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Superconductivity Web21

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What's New in the World of Superconductivity

초전도 뉴스 –세계의 동향–

超导新闻 –世界的动向-

chāo dǎo xīnwén - shìjiè de dòngxiàng-

Yutaka Yamada, Principal Research Fellow
Superconductivity Research Laboratory, ISTEC

★News sources and related areas in this issue

▸Power Application 전력응용 电力应用 [diànlì yìngyòng]

1km AmpaCity HTS Cable now Started

Nexans and RWE (5 May 2014)

Last week on April 30, 2014, RWE officially integrated the world's longest superconductor cable into Essen's power grid, thus putting it into real operation for the first time. About a year after the groundbreaking installation of the cable spanning a length of one kilometer, which connects two substations in Essen's city center, field tests are now starting for the future energy supply of inner cities. The particularly efficient and space-saving technology transports five times more electricity than conventional cables, almost without any losses.

This pilot project by the name of AmpaCity, has been made possible by grants from the German Federal Economics Ministry for the Environment and Energy (BMWi), € 5.9 million, together with the € 13.5 million

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invested in the project by RWE and its project partners, Nexans, who are the cable manufacturer and behind the designs of a superconducting short-circuit current limiter.
Prime Minister Hannelore Kraft said, "This is a good day for RWE, for the city of Essen, North Rhine-Westphalia and the energy transition in Germany. Today we send superconductor technology in the world's first practical test. Particularly, I am pleased that the traditional Energy-City Essen, is involved in the AmpaCity project and supports the project actively."
Reinhard Paß, Mayor of Essen, added: "The foundation stone is being laid here in Essen in the truest sense of the word for a technology which can be of great benefit to future generations. This fills the city and its population with pride. AmpaCity is already a showcase for innovation on the Ruhr."
Peter Terium, Chief Executive Officer of RWE AG, emphasized at the commissioning ceremony: "AmpaCity ranks among the outstanding innovative projects which RWE is implementing with a lot of energy and passion. The transformation of our energy system not only requires courage, inventive genius and reliable partnerships. The energy transition also needs healthy, competent companies able to rise to the challenges it poses. This is what we are impressively demonstrating at Essen."
"Today, scientists and researchers from all over the world are rightly looking to Essen with great interest. Together with the city and our project partners we are translating a pioneering pilot project into practice on a unique scale. Following the successful installation of the superconductor cable, we are now happy to start the two-year trial operation", said Dr. Arndt Neuhaus, Chief Executive Officer of RWE Deutschland AG.
"With AmpaCity, RWE is again charting new technological territory. We were already able to gather first valuable experience when laying the cables and assembling the sophisticated technical components. Now we are keen to see how the field trials go", Dr. Joachim Schneider, Technology Board Member of RWE Deutschland AG, commented, "
Christof Barklage, Chairman of the Board of Directors at Nexans Germany, said, "Following more than ten years of research and development in the field of superconductor technology, we can demonstrate, together with our partner RWE, by way of AmpaCity that superconduction makes economic sense." Frank Schmidt, Head of the Superconductor Division at Nexans added: "Essen can take pride in being a role model city. Its grid typology and the associated problems are symptomatic of large cities, also outside Germany; the superconductor involvement is exemplary. This project is a milestone on the path towards commercialization of superconducting operating resources."
At Essen, the 10,000-volt superconductor cable replaces a conventional 110,000-volt transmission line. This is also intended to reduce the number of transformer stations and to move them to the outskirts of cities. This would make valuable sites in city centres available again for other purposes.

Source: "World premiere in Essen: RWE integrates superconductor cable for the first time into existing power grid" Nexans Press Release (5 May, 2014)
URL: http://www.nexans.com/Corporate/2014/1405_Nexans_AmpaCity_GB.pdf
Contact: Angéline Afanoukoe Angeline.afanoukoe@nexans.com

Commercialization of Advanced Magnet system

AML Superconductivity and Magnetics(5 May 2014)

AML Superconductivity and Magnetics and Argonne National Laboratory announced that one of the world's most sophisticated superconducting magnet systems passed a landmark reliability test that demonstrates its suitability for wide-scale commercial applications. The successful test is the latest in a series of recent AML milestones that promises to accelerate the "mainstreaming" of superconductivity into such high-impact applications as power generation and distribution, advanced medical procedures, electric-powered transportation and wastewater treatment.

AML president, Mark Senti, stated, "While the magnet system that was tested is intended for use in an international science project located in Europe, its fundamental design employs an array of enabling superconducting magnet and manufacturing technologies, and unprecedented field characteristics. This design has now been validated for broader use in such platform products as rotating machines including significantly smaller, lighter and super efficient motors, generators, and all-electric propulsion systems. Senti added, "By offering application development services and defined field-of-use technology license agreements to visionary companies, we can rapidly propagate the application of superconductivity in critical multi-billion-dollar markets while addressing some of humanity's most pressing challenges."

Jerry Nolen, Distinguished Fellow of Argonne National Laboratory, oversaw the complex and stringent qualification test, conducted at the National High Magnetic Field Laboratory in Tallahassee, Florida. "This test has redefined the standards of magnetic performance and represents a long-awaited breakthrough in the advancement of superconducting technology," said Nolen.
AML's Chief Technology Officer, Dr. Rainer Meinke, is responsible for the creation of the proprietary end-to-end process that yielded the company's sophisticated magnet technology. Their approach combines proprietary materials and revolutionary magnetic coil configurations to overcome the most persistent challenges of superconducting systems. Meinke asserted, "As a result, our magnet technology not only demonstrates previously unobtainable field characteristics, it also achieves the reliability required for broad commercial adoption."

