} > 90$ Tesla) among all known three-dimensional superconducting solids. The dominance of strong electron correlations in defining their behavior poses significant challenges for understanding the highly robust superconducting response to both temperature and magnetic field in these highly correlated organic metals. Here I will attempt to trace the development of this field of science to date with emphasis on its current status and future prospects.

PL-2-INV

Status Of Long Length MgB₂ Wire Manufacturing After a Decade Of Industrial Production

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We present the status after ten years of industrial manufacturing of MgB₂ wires through the ex-situ process. Various conductor architectures have been meanwhile developed, and found suitable for MRI as well as cable applications. The process has been scaled up to very long lengths, enabling us to produce single batches up to 12,6 km long. Wire performance has now reached the target values for 1.5T whole body MRI systems, i.e. in the range of 800 A at 4 Tesla and 4.2K. The development now also includes superconducting joints, which are proven to be reliable in performance and processing even on our fully reacted wires. Ex-situ processed wires are robust enough to be handled in fully reacted state and employed in practical applications flawlessly. As a matter of fact, high current cables have been successfully realized and tested without any wire degradation. Successful demonstrators for various applications including magnets, generators, fault current limiters will be finally reported.

PL-3-INV

The near future power grid in TEPCO and superconducting applied technology

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Nowadays the four 'D' are well discussed in the energy industry and utility as a whole. That is, it is 'Deregulation, Decentralization, Decarbonization, Degitalization'.

In Japan, after the earthquake of 3.11, review and consideration of social infrastructure as well as electric power utility is actively carried out.

Especially as Japan's fifth 'D', technological development is required to be conscious of 'Depopulation' and solve it. I would like to talk about the possibility of related superconductivity application technology.

Keywords: Superconductivity application technology, depopulation, future electric grid

PL-4-INV

R&D of applied superconductivity by a small business: experiences and future perspective

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HTS-110¹

The increasing commercial availability of High-Tc Superconducting (HTS) wire in the decade following the discovery of this amazing class of materials opened the door to a range of unique application opportunities. The early international focus was on the power industry with a promise of a significant transformation in efficiency and supply security; however the realities of funding large and technically demanding prototypes and the lengthy timelines involved in realistic commercialisation pathways, meant that for a small business nearer-term opportunities would need to be explored. From a background in materials research and wire development activities, HTS-110 was established over 13 years ago to design and manufacture HTS magnets for a wide range of scientific and industrial applications; over the last decade significant progress has been made in the commercialisation of HTS magnets, both by HTS-110 and other manufacturers, paralleling the improvements in wire performance and quality. In this paper we review the developments of HTS magnet technology and applications leading to a range of niche application areas, from sample environments for synchrotron and neutron beamlines and other materials analysis applications, through to developments for the demanding realm of magnetic resonance, all of which leverage the benefits of high current density relative to copper and a relatively high operating temperature compared to the low-temperature superconductors. New future application areas promise to extend these developments and greatly expand the role of HTS magnets in our industrial society.



Fig. A 200 MHz HTS-NMR magnet produced by HTS-110

Keywords: HTS magnets, Applied superconductivity, Industrial

PL-5-INV

Recent Progress in the Development of Superconducting Wires in the U.S.A.

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Recent progress on the research-and-development (R&D) of superconducting wires in the U.S.A. will be reviewed. Significant efforts in the U.S.A. are on-going to develop long length manufactured wires of major families of superconductors, including REBa₂Cu₃O_{7-x} (REBCO or YBCO) coated conductors, Bi₂Sr₂CaCu₂O_{8-z} (Bi-2212), MgB₂, low temperature superconductors such as Nb₃Sn, and exploratory materials such as Fe-Se or Fe-As based. Efforts focus on improving properties for applications including long length uniformity, manufacturing issues, reducing wire cost, and also improving wire properties for applications such as by flux pinning and filamenting. The latest research to improve flux pinning of REBCO coated conductors by nano-defect additions for different manufactured processes will be reviewed, and the impact to dramatically improve performance and enable new applications and capabilities will be presented. Evolving improvements of the critical current density $J_c(H,T,\theta)$ values being achieved will be reviewed for ranges of temperatures from $T = 5$ K to 100 K, magnetic fields from $H = 0.1$ T to 30 T, and angular dependence $\theta = 0$ to 90 degrees.

