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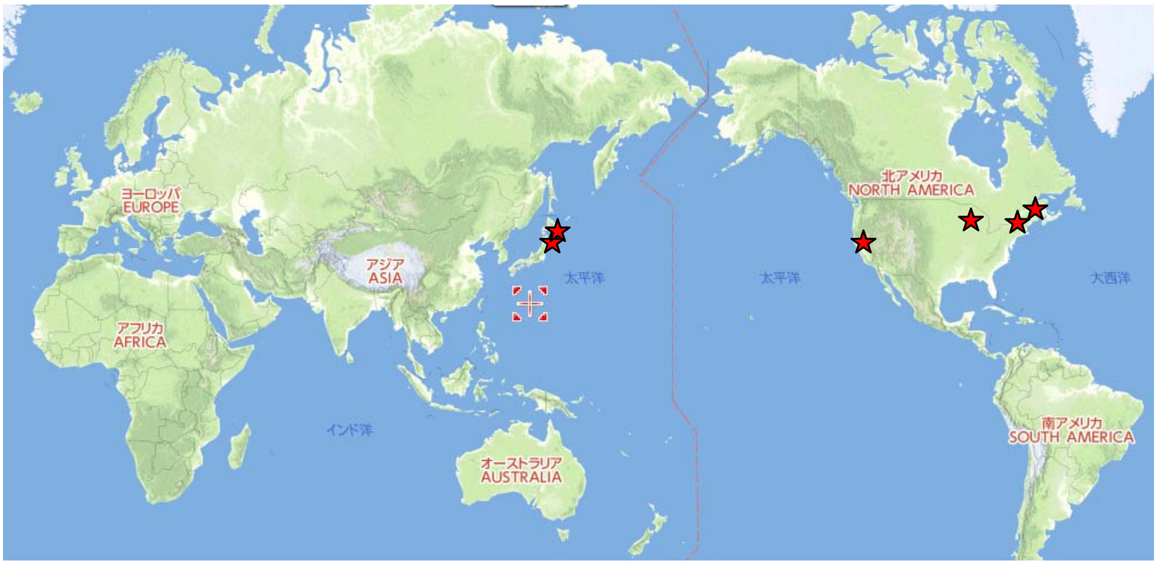
What's New in the World of Superconductivity

초전도 뉴스 −세계의 동향−

超电导新闻 −世界的动向-

chāo diàn dǎo xīnwén - shìjiè de dòngxiàng-

Yutaka Yamada, Principal Research Fellow
Superconductivity Research Laboratory, ISTEC



★News sources and related areas in this issue

▸Wire 선 재료 線材料 [xiàn cáiliào]

Low-cost Cu Substrate for YBCO Wire

Tanaka Holdings (7 Apr, 2015)
Tanaka Holdings Co., Ltd have announced that Tanaka Kikinzoku Kogyo K.K. has constructed exclusive production lines for textured Cu metal substrates using YBCO superconducting wire and has established mass production systems for operation planned for April 2015.

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This superconducting wire replaces the use of Ni alloys, with low-cost and high orientation copper, thereby reducing costs by more than 50 %. One of the weaknesses of copper is its susceptibility to oxidation, which can lead to thin film delamination. However, the orientation and the surface smoothness can be improved by the use of a nickel-plating solution that contains palladium as the oxygen metal barrier layer.

Production began and samples were distributed from December 2008. It was in October 2008 when Tanaka Kikinzoku Kogyo together with Chubu Electric Power and Kagoshima University jointly developed the first ever textured Cu metal substrates using superconducting wire. It is expected that this technology will be applicable to long-distance and high-capacity electricity supply cables, Magnetic Resonance Imaging (MRI) and Nuclear Magnetic Resonance (NMR), which require high magnetic fields, and motors for large ships. The company is aiming to achieve annual sales of 1.2 billion yen by the year 2020.

Source: "Establishment of Mass Production System for Textured Cu Metal Substrates Using YBCO Superconducting Wire" (7 Apr, 2015) Topics
http://pro.tanaka.co.jp/en/topics/fileout.html?f=170

▸Industrial Application 산업응용 工业应用 [gōngyè yìngyòng]

HTS Degaussing System for US Navy Ship

AMSC (20 Apr, 2015)

The U.S. Navy is to use AMSC's high temperature superconductor (HTS) equipment to develop HTS power cable hardware for shipboard power applications, in particular AMSC's advanced HTS degaussing systems. Such degaussing systems reduce the magnetic signature of a ship, offering protection from undersea mines. HTS is an enabling technology for advanced degaussing systems on platforms where weight and power limitations are crucial in order to improve power efficiencies. HTS versions of such technologies require significantly less power to operate and can reduce the overall degaussing system weight by 50-70 %.