Source: "AML Passes Superconductivity Mainstreaming Test" AML Superconductivity and Magnetics Press Release (5 May, 2014)
URL:
http://amlsuperconductivity.com/aml-clears-final-hurdle-toward-broad-commercialization-of-superconductivity-advanced-magnet-system-passes-critical-reliability-test/
Contact: info@amlsm.com

▸Basics 기초 基础[jīchǔ]

Control a Superconducting phase in Fe-based Material

DOE/Oak Ridge National Laboratory (5 May 2014)
2014 MAY 22 (Vertical News) – For the first time, scientists have a clearer understanding of how to control the appearance of a superconducting phase in a material, adding crucial fundamental knowledge and perhaps setting the stage for advances in the field of superconductivity.
The paper, published in Physical Review Letters, focuses on a calcium-iron-arsenide single crystal, which has structural, thermodynamic and transport properties that can be varied through carefully controlled

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synthesis, similar to the application of pressure. To make this discovery, researchers focused on how these changes alter the material's Fermi surface, which maps the specific population and arrangement of electrons in materials.
"The Fermi surface is basically the 'genetic code' for causing a certain property, including superconductivity, in a material," said Athena Safa-Sefat of the Department of Energy's Oak Ridge National Laboratory, which led the research team. "We can make different phases of this material in single crystal forms and measure their structure and properties, but now we have Fermi surface signatures that explain why we can't induce superconductivity in a certain structural phase of this material."
The lead author of this paper, Krzysztof Gofryk, who did this work as a post-doctoral fellow at ORNL, showed how the interplay of structure and magnetism affected the Fermi surface and hence the electronic properties. In calcium-iron-arsenide, the bulk superconducting state is absent because of the large Fermi surface modification at the structural transition. This work represents a significant step forward for understanding this material's rich phase diagram and causes of superconductivity, Sefat said.

Source: "ORNL paper examines clues for superconductivity in an iron-based material"
ORNL News (5 May, 2014)
URL:http://www.ornl.gov/ornl/news/news-releases/2014/ornl-paper-examines-clues-for-superconductivity-in-an-iron-based-material
Contact: Ron Walli, wallira@ornl.gov

Mysteries of Cuprate High-Temperature Superconductivity

Brookhaven National Laboratory and Cornell University (8 May 2014)

A research team lead by scientists at the U.S. Department of Energy's (DOE) Brookhaven National Laboratory and Cornell University have used unique capabilities to reveal detailed characteristics of the electrons in one of these materials as it transforms from an insulator through the mysterious pseudogap phase and eventually into a full-blown superconductor. The results, described in the May 9, 2014, issue of Science, link two distinct personality changes in the material's electrons: the disappearance of a rather exotic periodic static arrangement of certain electrons within the pseudogap phase, and the sudden ability of all the material's electrons to move freely in any direction. The finding strengthens support for the idea that the periodic arrangement-variously referred to as "stripes" or "density waves"-restricts the flow of electrons and impairs maximal superconductivity in the pseudogap phase.
"This is the first time an experiment has directly linked the disappearance of the density waves and their associated nanoscale crystal distortions with the emergence of universally free-flowing electrons needed for unrestricted superconductivity," said lead author J.C. Seamus Davis, a senior physicist and Director of DOE's Center for Emergent Superconductivity at Brookhaven Lab and also a professor at both Cornell University and the St. Andrews University in Scotland. "These new measurements finally show us why, in the mysterious pseudogap state of this material, the electrons are less free to move."

That information, in turn, may help scientists engineer ways to get superconductivity flowing under more favorable conditions. The hope is to find ways to raise the operating temperature for real-world energy-saving applications-things like highly efficient power generation and transmission and computers that work at speeds thousands of times faster than today's.

Source: "Scientists Find Solution to Two Long-Standing Mysteries of Cuprate High-Temperature Superconductivity" Brookhaven National Laboratory Newsroom (8 May 2014)
URL: http://www.bnl.gov/newsroom/news.php?a=11637
Contact: Karen McNulty Walsh, kmcnulty@bnl.gov

Quantum Entanglement in D-Wave Systems

D-Wave System (30 May 2014)

Research published today presents groundbreaking evidence verifying the presence of entanglement in D-Wave's commercially available quantum computer. The results of the research prove the presence of an essential element in an operating quantum computer: entanglement. This is when the quantum states of a collection of particles (or qubits) become linked to one another.

"The research published in PRX is a significant milestone for D-Wave and a major step forward for the science of quantum computing. The findings are further proof of the quantum nature of our technology," said Vern Brownell, CEO of D-Wave. The PRX paper provides four levels of evidence that the eight-qubit unit cell is entangled including: (a) a demonstration of an avoided crossing of two energy levels, (b) a partial restoration of a density matrix of the system with calculations of standard entanglement measures, (c) calculations of an entanglement witness using measured populations and energy spectra of the system, (d) measurements of a susceptibility-based entanglement witness, which reports entanglement of the ground state.

These findings demonstrate entanglement within D-Wave's processors at the most critical stages of the quantum annealing procedure. D-Wave will perform additional research that address the extent of spatial entanglement and will also continue to explore the computational advantages of quantum algorithms. The paper published today is available https://journals.aps.org/prx/abstract/10.1103/PhysRevX.4.021041 on the PRX website.