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PL-6-INV

30 Years of History and Future Perspectives of Superconducting Electronics

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From early on, Superconductive Electronics was in the mind of people looking to extend the boundaries of sensitivity, speed and energy efficiency. In Large Scale Applications, Kamerlingh Onnes very early on thought of creating high magnetic fields in a permanent current configuration. For Superconductive Electronics, it took a little longer to use the advantages of superconductivity: first digital devices – the Cryotrons - were developed in 1955 by Buck. With the invention of Josephson junctions in 1962, the age of the modern Superconductive Electronics began: within a short time, microwave effects like the Shapiro steps were found and the combination of Josephson effect and flux quantization led to the invention of rf- and dc SQUIDS and their application as highly-sensitivity magnetic field sensors, e.g. for detecting brain and heart magnetic signals. Applications in digital electronics followed: the famous IBM superconducting computer project and projects in Japan opened the field. Transition edge bolometers and tunnel junction detectors are very successful as sensitive detectors over a very wide frequency range - the list of device applications is too long to be fully covered in this talk.

The industrial side of Superconducting Electronics is a mixture of success and failure: the rise of the IBM Josephson computer project was a big stimulation for research on Superconductive Electronics, it's fall on the other side was a big blow to the community and only the steady excellent work of research groups like the groups in Japan kept digital SE alive. New ideas came up like RSFQ of the group around Likharev and stimulated new research and new enthusiasm in the field. With the need for very high energy efficiency and with superconducting quantum computing, it seems that digital superconducting electronics has finally found its niche to successfully compete with semiconductor electronics.

The situation for the commercial superconducting sensor market is similar: superconducting sensors are very successful in science, e.g. in astronomy, but gained only slowly access to the industrial markets. But in the last decade, applications in detecting minerals were very successful and the application for ECG in hospitals (demonstrated e.g. in Tsukuba and Osaka) finally seems to get ground.

Seen the long time, superconductivity and superconductive electronics is around, and seen the excellent results achieved internationally – well supported by the availability of smaller and high-reliability cooling techniques - it is highly likely that wider applications of this technique in our societies will take place.

LN-1-INV

Enhanced Vortex-Pinning in Superconducting Wires

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Engineered nanoscale defects within $\text{REBa}_2\text{Cu}_3\text{O}_{7-\delta}$ (REBCO) based coated conductors are of great interest for enhancing vortex-pinning, especially in high-applied magnetic fields. We have conducted extensive research to optimize vortex-pinning and enhance J_c via controlled introduction of various types of nanoscale defects ranging from simple rare-earth oxides and Ba-based perovskites to double perovskite rare-earth tantalates and niobates ($\text{Ba}_2\text{RETaO}_6$ and $\text{Ba}_2\text{RENbO}_6$). This talk will provide an overview on how density, morphology, and composition of these engineered nanoscale defects affects vortex-pinning in different temperature, field and angular regimes. Detailed microstructural and superconducting properties coated conductors with these engineered defects will be presented. It will be shown that certain nanodefekt configurations that provide the best performance at high-operating temperatures also provide the optimal properties at low operating temperatures out to high-applied magnetic fields. The talk will discuss vortex-pinning in both PLD films with self-assembled nanodefekts as well as ex-situ MOD films with irradiation produced defects.

LN-2-INV

A novel route to prepare bulk superconductors: Spark Plasma Sintering and Texturing