AMSC has been working jointly with the Navy Metal Working Center of Excellence to streamline manufacturing costs associated with HTS degaussing cables. The advanced cable making process knowledge gained via the Manufacturing Technology or ManTech programme, has been optimized and is expected to meet the delivery and cost targets associated with full ship production.

Daniel P. McGahn, President and CEO, AMSC is quoted as saying, "prototypes of the HTS advanced degaussing systems on surface platforms have been developed, with the systems having travelled close to 75,000 miles and compiled over 20,000 hours of run time". AMSC is working to expand HTS technology into the US Navy's fleet via a number of applications for power, propulsion, and protection equipment.

Source: "AMSC Announces U.S. Navy's Intention to Order High Temperature Superconductor (HTS) Equipment" (20 Apr, 2015) Press Release
http://ir.amsc.com/releases.cfm

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Contact: Kerry Farrell, Kerry.farrell@amsc.com

▸ Accelerator 加速器 [jiāsùqì] 가속기(加速氣)

First Nb_3Sn Accelerator Magnet

DOE National Laboratories (20 Apr, 2015)

A superconducting magnet made of niobium-3-tin or Nb_3Sn, developed and fabricated at DOE's Fermi National Accelerator Laboratory has successfully reached its design field of 11.5 Tesla. As a comparison, the Nb-Ti dipole magnets built in the early 1980s for the Tevatron particle collider produced about 4 Tesla. The most powerful niobium-titanium magnets used in the Large Hadron Collider operate at roughly 8 Tesla. This is the first reported twin aperture accelerator magnet, realized after decades of worldwide R&D efforts both in the Nb_3Sn conductor itself and in associated magnet technologies.

Advancements in Nb_3Sn magnet technology and the continuing collaborative development with CERN are enabling the use of this innovative technology for future upgrades of the Large Hadron Collider.

Source: "New superconducting magnet achieves high-field milestone"
(20 Apr, 2015) DOE Pulse
http://web.ornl.gov/info/news/pulse/no437/story3.shtml
Contact: Kurt Riesselmann, media@fnal.gov

►Fusion 핵융합반응 聚变[jùbiàn]

1,000-ton Superconducting Magnet for ITER-CS

General Atomics (10 Apr, 2015)

General Atomics (GA) is to fabricate the ITER Central Solenoid, comprising a 1,000-ton superconducting electromagnet that will initiate and drive a hot plasma for fusion energy. GA is a California-based technology innovation firm that has been a world leader in fusion research for more than half a century.

ITER is an international nuclear fusion research project involving the collaboration between 35 nations, which aims to design and build the world's largest experimental tokamak fusion reactor. Ned Sauthoff, U.S. ITER Project Director said, "The central solenoid represents the heartbeat of ITER, allowing magnetic pulses that drive electric current through the Tokamak plasma. General Atomics' contributions are critical for the success of the project."

Fabrication of the solenoid involves winding 4 miles of metal conductor into coiled layers for the 250,000 pound magnet modules. GA will fabricate 7 modules, with 6 making up the central solenoid and one acting as a reserve. Fabrication comprises of 10 custom manufacturing stations for the superconducting magnet, which includes a 200-ton capacity air-driven transport cart, a 1200 °F two-story convection oven and a

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two-story insulating machine that will apply 125 miles of fiberglass tape.

Source: "General Atomics Fabricates the World's Largest Superconducting Electromagnet"
(10 Apr, 2015) News & Media
http://media.ga.com/2015/04/10/general-atomics-fabricates-the-worlds-largest-superconducting-electromagnet/
Contact: Lisa Petrillo, lisa.petrillo@ga.com

►Electronics 엘렉트로닉스 电子应用 [diànzǐyè yìngyòng]

Building First Practical Quantum Computer

IBM (29 Apr, 2015)

For the first time, IBM scientists revealed the ability to detect and measure two types of quantum errors (bit-flip and phase-flip) simultaneously. In addition, they have demonstrated a novel square quantum bit circuit design based on a square lattice of four superconducting qubits - the only physical architecture that could successfully scale to larger dimensions by adding more qubits to arrive at a working quantum system.