Source: "Latest Research Validates Quantum Entanglement in D-Wave Systems" D-wave Press Release (30 May, 2014)
URL:
http://www.dwavesys.com/press-releases/latest-research-validates-quantum-entanglement-d-wave-systems
Contact: for media inquiries, media@dwavesys.com

▸Management and Finance 경영정보 经营信息[jīngyíng xìnxī]

▸Wire 선 재료 线材料 [xiàn cáiliào]

2014 First Quarter Results and Production Plan

Superconductor Technologies Inc. (8 May 2014)

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Superconductor Technologies Inc. (STI) (Nasdaq:SCON), reported results for the first quarter ended March 29, 2014. "In the first quarter of 2014, we made significant progress in our effort to commercialize Conductus® wire," said Jeff Quiram, STI's president and chief executive officer. "We achieved a minimum current of 500 Amps per centimeter (A/cm) width at 77 K across 100 % of the design capacity of our pilot production manufacturing system. We expect that our demonstrated high performance/high yield combination will allow STI to produce large quantities of wire from a cost leadership position".

During the first quarter of 2014, STI shipped nine orders: six for Stage 1 customers conducting performance evaluation and three for Stage 2 customers testing simulated devices for commercial deployment. This quarter we shipped to five new customers and STI's purchase order commitments continued to grow. The company expects their new 1km Reactive Co-Evaporation Cyclic Deposition and Reaction (RCE-CDR) machine to be operational shortly and now plan to have commercial quantities of Conductus wire available in the third quarter. The company also plans to ramp this machine to its full annual capacity of 750 km by the end of 2014.

As of March 29, 2014, STI had $7.8 million in cash and cash equivalents, which included cash proceeds to the company of $3.8 million resulting from the exercise of 1.5 million outstanding warrants during the first quarter of 2014.

Source: "Superconductor Technologies Reports 2014 First Quarter Results" STI Press Release (8 May, 2014)
URL:http://phx.corporate-ir.net/phoenix.zhtml?c=70847&p=irol-newsArticle&ID=1928621&highlight
Contact: Cathy Mattison or Kirsten Chapman, invest@suptech.com

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Feature Article: Progress in Superconducting Wire Technology - Technology Trends of Y-based Coated Conductors Fabricated by IBAD/PLD

Yasuhiro Iijima, Director
Superconductor Business Development Department
New Business Promotion Center
Fujikura Ltd.

Y-based coated conductors exhibit a common taping structure that comprises of highly aligned thin films deposited onto a polished metal substrate. Here, a reliable manufacturing method is necessary in order to establish mass-production processes offering high yields and low costs. Fujikura has consistently developed physical vapor methods of producing Y-based coated conductors combining IBAD buffer layers with a PLD superconducting layer. Although PLD is a bespoke vapor phase synthesis method, the operating costs associated with an excimer laser conventionally employed as part of this process have fallen in recent years. Additionally, raw materials can also be processed by powder sintering alone, which has less control parameters and demonstrates high material yield (around 50 %). These overall benefits are effective from both a production and cost viewpoint, allowing the fabrication of multicomponent oxide thin films. Furthermore, a hot-wall method, essentially an isothermal furnace, where radiant heating is distributed equally to the deposition chamber, has resulted in better performance control of the film surface temperature and is much closer to thermal equilibrium. The results have tended to show enhanced homogeneity over the entire wire length within wire lots and between lots. Currently, the deposition of around 300-500m long wires is routinely undertaken for 10mm-width tapes. For commercial use this tape is processed by splitting the wire into less than 5mm-widths and laminated with copper stabilization and insulation layers. However, since the smaller the wire widths become the greater the impact from local defects, long wires have a tendency to show difficulties in attaining a homogeneity required by the users.

An IBAD Y-based coated conductor employs a high mechanical strength Ni-alloy substrate. The mechanical characteristics necessary have been therefore anticipated since the initial stages of development. Cyclical tensile tests numbering 10,000, which were conducted in liquid nitrogen under 0.46 % strain and 765 MPa stress, have maintained superconductivity characteristics without degradation (Figure 1). This implies that even brittle thin films supported by a high mechanical strength substrate can be employed for high-field applications where large hoop stresses are present. On the other hand, delamination of the wire due to a peel force applied perpendicular to the wire surface is a concern for resin-impregnated coils, requiring elaborate efforts in both wire structure and wire winding methodologies since stress distribution in fragile superconducting layers cannot be avoided. Fujikura fabricated a 24 impregnated pancake coils utilizing 7.2 km-long wires that were elaborately devised to reduce the impact from the resin impregnation. The development of a 20cm bore-diameter conduction cooled coil realized a magnetic field of 5T at 25 K operation. Following the manufacturing of this coil in autumn 2012, the coil has entered practical applications at Fujikura's magnetic field characteristic evaluation facility. There have been no degradation problems reported over its operation in the last 18 months.

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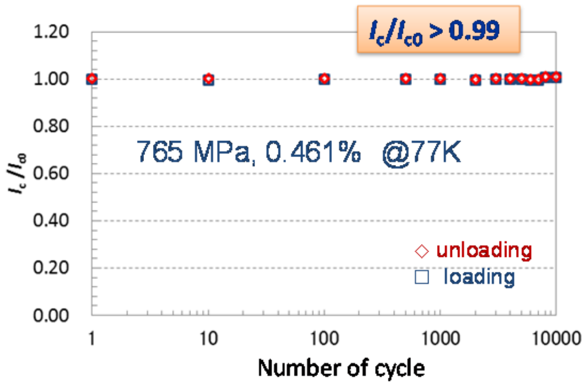

Fig. 1 Results from 10,000 cyclical tensile tests conducted in liquid nitrogen

A project commissioned by NEDO entitled, "R&D of Fundamental Technologies for Superconducting AC Power Equipment", fabricated a 15m-long prototype power cable comprising of 4-layers and a total of 60 IBAD/PLD wire strands (4mm-width) twisted. The cable successfully achieved a low loss of 1.4 W/m at 77 K and 5000 A (Figure 2). This result implies that reducing wire volume reduces the thermal loads for an equivalent capacity cable. This confirms that the utilization of highly homogeneous Y-based coated conductors reduces the influence of vertical magnetic field components acting at the wire boundary area, offering the prospects of a reduction in costs associated with cable manufacturing.