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The unconventional sintering process called Spark Plasma Sintering (SPS) was used to prepare superconducting MgB₂ cryo-magnets. The role of the starting powder on the superconducting properties of MgB₂ has been investigated. Three sets of bulk MgB₂ material were processed from: (i) commercial available powder, (ii) a mixture of Mg metal and amorphous B using a single-step solid-state reaction process and (iii) a mixture of amorphous boron coated with carbon and Mg metal. The samples were prepared by varying different SPS processing conditions such as temperature, dwell time, applied pressure and atmosphere. The structural, microstructures of the samples were investigated by SEM and TEM and correlated to their superconducting properties. The best sample was prepared at 850°C. At 20K its critical current density was $J_c = 500 \text{ kA/cm}^2$, while the trapped field measured at the surface of a 20 mm diameter disk was equal to 3.9 T. The dependence on temperature of the levitation force was investigated on MgB₂ disks with various diameters and thicknesses. On the same samples, the levitation force took the same values from 17 to 32 K, as could be expected from the expression of the magnetic moment of the currents flowing in a superconducting cylinder proposed by E.H. Brandt [1]. Otherwise, the T_c determined from these measurements was equal to 38 K, in good agreement with measurements by other techniques. Overall these results suggest that bulk MgB₂ superconductors could be a viable variant for magnetic levitation and cryo-magnet applications.

The measurement of the properties of single phase Bi₂Ca₂Sr₂CuO₈ superconductor ceramics consolidated using new route referred as "Spark Plasma Texturing" (SPT) is in progress and will be also discussed.

[1] E.H.Brandt, Phys.Rev.58, 6506 (1998)

Keywords: MgB₂, Cryomagnet, Spark Plasma Sintering, Spark Plasma Texturing

LNP-1

Laying of the superconducting feeder cable along railway line

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The superconducting feeder cable shrinks in cooling process from the room temperature to temperature of liquid nitrogen. When a long length superconducting feeder cable is constructed in railway line, it is needed to consider as a measure against the cooling force. In this paper, it was considered a suitable laying method of superconducting feeder cable, and the manufactured 300-m class superconducting feeder cable was actually set up on the test track. After that, a x-ray radiograph was taken over the whole length of the cable after the construction of the cable, and there were no buckling and rupture points, so the laying method is suitable for this superconducting cable.

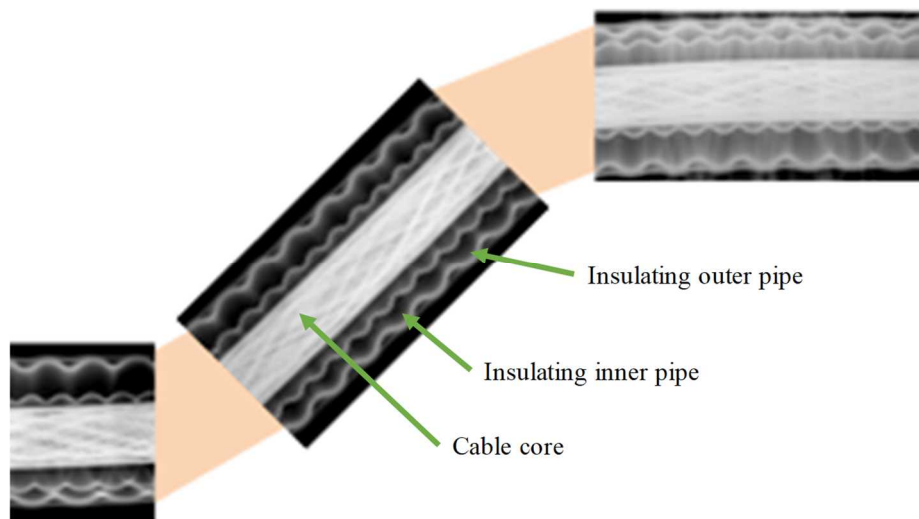


Fig. X-ray radiograph of the superconducting feeder cable

Keywords: superconducting feeder cable, X-ray radiography, laying method, cooling force

LNP-2

Dynamic performance of high temperature superconducting maglev system

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we report the variation of force in the direction along guideway on high temperature superconducting (HTS) bulk running over permanent guideway with AC magnetic field at different speed. Larger variation of force is suggested to be caused by hysteresis loss at lower speed. While smaller variation of force observed at higher speed should be caused by eddy current loss.