These findings are critical advances towards quantum error correction that brings us one step closer towards the realization of a practical and reliable large-scale quantum computer. Quantum computers with just 50 qubits could offer new capabilities in the fields of optimization and simulation not possible using any combination of today's top 500 superconductors combined together.

"Until now, researchers have been able to detect bit-flip or phase-flip quantum errors, but never the two together. Previous work in this area, using linear arrangements, only looked at bit-flip errors offering incomplete information on the quantum state of a system and making them inadequate for a quantum computer," said Jay Gambetta, a manager in the IBM Quantum Computing Group. For Big Data requirements, quantum computers could quickly sort ever-larger databases as well as massive stores of diverse, unstructured data, eventually transforming the way people make decisions and how researchers make critical discoveries.

The work at IBM was funded in part by the IARPA (Intelligence Advanced Research Projects Activity) multi-qubit-coherent-operations program. Their work is described in the April 29 issue of the journal Nature Communications.

Source: "IBM Scientists Achieve Critical Steps to Building First Practical Quantum Computer"
(29 Apr, 2015) News Release
https://www-03.ibm.com/press/us/en/pressrelease/46725.wss
Contact: Christine Vu, vuch@us.ibm.com

▸Basics 기초 基础[jīchǔ]

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How to Maximize T_c

Tohoku University (20 Apr, 2015)

An international research team, led by Professor Kosmas Prassides of Tohoku University, has studied the electronic properties of unconventional superconductor, which is based on a new family of chemically-pressurized fullerene materials. The research team has addressed for the first time the relationship between the parent insulator, the normal metallic state above *Tc* and the superconducting pairing mechanism in this unconventional superconductor.

Results published in the American scientific Journal Science Advances, demonstrated the influence of the molecular electronic structure in controlling superconductivity and achieving the maximum *Tc*, thereby providing alternative novel routes in the pursuit of new molecular superconductors.

The studies also uncovered a new state of matter - the Jahn-Teller metal, and also showed that optimizing the molecular and lattice characteristics of the electrons at the Fermi level attained the highest achievable temperature for the onset of superconductivity.

The influence that the electronic structure has on superconducting characteristics was determined by demonstrating that the insulating parent state involves Jahn-Teller distortion of the anions that produce magnetism (Nature Communications 3, 912, 2012). Since chemistry allows the fabrication of new electronic structures distinct from most known superconductors, there is greater enthusiasm to seek for new molecular superconducting materials.

Source: "How to maximize the superconducting critical temperature in a molecular superconductor" (20 Apr, 2015) News
http://www.tohoku.ac.jp/en/news/research/news20150420.html
Contact: Prof. Prassides Kosmas, k.prassides@wpi-aimr.tohoku.ac.jp

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Feature Article: Progress in Superconducting Wire Technology -Prospectus of Fujikura's PLD RE-based Wires

Yasuhiro Iijima, Director
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New Business Promotion Center
Fujikura Ltd.

RE-based wires fabricated by PLD have progressed mainly in Japan under the NEDO project, where since the initial stages of development the aims have been for long wire production by combining a buffer layer on an IBAD substrate. Fujikura employs a superconducting thin film deposition method (hot-wall), equally distributing radiant heating around the entire PLD chamber to increase homogeneity over the entire 300-500 m wire length. To increase production capacities, the construction of a large-scale hot-wall production line equipped with load-lock is currently under development. Recent performance improvements in laser oscillators have led to the commercial launch of reel-to-reel deposition systems. Newly emergent companies such as Super-OX in Russia have appeared on the market.

Crystal growth occurs rapidly due to the high energies used to evaporate materials during PLD growth and there is a tendency that micro defects are evenly distributed within the material. Current understanding points towards this being one of the reasons behind the relatively large flux pinning characteristics observed in these materials. In particular, the in-field characteristics measured at low temperature regions, which are important attributes for coil designs scale accordingly with the measurements conducted at higher temperatures. Therefore, at operating temperatures, sufficient longitudinal homogeneity at the magnetic field region is an advantage that is expected. Future plans include realizing thin films with artificial pinning centers that have enhanced homogeneity characteristics as well as production capabilities that would reduce costs further - these have been the current issues surrounding RE-based wires.