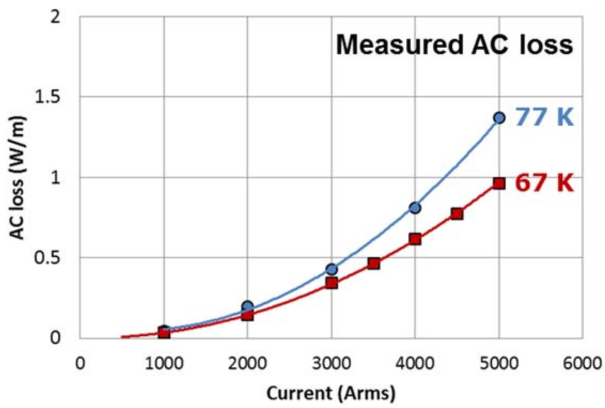

Fig. 2 Measured AC loss of a 15m-long prototype cable fabricated utilizing IBAD/PLD wires

The author expects that by focusing on the high performance homogeneity characteristics afforded by Y-based coated conductors produced by IBAD/PLD methods, progress of R&D efforts and verification trials aiming for mass-production will realize a further cost reduction in future. Present development is ongoing for the production of a large-scale hot-wall system production line assumed for a 10mm-width wire production of 300 km/year. Further improvement of quality, yield and production capacity is to be investigated.

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Feature Article: Progress in Superconducting Wire Technology - Technology Trends in Y-based Coated Conductors (Industrial Trends)

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SWCC Showa Cable Systems Co., Ltd.

SWCC Showa Cable Systems have developed Y-based coated conductors based on a TFA-MOD (Trifluoroacetic acid – metal organic deposition) method, introducing artificial pinning centers in order to improve in-field characteristics. Advancements have been realized under the "Materials & Power Applications of Coated Conductors (M-PACC)" project, which successfully concluded last year. Non-superconducting nanoparticles of $BaZrO_3$ (BZO) have been dispersed into the superconducting layer, thereby introducing pinning centers into the wire. This wire is termed "nPAD-YBCO® (nano-Particle Artificial-pinning-center Distributed YBCO)", and is currently being prepared towards mass production.

Figure 1 shows the architecture and the outline of the nPAD-YBCO® wire. The wire has a stabilized layer, superconducting layer and highly textured buffer layers, which are fabricated onto 0.1mm-thick high strength metal Hastelloy™ tape.

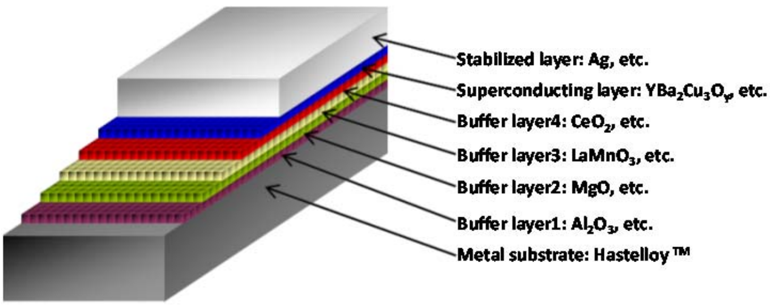

Fig. 1 Architecture and outline of nPAD-YBCO®

In the TFA-MOD method, a metal-organic salt solution route for fabrication of yttrium-based superconductor is formed and coated onto the highly textured buffer layers, which are deposited on the metal substrate. Calcinating and sintering follow. The company employs a batch sintering heat-treatment process, the characteristics of which enable sintering to be completed in around two days. This method is used to fabricate nPAD-YBCO® wires employing a manufacturing process similar to that used for the production of YBCO coated conductors. Hence, manufacturing costs are comparable. Presently, the company aims to mass-produce two types of wires; YBCO coated conductors and nPAD-YBCO®, providing specific wires as dictated by application specifications.

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Until now, current leads utilizing Bi-based bulk superconductors have been sold with sales figures exceeding 1000 leads. There were, however, some issues related to the bulk superconductor including weakness from bending and external impacts and difficulties associated with increasing yields effortlessly. In particular, a number of issues associated with Bi-based superconductors arose when exposed to magnetic environments and therefore restricted their installation environment. The latest successful development of nPAD-YBCO® superconducting current leads has circumvented any issues associated with external magnetic field environments. Figure 2 shows nPAD-YBCO® superconducting current leads along with their associated major specifications described in Table 1.

The development of superconducting current leads have until now been undertaken by employing a variety of superconducting wires. However, in-field characteristics had reached an impasse and low thermal leak characteristics were difficult to realize due to the large volume of wires required. The utilization of nPAD-YBCO® allowed for the volume of wires consumed in superconducting current leads to be reduced and low thermal leak characteristics successfully realized as shown in Table 1. Market introduction and sales of nPAD-YBCO® superconducting current leads are now future objectives.