Keywords: HTS maglev, YBCO bulk, AC magnetic field, Dynamic response

LNP-3

Realization and First Tests Results of the EuCARD 5.4-T REBCO Dipole Magnet

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A HTS dipole magnet relying on 12 mm REBCO tapes was built at CEA Saclay in 2016. Magnet studies had been started in the framework of the EuCARD High Field Magnet program and continued within a collaboration agreement between CEA-Saclay and Cern. The final goal is to generate 5.4 T at 4.2 K in the 13 T background field of FRESKA2 Nb₃Sn dipole magnet. The HTS winding is made of three double-layer racetrack-type coils, wound from a stack of two double layer REBCO tapes, stabilized with beryllium copper ribbons. Before it is installed inside the aperture of FRESKA2, at CERN, the magnet has been tested at CEA-Saclay in standalone mode. After a brief recall of the magnet design, we will report on the magnet manufacturing, the screening current computations and the first powering tests results.

Keywords: Dipole, HTS, accelerators, screening currents

LNP-4

No-Insulation REBCO Pancake Coil with Stainless Steel Co-Winding Tape - Tests under High Resistive Background Field and High Current at 4.2 K

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Following our ongoing work on the French NOUGAT project under the French National Research Agency funding, we have built and test a single pancake coil under very high background magnetic field. Like for the insert project, the pancake consists of a REBCO HTS tape co-wound with a stainless steel tape (Metal-as-Insulation (MI) winding way). The MI winding is inducing a significant turn to turn electrical resistance which helps to reduce the charging time delay. Despite this resistance, the self-protection feature of No-Insulation (NI) coils is still enable, thanks to the voltage limit of the power supply. Our coil experienced over hundred heater induced quenches without “significant” increase of its internal resistance. We have gathered stability and quench behavior data in the 0-17 T and 0-635 A/mm² ranges. We also present our very first experiments on the insert/outsert interaction in the case of a resistive magnet fault. We show that if self-protection of the MI winding is really effective in the case of a MI coil fault, a major issue comes from the outsert fault which induces a huge current inside the MI coil.

Keywords: REBCO Tape, No-Insulation coil, Metal as insulation coil, magnet interaction

LNP-5

NUMERICAL SIMULATION OF INSTABILITIES IN MAGNETIC VORTICES IN TYPE-II SUPERCONDUCTOR UNDER NON-UNIFORM MAGNETIC FIELDS USING TIME-DEPENDENT GINZBURG-LANDAU EQUATIONS

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The complex Ginzburg–Landau equations are often encountered in physics and engineering applications, such as nonlinear transmission lines, solitons, and superconductivity. Various numerical methods have been developed for the solution of GL equations, which include finite difference method, finite element method and spectral method. In the present work, time-dependent Ginzburg-Landau equations were solved for cubic superconductor by finite difference method using staggered grid scheme under the influence of 1) Static magnetic field 2) oscillating magnetic field and 3) hybrid static and oscillating magnetic field. Carrier concentration, magnetization and energy distributions were studied as a function of variation in external magnetic field. Small steps and kinks in carrier concentration was observed at positions of entrance and leaving of a set of vortices, such small steps were also observed in superconducting energy and sample magnetization. Instability in interaction energy which can result in thermal quenching of superconductor was observed to be lower in hybrid field case, compared to that observed in purely oscillating field, while no such instability was observed in the case of static magnetic field. This effect is strongly related to the magnetic field experienced by the superconducting maglev vehicle on permanent magnet guideway with intrinsic defects.