On the other hand, RE-based wires are architecturally weak and have issues with delamination. It is therefore desirable to form a mold release between the resin and wire when using resin impregnation for the coil windings. Fujikura realized such functionality in 2012 by employing elaborate impregnation methodology, which preserved mechanical rigidity, producing a 20 cm-bore 5 T-class magnet. There has been two years of trouble free operation with no signs of degradation. As well as the wires utilized for coil development, the low manufacturing costs of soldering copper plates has proved commercially viable for enhancing stability characteristics. Currently, in addition to coating the entire circumference with copper plates, new copper-forming techniques to coat using copper foils have been developed and resulted in significant stress tolerance enhancement at the wire edges. Additionally, improved hermetic methods with remarkably better moisture characteristics compared to conventional products have been proposed. Their commercial launch is planned from 2015.

Research efforts are continuously being dedicated towards yield improvements. For example, enhancing processes that yield greater production capabilities and introducing artificial pinning, all to realize structures that can meet customer-required production volumes. Developments are also pursuing mechanically reliable wire fabrication methods that are more tolerant to a range of stresses that occur during coil winding

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and is currently the disadvantage of RE-based wires. For high precision applications such as NMR, MRI and accelerators it is necessary to reduce shield current in rectangular wires by using filament wires. Future progression plans include the introduction of scribing techniques to achieve higher productivities by forming 4 mm-width copper wire structures that will become commercially available later.

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Feature Article: Progress in Superconducting Wire Technology

-Current Status of DI-BSCCO Wires and the Prospects for 2015

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

DI-BSCCO wires manufactured by Sumitomo Electric Industries, Ltd. are utilized in demonstration and research trials in Japan and overseas, being applicable to cables, coils and current-lead applications.

A multi-filament Bi2223 superconductor coated with silver or a silver alloy allows the otherwise fragile oxide-based superconductor to be formed into filaments, enabling superconducting tapes with flexible properties to be fabricated. However, there are reported issues with high concentrations of silver reducing the mechanical strength of such wires. To address this issue a method of soldering a metallic tape (reinforcement) on Type H wire surfaces has actually led to the commercial launch of both Type HT-SS wires aimed mainly for coil applications and Type HT-CA wires aimed mainly for cable applications. However, superconducting wires with a tensile strength greater than 400 MPa are required for high-field magnet applications over 20 T or for large-scale magnet applications. Here, as a result of advanced studies and the fabrication of wire prototypes with enhanced strength compared to present DI-BSCCO wire product line-ups, Type HT-NX wires that satisfy 400 MPa tensile strength requirements have been developed. Type HT-NX wires have been reinforced by utilizing a high strength Ni alloy which exhibits a higher Young's modulus and greater tolerance compared to stainless tapes. Figure 1 shows the results of tensile testing of Type HT-NX wires at 77 K. Whilst BSCCO wires has been regarded as having a lack of strength until now, Type HT-NX wires with 400 MPa tensile strength characteristics can be expected for impending wire development, broadening the design freedom for superconducting magnet applications. It is now planned that Type HT-NX wires will be included in the product line up at an early stage.

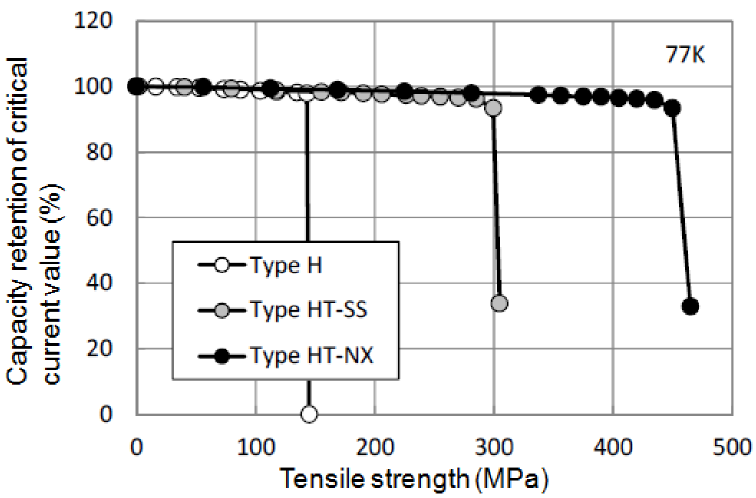

Fig. 1: The relationship between tensile strength and capacity retention of critical current value at 77 K, Three types of wires; Type H, Type HT-SS, Type HT-NX

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Table 1 shows the current available products and the new products planned for 2015. Type G wires exhibit low thermal conductivity characteristics realized by utilizing gold-silver alloy coated materials and are employed for current-lead applications. A record number of Type G wires have been shipped worldwide to magnet manufactures where they are employed in applications such as accelerators and nuclear fusion reactors. Type ACT-CA thin wires have been developed for AC applications, reducing AC losses by twisting Bi2223 superconducting filaments.