Fig. 2 nPAD-YBCO® superconducting current leads

Table 1 Major specifications of nPAD-YBCO® current lead

Items	YPL①	YPL②	YPL③
Rated current (A) [@77K, Self field]	250	500	1,500
Thermal leak (W) [77K-4.2K]	0.02	0.05	0.11
Size (mm)	$220^{L}\times 9^{W}\times 16^{t}$	$220^{L}\times 16^{W}\times 16^{t}$	$220^{L}\times 23^{W}\times 16^{t}$

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Feature Article: Progress in Superconducting Wire Technology - Technology Trends in Y-based Coated Conductors (Industrial Trends)

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Furukawa Electric and the Railway Technical Research Institute published a press release on 10 March 2014 regarding the successful development of a high-temperature superconducting magnet specifically aimed for the next generation flywheels. The development has been undertaken as part of a project entitled, "Development of Safe, Low-cost, Large-size Technology for Battery Systems," commissioned by the New Energy and Industrial Technology Development Organization. Together with current-carrying characteristics of 110A, it was confirmed to have a levitation force exceeding two tons.
（http://www.furukawa.co.jp/what/2014/kenkai_140310.htm）

The coil employs the next generation high temperature superconducting wires (REBCO coated conductors), manufactured by SuperPower in USA. SuperPower has successfully fabricated REBCO coated conductors at remarkably enhanced deposition speeds with the introduction of an IBAD-MgO buffer layer. The MOCVD method was selected to fabricate the superconducting layer from the viewpoint of its deposition speed, the introduction of artificial pinning centers and maintenance costs. Currently, this is the world's first mass-produced and commercially available high performance (high I_c) wire. SuperPower's present aims in collaboration with Waukesha Electric Systems are the development and demonstration of a fault current limiting superconducting transformer that employs 2G wires. The ARPA-E REACT project, promoted by the DOE and in collaboration with the University of Houston and others since 2011, has developed and enhanced in-field characteristics specifically aimed for wind power applications. SuperPower employs a 17 T-class high-field superconducting magnet owned by Furukawa Electric. The evaluation of I_c-B characteristics has been undertaken jointly with the development of a high-field MRI and wire development aimed at an insert coil. SuperPower is planning to advance wire development by employing artificial pinning centers, which are necessary for future high-field and high strength magnets.

SuperPower/Furukawa Electric as the leading company producing 2G wires endeavors to work day and night to realize performance enhancements at low costs, aiming to contribute to society through the realization of 2G-wire application technology with close collaborations with its clients.

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Feature Article: Progress in Superconducting Wire Technology - Current Status of DI-BSCCO Wires and the Prospects for 2014

Kazuhiko Hayashi, General Manager
Superconductivity Technology Division
Sumitomo Electric Industries, Ltd.

DI-BSCCO wires (Bi2223) have been utilized in demonstration and research trials applicable to an array of fields including cable and coil applications (including current leads).

In general, the self-field critical current values (I_c) measured at 77 K are representative of wire characteristics. However, operational conditions (temperature and magnetic field) actually differ depending upon the cable and coil applications. Thus, I_c characteristics need to be improved according to specific operational conditions. Wire manufacturing for coil applications in particular, operating at less than 30K which is attainable by cryocooler, has already employed methodologies to improve in-field I_c characteristics by controlling the carrier-doping in Bi2223 superconductors during the manufacturing process. Coil applications also necessitate enhanced critical current density (Je) characteristics of superconducting wires in order to realize compact designs. The development has involved the employment of wire thinning processes realized by improving wire drawing and rolling techniques without degrading I_c characteristics. Currently, the prospects of these wires involve the development of 0.20 mm-thick DI-BSCCO wires that are 0.03mm thinner compared to conventional Type H wires and are now heading towards early commercialization.

Mechanical strength attributes of the wires needs to be taken into account when considering commercial applications. To address this and increase mechanical strength characteristics of DI-BSCCO wires, a method of soldering metallic tapes on both wire surfaces has been employed and led to increased mechanical strength without compromising I_c characteristics. Type HT-CA and Type HT-SS wires, comprising of a brass or a stainless steel tape, respectively, have currently been commercialized. The majority of Type HT-CA wires are destined for cable applications. Coil applications require highly reinforced superconducting wires that are tolerant to hoop stresses that are present at high fields and in larger-scale superconducting magnets. The Type HT-SS wire has not been applicable for some high-field coil applications due to lack of mechanical tolerance. To address this, reinforced metallic tapes with greater tensile strengths than stainless have recently been proposed. A prototype Type HT-XX wire fabricated utilizing this reinforced metallic tape has realized more than 500 MPa of tensile strength at 77 K, around twice as strong compared to Type HT-SS and Type HT-CA wires. This wire is therefore anticipated to be applicable to a variety of coil applications and early commercialization is the principle aim.

Table 1 shows the current and the new product line-ups planned for 2014. A Type G wire has low thermal conductivity characteristics realized by utilizing a gold-silver alloy matrix, and achieving worldwide deliveries of current leads to magnet manufacturers for fusion and accelerator applications. A slim wire Type ACT-CA developed for AC application has reduced AC loss by twisting the Bi2223 superconducting filaments.