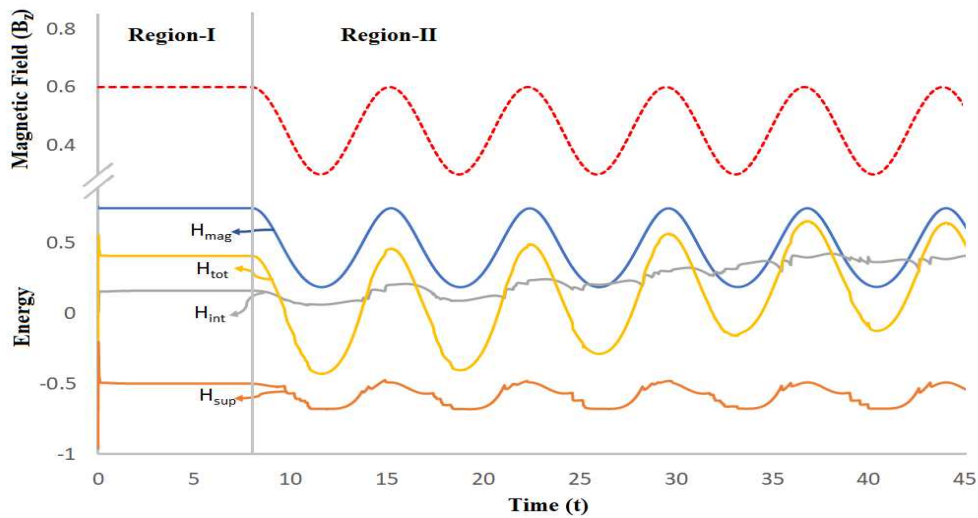


Fig. Temporal variation of average values of Magnetic, Superconducting, Interaction and total energies in static (region-I) and hybrid (region-II) magnetic fields (sample size $20\xi \times 20\xi \times 20\xi$, $\kappa=4$, $\sigma=1$ and $B_z = 0.45 \kappa + 0.15 \kappa \cos \theta$)

LNP-6

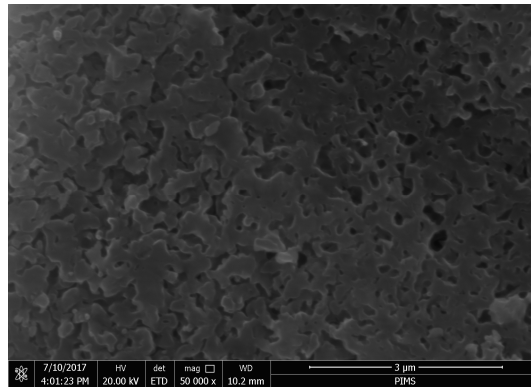
The improvement of MgB_2 prepared by hot-pressing sintering method with the MgB_4 precursor powder

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To improve the density of MgB_2 is the key to improve the performance of the MgB_2 . Hot pressing method can effectively improve the density of MgB_2 . But the temperature up to the 1000 degrees, the density of MgB_2 increase has been very difficult. The volume shrinkage of magnesium and boron in the reaction process and brings holes which resulting in a decrease in density. If using MgB_4 precursor powder preparation, it can reduce the volume shrinkage rate, thereby reducing the porosity. In this paper, the MgB_4 precursor powder is carried out to prepare MgB_2 under the vacuum hot pressing conditions. Finally, the high-quality MgB_2 bulks are achieved with high density.



LNP-7

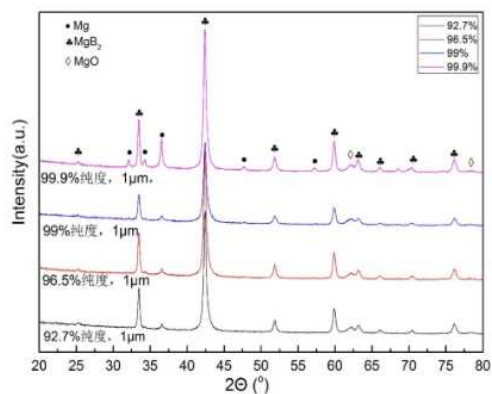
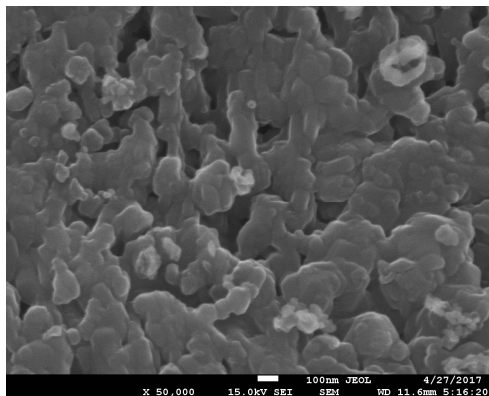
The effects of Mg precursor powder on the MgB₂ superconductor prepared by diffusion method