Table 1: Current products available and the new products planned for 2015

Wire type		Type H	Type HT-SS	Type HT-CA	Type HT-NX	Type G	Type ACT-CA
Average width	mm	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	0.30±0.04	0.36±0.04	0.31±0.04	0.23±0.03	0.31±0.04
Material reinforcement	−	−	Stainless steel	Copper alloy	Ni alloy	−	Copper alloy
Critical current value @77K, self-field	A	180, 190, 200					60, 70
Allowable tensile strength @77K	MPa	130	270	250	400	90	270
Allowable bending radius @room temperature	mm	70	60	60	40	110	40

* : Level to sustain 95% of critical current value

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Feature Article: Progress in Superconducting Wire Technology -Progress in MgB_2 Wire Processing Technology

Hiroaki Kumakura, Senior Scientist with Special Missions
Superconducting Wires Unit
National Institute for Materials Science

The author briefly highlights the recent developmental status of MgB_2 wires herewith. Firstly the powder-in-tube (PIT) method is discussed, which involves filling a metal tube with raw powder materials of MgB_2 and drawing into a wire form that is heated to produce the superconducting wires. Here, a research group at the Institute of High Pressure Physics in Poland has achieved high J_c by employing Hot Isostatic Press (HIP), utilizing the solid powder as the pressure medium[1)]. The wire strands are pure and SiC added monel-sheathed 6- and 18-filamentary wires fabricated with Cu-sheathed single filamentary wires with Nb barriers. Hypertech, USA, has supplied these wires. A five minute HIP process at 200 MPa, 700 °C, is performed using either graphite or BN powder as the pressure medium contained in a stainless steel container. Temperature changes are not rapid since heat capacities are significant. Thus, HIP-processed wires have demonstrated higher J_c compared to normal-heating processed wires. In particular, by employing the HIP method, wires processed without SiC additions have realized significantly high values of over 100 A/mm^2 (4.2 K, 10 T), which compares to 35 A/mm^2 (4.2 K, 10 T) attained by a normal heating process. The comparison between graphite and BN shows that BN can realize slightly higher J_c.

Contrary to the PIT method is an alternative route to processing, the so-called internal Mg diffusion (IMD) method that diffuses Mg to the external B powder to form MgB_2. The advantage of this method is the remarkable enhancement of J_c for MgB_2 layer, which comes from the improved MgB_2 filling factor. Recent wire development employing the IMD method has been actively progressed. A research group at Ohio State University has realized enhanced J_c characteristics in single filament MgB_2 wires processed by IMD, adding Dy_2O_3 nano powders into B powder [2)]. When 2 wt. % Dy_2O_3 was added, the measured J_c for the MgB_2 layer was high at 1.35x10^5 A/cm^2 (4.2 K, 10 T), an about 30 % improvement of J_c compared to the case without Dy_2O_3 additions. Also, J_c enhancement by this Dy_2O_3 addition becomes more significant with increasing temperature. In contrast, whilst the addition of well-known carbon and carbon compounds is effective in improving J_c at 4.2 K, there is almost no effect when the temperature increases over 20 K. It is understood that the J_c increases due to Dy_2O_3 additions is because of an increase in irreversibility field rather than enhanced flux pinning due to the additions.