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Table 1 Current and new product line-ups planned for 2014

Wire Type	Type H	Type H released in 2014	Type HT-SS	Type HT-CA	HT-XX released in 2014	Type G	Type ACT-CA
Average width (mm)	4.3±0.3	4.3±0.3	4.5±0.3	4.5±0.3	4.5±0.3	4.3±0.3	2.8±0.3
Average thickness (mm)	0.23±0.03	0.20±0.03	0.30±0.04	0.36±0.04	0.28±0.04	0.23±0.03	0.31±0.04
Reinforcement	-	-	stainless steel	brass	XX	-	brass
Ic@77K, sf (A)	180, 190, 200						60, 70
Je@Ic Max @77K, sf (A/mm2)	200	230	145	120	155	200	80
Permissible tensile stress @R.T.(mm)	80	80	230	280	500	50	150
Permissible tensile strength @77K (Mpa)	130	130	270	250	500	90	270
Permissible bend diameter @R.T.(mm)	70	70	60	60	40	110	40

※ Mechanical strength equivalent to critical currents falling down to 95 % (reference value).
※ Specifications of new products planned for 2014 may change.

Prospects for 2014 include the commercial sales launch of DI-BSCCO wires, 0.03mm thinner than conventional Type H wires from April onwards. The aim is to transfer entirely from Type H wires from June onwards. Accompanying the change from Type H wire strands, Type HT-SS and Type HT-CA will also be thinned. The plan now is to supply prototype Type HT-XX wires exhibiting superior mechanical strengths of 500 MPa at 77 K with the aim of adding this to the product line-up before June.

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Feature Article: Progress in Superconducting Wires Technology
- Progress in MgB_2 Wire Process Technology

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The PIT (power-in-tube) method is the mainstream technique currently employed to fabricate MgB_2 wires. The method involves heating raw MgB_2 powders filled in a metal tube to process the wires. There is an issue of low J_c associated with these wires due to the low filling factor of MgB_2. An alternative route to processing is the so-called IMD (Internal Mg diffusion) method [1], which involves placing B powder concentrically around an Mg rod and forming MgB_2 by Mg diffusion. Filling factors close to 100 % have been realized via this method, which significantly enhances the J_c per MgB_2 layer. This has recently sparked wire development activities employing the IMD method. However, it is well recognized that the IMD method leaves a large air-hole at the center of the superconducting filament. Despite this, the IMD method significantly increases J_c because of notable improvements in filling factors, producing higher $J_c(J_e)$ per wire cross-sectional area compared to PIT wires even when taking into account the air-hole.

The purity of the starting raw powder is important for MgB_2 wire fabrication. In particular, it is well known that the purity of B powder significantly influences J_c. The addition of carbon or its compound in the starting raw powder is well known to considerably improve J_c of MgB_2 wires operating in high magnetic fields. Recently, carbon-coated high purity amorphous B powders have been utilized as the starting raw material and MgB_2 wires exhibiting both high J_c and J_e have been fabricated utilizing IMD method [2)-4)]. Figure 1 shows the typical J_c-H characteristics [4] of MgB_2 wires fabricated utilizing carbon-coated B powders by the IMD method, which are compared to the characteristics of PIT MgB_2 and practical Nb-Ti/Nb_3Sn wires. IMD wires utilizing carbon-coated B powders have realized J_c exceeding 10^5 A/cm^2 at 4.2 K, 10 T, and 76,000 A/cm^2 at 20 K, 5 T. Furthermore, J_c values far exceeding 10^5 A/cm^2 have also

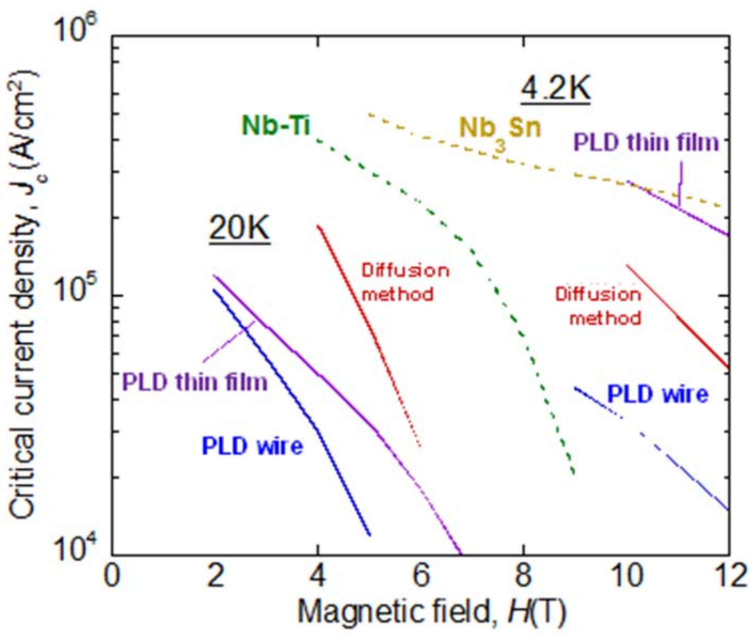

Fig. 1 J_c-H characteristics of MgB_2 wires measured at 4.2 K and 20 K, produced utilizing the internal Mg diffusion (IMD) method. For comparison, the characteristics of PIT MgB_2 wires and practical Nb-Ti/Nb_3Sn wires are also shown.

been realized at 20 K, 4 T, with a J_c exceeding 130,000 A/cm^2 at 4.2 K, 10 T recorded quite recently. The measured J_c characteristics are higher than those of well-known SiC added wires, where it is believed that Mg_2Si precipitation becomes the J_c limiting factor for wires with SiC additions [5]. Recent IMD wires have J_e exceeding 10,000 A/cm^2 at 4.2 K, 10 T. A research group at the University of Florida and Hyper Tech Research, Inc. have achieved J_e exceeding 17,000 A/cm^2 at 4.2 K, 10 T [2]. Future optimization of the IMD method is anticipated in order to further enhance J_c and J_e characteristics. R&D for long wires produced utilizing the IMD method is now going to commence. As mentioned above, since practical-level J_c at 20 K is soon to be realized, it will become a reality to utilize MgB_2 wires operating at around 20 K without employing liquid helium.