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The diffusion method can effectively inhibit the formation of MgO into the MgB₂ samples and improve the purity and density of the MgB₂ superconductors. Therefore, in this paper, the MgB₂ superconducting bulks are prepared by diffusion method to improve the MgB₂ application performance. The precursor B powders are pressed into bulks and the excess of Mg precursor powders with different purity and particle size are added into the iron pipe. Then the heat treatment is carried out under the pure argon atmosphere. Finally, the high-quality MgB₂ bulks are achieved with high density. The effects of precursor Mg powders with different purity and particle size on the MgB₂ superconductors were investigated. The experimental results show that the precursor Mg powder with low purity and large particle size are in favor of the preparation of high performance MgB₂ superconductor. Low purity and high size decrease the Mg powder cost. Therefore, this experiment provides a low cost to prepare MgB₂ superconductor with diffusion method.



LNP-8

Installation Design of 23kV 50MVA Class HTS Cable in S.Korea Grid

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As an initial step of this innovation, in September of 2016, KEPCO (Korea Power Electric Corporation) has launched world first commercial superconducting cable project, named **SSS** (**S**uperconducting **S**mart platform **S**tation in Korea) project, which will be not only the first commercial trial in grid but also a test bed for Smart Superconducting Platform in Korea.

Main target design of this project is installation of 23kV 50MVA class HTS cable system in power grid. Type of this HTS cable is 3 phase in One Cryostat which is remarkable way to transfer large power with low voltage and no electric magnetic field that means prevention of heating of other cores and metal sheath of cable. Total length of HTS cable between ShinGal and HeungDuk substations is slightly over 1km and it has 2 sets of normal joint box and 2 sets of termination. In this HTS cable system, mechanical stress during the cool-down and warm-up is major issue for increasing stability to set-up the HTS system and to connect existing power lines. To solve this issue of SSS project, we developed simulation program which used Equivalent Solving Method for reducing and predicting thermal contract force of HTS cable under the mechanical stress. Also, mechanical strength of metal sheath and copper wires as the former was measured by bending and tensile tests. Coefficient of elastic and thermal expansion according to various temperatures was calculated by these data. Analytical method was verifying by approximately 40m length HTS cable that has various installation condition such as using snake method at straight route in installation path. From the above procedures, we found that mechanical strength can calculate based on installation route in power grid

Keywords: 23kV 50MVA class HTS cable, 3 Phase in One Cryostat, snake method

LNP-9

Constitutive Equation of Multiferroic Bismuth Ferrite under the Framework of Onsager's Reciprocity Relations

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The rapid emergence in the field of multifunctional materials in the field of multi-ferrocity has sparked the experiments like molecular beam epitaxy, captivating fundamental physics and development of various propitious noble materials of thin films or multilayer. The magnetic control electricity or electricity control magnetism thin films or materials spurred the potential application in magneto-electronics or magnetoelectric effect. We have investigated the Onsager relations in the context of electromagnetic constitutive relations of linear, homogeneous multiferroic bismuth ferrite. The fundamentals of electrodynamics under coupled ferroic orders are elucidated along with balance laws of mass, linear momentum, angular momentum, energy and entropy and integrated with Maxwell's equations. Onsager's reciprocal relations and second law of thermodynamics are invoked to deduce bounds on the kinetic coefficients and to develop the thermodynamic admissible constitutive equations. The linear formulation is specialized for multiferroic bismuth ferrite for the application of plasma physics. Hitherto, it is envisioned in design implementation and characterisation of functional materials by optimising the material properties.

Keywords: Bismuth Ferrite, Multiferroic, Onsager's reciprocal relations, high degree of ferroic orders

LNP-10

Upper critical fields and critical current densities characteristics of Nb₃Sn doped with fourth elements

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It is well known that adding a small amount of Titanium (Ti) to the bronze significantly increases the growth rate of the Nb₃Sn layer [1]. Furthermore, this addition improves the critical current density J_c and the upper critical field B_{c2} due to the refinement of crystal grains and the reduction of coherence length. On the other hand, the addition of Tantalum (Ta), Gallium (Ga) and Hafnium (Hf) also improves B_{c2} , while the addition of Magnesium (Mg) or Germanium (Ge) improves pinning force density F_p .

In this study, the influence on B_{c2} and J_c when adding Mg, Hf, Ge, Ga, and Ta elements to bronze as a fourth element for Nb₃Sn (composition Cu-15Sn-0.3Ti) was investigated. The appropriate addition amount of each element will be clarified in the future.

The thermal diffusion treatment for generating Nb₃Sn was carried out at 700°C for 50 hours and 100 hours. Table 1 shows the specifications of all samples. The size of the samples is approximately 4.0 mm length × 3.0 mm width × 0.40 mm thickness. A SQUID magnetometer was used to measure $B_{c2}(T)$ and J_c . The temperature dependence of B_{c2} was determined from the temperature dependence of DC susceptibility. The magnetic field dependence of J_c was obtained from DC magnetization measurement. For all measurements, the magnetic field was applied perpendicular to the wide surface of the sample.

Table 2 shows the results of evaluating $B_{c2}(0)$ at 0 K using the WHH theory [2] from the temperature dependence of B_{c2} at 12–18 K. Overall, B_{c2} is higher in 100 h than in 50 h of heat treatment time. In addition, the difference in B_{c2} is largest in samples with added Mg for 50 h, but 100 h for those with Hf and Ta. On the other hand, the addition of Ga yielded the lowest B_{c2} in this measurement.

Figure 1 shows the magnetic field dependence of J_c normalized by the value in self-field at 14 K for 100 h samples. The magnetic field dependence of J_c was excellent in samples containing Hf, Ta and Mg. On the other hand, the samples with added Ga showed the worst magnetic field dependence on J_c among the samples measured in this measurement. However, since Ga is easily incorporated into Nb₃Sn [3], excessive Ga added is considered to be the cause of J_c deterioration.

[1] K. Tachikawa, H. Sekine, Y. Iijima: J. Appl. Phys. **53** (1982) 5354–5356; [2] E. Helfand *et. al.*: Phys. Rev. B **23** (1964) 686–688; [3] K. Tachikawa *et. al.*: Abst. CSJ Conference, **94** (2017) 37

Composition (mass%)	50 h		100 h	
	ST-50	Mg-50	Hf-100	Ta-100
Cu-15Sn-0.3Ti	+0.5Mg	Mg-50	Mg-100	
	+0.5Hf	Hf-50	Hf-100	
	+0.05Ge	Ge-50	Ge-100	
	+5Ga	Ga-50	Ga-100	
	+0.08Ta	Ta-50	Ta-100	

	ST	Mg	Hf	Ge	Ga	Ta
50 h $B_{c2}(0)$ [T]	19.9	22.0	20.3	20.1	17.5	21.3
100 h $B_{c2}(0)$ [T]	22.4	23.5	25.9	23.1	20.7	25.3

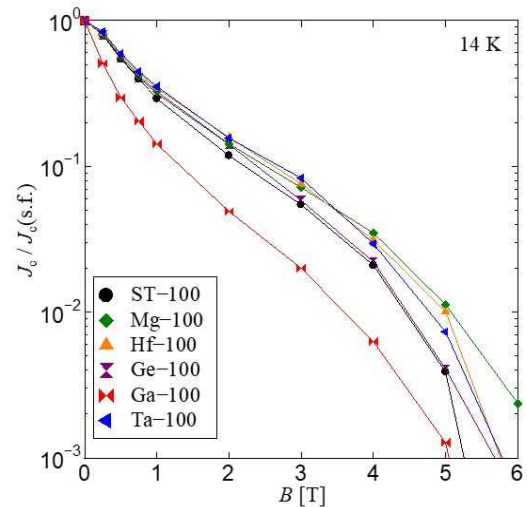


Fig. 1: Magnetic field dependence of J_c at 14 K for 100 h samples.