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Feature Article: Progress in Superconducting Wires Technology - Development Trend in HTS Conductor for Fusion Applications

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Nuclear fusion is one of the key solutions to prevent global warming, using a virtually unlimited supply of fuel with high reliability and benign environmental impact. Moreover, it is also foreseen as the ultimate energy source able to manage the effects of global cooling in some future. Presently, international collaborations between seven members including Europe, Japan, USA, Russia, China, Korea and India are involved progressively in the construction of the International Thermonuclear Experimental Reactor (ITER) in Cadarache, South France. The JT-60SA is being constructed in Japan as part of "Broader Approach". For these systems, cable-in-conduit (CIC) conductors make up the superconducting coil that generates a magnetic field for plasma confinement. The toroidal field (TF) coil conductor employed in ITER is capable of carrying 68 kA current at a maximum magnetic field of 11.8 T. The CIC conductor is the world-standard conductor utilized in large-scale coils due to its cryogenic stability and reduced AC loss specifications. Japan is responsible for the fabrication of quite a large volume of the superconducting cables and coils required by ITER and JT60-SA, which are currently ongoing.

ITER aims to sustain nuclear fusion burning for up to 1000 seconds. The construction of a prototype or DEMO reactor is later planned to demonstrate the desired steady and quasi-steady power generation characteristics. With a target set for the early 2040s, each country is intensely discussing how they can proceed with its construction. A DEMO reactor will be much larger than ITER and with greater technical issues associated with the magnet – the heart of the reactor. Specifically, discussions are ongoing as to whether the adoption of a CIC conductor is satisfactory as an extension of the technologies employed in ITER. Other questions include: can strain-resistant Nb_3Al strands be used instead of Nb_3Sn strands? Will further increases in scales be a problem at ITER? Have issues associated with the degradation of critical current due to repeated excitations been circumvented by optimizing the wire twist pitch? Additionally, it is assumed that the construction of the DEMO reactor will lead to the deployment of many more reactors designed for commercial use, aiming for their introduction in the 2050s. It is therefore desired for manufacturing to be kept easy by adopting simple coil windings having a simple cooling architecture. Here, there is an opportunity to solve many of these issues arising during the conceptual stages by replacing low-temperature superconducting (LTS) wires with their high-temperature superconducting (HTS) wire equivalents. This option is almost becoming a reality with the rapid progress in wire characteristics and manufacturing technology seen in recent years.

The investigations of HTS conductors applicable to large-scale magnets still remain at a relatively limited, with gradual developments mainly undertaken by activities in Europe and USA. It is well known that the following three HTS strands are the mainstream of discussions: (1) Roebel-Assembled Coated Conductor (RACC) by W. Goldacker (KIT) [1)], (2) Twisted Stacked-Tape Cable (TSTC) by M.Takayasu (MIT) [2)], and (3) Conductor on Round Core (CORC) by D. van der Laan (ACT) [3)]. (1) The initial proposal of RACC involved

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introducing a spatial transposition in the tapes, however, it is necessary to cut out a part of the tapes. A Rutherford-type cable is adopted by employing a number of Roebel coated conductors, which are twisted to increase the current carrying capacities. (2) TSTC completely twists the stacked tapes. Although there is no complete transposition between the tapes twisting can be introduced. The concept involves fabricating CIC conductors utilizing many TSTCs. (3) CORC employs a winding concept with a short-twist pitch by stacking the multiple tapes around the core. By twisting, a relatively small bend radius can be accommodated. A CIC conductor utilizing six CORCs has been conceptually proposed, leading to a potential utilization in fabrication of split TF coils with elaborately modified terminals. All the above-mentioned HTS strands have been successfully transposed and twisted by tactically taking advantage of the wire characteristics when flexed at small curvatures towards the flatwise direction of the tape. Currently, each prototype conductor has been fabricated and realized results ranging between 4-5 kA at 4.2 K, ~20 T. Additionally, elaborate efforts have been undertaken to fabricate higher capacity and longer wires, all introduced with complex tape twists that have produced local mechanical strains and which are now receiving a great deal of attention. Future attention has focused towards the successful completion of practical magnet applications, however, a detailed full-scale conceptual design of a practical large-scale coil winding utilizing these conductors is yet to be proposed.

As the forth conductor candidate, a research team based at the National Institute of Fusion Science (N. Yanagi, Y. Terazaki, A. Sagara) and the Department of Quantum Science and Energy Engineering at Tohoku University (S. Ito, H. Hashizume) have been jointly developing a “simple-stacking HTS tape conductor”. This development has advanced for helical fusion reactor applications. Differing from the tokamak, the helical magnetic configuration does not utilize pulses as part of its operation. Regardless of whether more or less non-uniform current distributions are accompanied by slow coil excitations generated between the tapes, these are permissible since the HTS tapes essentially features high cryogenic stability. Thus, this concept could be a counter option to the general approach to employ wire thinning, twisting, transposed conductor structure, all of which have been widely applied to LTS conductors [4]. Simple-stacking conductors do not have local fractures within the tape. Moreover, since the tapes are embedded in copper and stainless steel jackets without voids between the wires, the entire conductor is greatly reinforced than compared to CIC conductors (a cross-section has around 30 % voids).