Keywords: Nb₃Sn, Element addition, Bronze process, Critical current density, Upper critical field

LNP-11

Novel Discovery of Nano Tubular $\text{YBa}_2\text{Cu}_3\text{O}_x$

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Herein, we report the first known fabrication of the high temperature superconductor $\text{YBa}_2\text{Cu}_3\text{O}_x$ (YBCO) in the morphological form¹⁾ of nanorods and nanotubes^{1,2)} by solution chemistry³⁾. Reagent grade oxides of Yttrium, Barium, and Copper in 1:2:3 stoichiometric proportions were dissolved in an acidic solution and upon precipitation, a fine-grained, less than 5nm, mixture was obtained. The precipitate was calcined at 773 K for 2 h, then subsequently converted to YBCO nanorods and nanotubes by heating to 1223 K in oxygen for 12 h. X-ray diffraction showed that the powder consisted of nanorods and nanotubes predominantly of the $\text{YBa}_2\text{Cu}_3\text{O}_x$ phase. A critical superconducting transition temperature T_c of 92 K was achieved in a critical magnetic field of 10 Oe, along with observing the Meissner effect.

The poster presents the novel discovery of nanotubular structures. Transmission electron microscope (TEM) and scanning electron microscope (SEM) images (Figures 1 and 2) reveal the tubular morphology of the structures. A significant finding is that the nanorods and nanotubes are superconducting without the need for further sintering or oxygenation, providing an avenue for the application of $\text{YBa}_2\text{Cu}_3\text{O}_x$ to substrates at room temperatures or direct use in the form of nanorods and nanotube powder.

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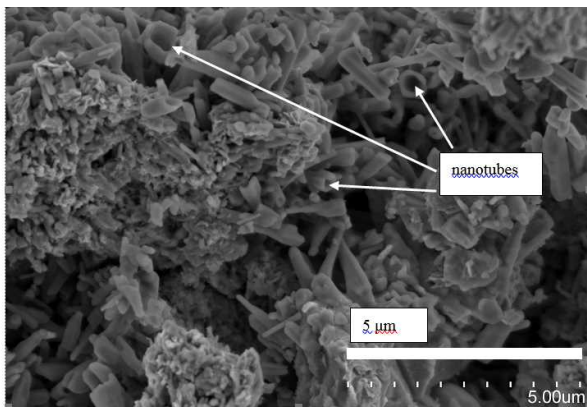


Figure 1: SEM image of superconducting nanorods and nanotubes showing nanotubes

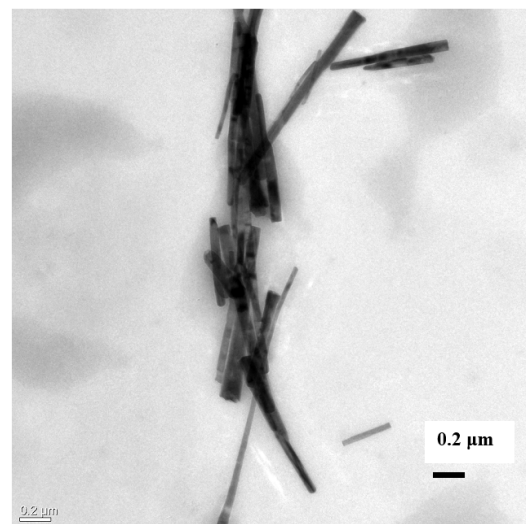


Figure 2: TEM image of superconducting nanorods and nanotubes showing thickness as little as 50 nm and lengths as large as several micrometers

LNP-12

A simplified white box model for real-time application to estimate the magnet temperature of superconducting tokamaks

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As a minimalist model of physics-based magnet safety monitoring tool, a 0-D model of thermo-hydraulic quantities of the KSTAR PF magnets [1] is developed as a pessimistic temperature estimation for given current scenarios. To check the feasibility of real-time application, we implement a fast routine using the multi-thread parallelization of hardware accelerator. To meet the performance, we attempt not only to simplify the ODE solver as a simple Runge-Kutta step, but also to replace the functions of material property with the data tables in texture memory. Through these types of acceleration, it is achieved that 0.1 sec of real operation can be forecast within ~10 ms, which means the calculation is fast enough to monitor in advance of the actual change in the devices. Including the possibility of a gray-box model to take into account the convective and diffusional couplings, the technical issues to implement the usable model are also discussed especially in terms of the operation of the plasma control system (PCS).

References:

[1] Dong Keun Oh, "KSTAR hotspot – a zero-dimensional model analysis code for the thermal behavior of the KSTAR PF magnets" technical document of NFRI (NFRI-2011-100001-0305-0389) written in Korean.