Currently, a simple-stacking HTS tape conductor prototype has undergone demonstration trials [5)-7)]. By employing a total of 54 GdBCO tapes manufactured by Fujikura (FYSC-SC10, 10 mm-width, 0.22 mm-thick, critical current ~600 A@77 K, s.f.), a 3-row x 18-layer simple-stacking tape has been embedded in copper and stainless steel jackets. Figure 1 shows the basic architecture of the HTS conductor sample. This sample has been fabricated into a racetrack-shape single-turn short circuit coil and has undergone comprehensive current loading tests by modulating the external magnetic fields [5)]. The entire HTS conductor sample is shown in Figure 2. The conductor was

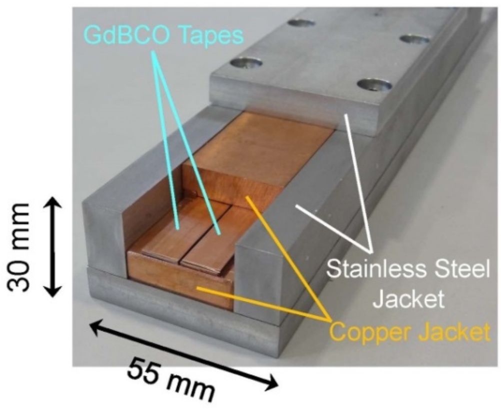

Fig. 1 The structure of a simple-stacking HTS tape conductor (This photo is a mock-up with 2-rows x 6-layers of GdBCO tapes. Actual conductor sample is 3-rows x 14-layers

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connected by bridge-type mechanical lap joint, developed by Tohoku University, at one side of the straight region [6]. The test results showed that a current of 100 kA was successfully applied at 20 K with an external magnetic field of 5.3 T (Figure 3). At this point, a rapid attenuation of current occurred due to quenching at 100 kA. The reason behind this was not due to the part under test, but instead, due to the curved region, which had less number (42) of HTS tapes. The future plan is to modify this area and repeat the tests. A case study where quenching did not occur at elevated temperatures of up to 45 K can be used here to explain the entire critical current of the conductor by self-consistent analysis of the self-field and current distribution within a conductor, based upon the critical current characteristics in single tape [7]. A maximum current of 120 kA has been achieved at 4 K without quenching, and current attenuation has occurred because of joint resistance, which was determined to be 2 nΩ, as evaluated by time constant of the current decay and the self-inductance of the sample. We consider that employing this joint architecture can speed up the fabrication of continuously wound helical coils exceeding 30m-diameter. Further investigations are now ongoing for the “joint winding” by connecting short conductors using this joint architecture [4)-7)] (Figure 4). Adequate automated joining technology using industrial robots needs to be established in order to completely realize a several-thousand joint architecture. Once this has been established, the author expects that this approach can be applicable to other potential large-scale and complex-structured magnets applications.

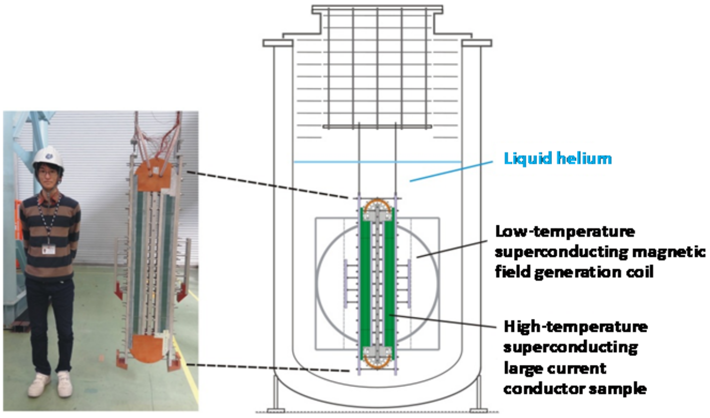

Fig. 2 Complete picture of the conductor sample and an overview of its installation in the NIFS large-scale conductor testing system.

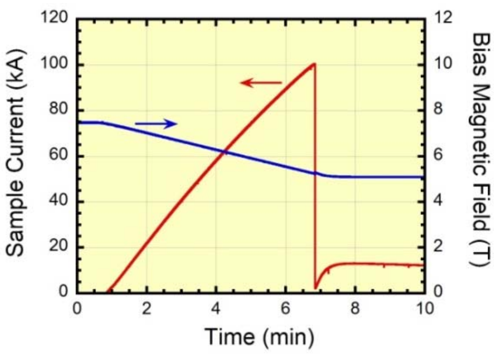

Fig. 3 An example of current loading test results at 20 K. An external magnetic field of 5.3 T realized when max current

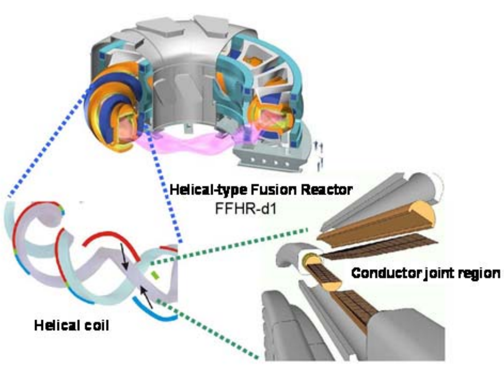

Fig. 4 Conceptual illustration of joint winding of HTS Helical coil

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