On the other hand, NIMS employed the IMD method utilizing boron powder (average size 250 nm) with coronene ($C_{24}H_{12}$), which is a type of aromatic hydrocarbon, fabricating MgB_2 wires that exhibited a J_c of over 10^5 A/cm^2 and J_e of over 10^4 A/cm^2 at 10 T, 4.2 K [3)]. It is understood that one of reasons behind why $C_{24}H_{12}$ additions can lead to high J_c and J_e is due to lower melting point (438 °C) of $C_{24}H_{12}$ compared to its pyrolysis temperature and the reaction temperature of MgB_2. This enables B powder to be coated with $C_{24}H_{12}$ prior to a reactive heating process, which is considered to result in a homogenous carbon substitution for boron in MgB_2. However, in the case of most popular additive, SiC, it is difficult to homogeneously distribute SiC particles into the boron powder. Also, since Mg_2Si is precipitated as an impurity after heat treatment process, hydrocarbons such as $C_{24}H_{12}$ are considered more suitable as

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additives. Recently, 100 m-class wires have been fabricated with $C_{24}H_{12}$ additions utilizing IMD methods, heightening expectations towards future progress.

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3) S. J. Ye, *et al.*, Supercond. Sci. Technol. 27(2014) 085012.

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Feature Article: Progress in Superconducting Wire Technology -Progress in HTS conductors for Fusion Applications

Nagato Yanagi
National Institute for Fusion Science
National Institutes of Natural Sciences

The author herewith introduces the current developmental status of large-scale high temperature superconducting (HTS) conductors, which are applicable for potential magnets used in nuclear fusion reactors. Please refer to April 2014 issue and April 2010 of the Superconductivity Web21 for further information regarding the background and other related matters.

Currently, the construction of the International Thermonuclear Experimental Reactor (ITER) in Cadarache, France is progressing. Seven regional members that comprise EU, Japan, Russia, USA, China, Korea and India have been involved in the fabrication of components for ITER. In Japan, the fabrication of the toroidal field coils in particular is on track. On the other hand, parallel to the construction of ITER, are discussions involving each regional member for the potential transfer to a future DEMO reactor for nuclear fusion. The EU summarized a road map for the development of a DEMO reactor with its construction possibly beginning in the early 2030s. Also, China is making concrete plans to construct the China Fusion Engineering Test Reactor (CFETR), which will be a little smaller than ITER but a unique experimental reactor. In Japan, the "Joint-Core Team for the Establishment of Technology Bases Required for the Development of a Fusion DEMO Reactor" has been organized. The team summarized their report on future directions. According to (http://www.jspf.or.jp/2015/genkeiro/index.html), "Intermediate Check & Review" will be held to discuss whether or not the DEMO reactor will enter engineering design stages in 2020. Before that conceptual designs and component technology developments will need to be accelerated.

The superconducting magnet is the most crucial component required for magnetic confinement fusion. The required DEMO reactor is to be much larger than ITER with greater magnetic field capabilities. Current conductors adopt cable-in-conduit (CIC) principles that make up low temperature superconducting (LTS) wires. Nb_3Sn are the first wire candidates and further extensions of conductor technology beyond ITER and JT-60 SA are desired. The second candidates are Nb_3Al, which show much stronger strain characteristics. The third candidates are HTS conductors that presently offer long-term future developmental prospects. Their selection is considered remarkable since this option was not discussed several years ago and is attributed to the significant progress made in this area. This reflects the rapid progress made by HTS wire development and has already led to the production of practical wires. Here, the utilization of Yttrium-based wires as conductors for the fusion reactor magnet prove promising based upon the issues associated with low activation (due to low silver content) and their corresponding mechanical strength.

The discussion of HTS conductor development for nuclear fusion reactors has been led by Europe and USA mainly. The HTS4 Fusion Conductor Workshop has been held twice since 2011. However, since institutional budgets remain tight, discussions are focused on progressing the research under international collaborations. The following five types of HTS high-current conductors are the mainstream of discussions:

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(1) Roebel-Assembled Coated Conductor (RACC) by KIT Germany, (2) Twisted Stacked-Tape Cable (TSTC) by MIT, USA, (3) Conductor on Round Core (CORC) by ACT, USA, (4) Round Strand Composed of Coated Conductor Tapes (RSCCCT) by CRPP, Switzerland, and (5) Slotted Core HTS by ENEA, Italy. Each of the proposed conductors has been fabricated by elaborately twisting the wires and introducing transposition between the tapes. The current development of prototype conductors is aimed at being in the realm of 10 kA-class current.

In Japan, a research team based at the National Institute of Fusion Science and the Department of Quantum Science and Energy Engineering at Tohoku University, have been jointly developing a simple-stacking HTS tape conductor based upon a different concept derived from the above-mentioned five types of conductors. This development has advanced helical fusion reactor applications. Helical has the same torus-type magnetic confinement as world's mainstream tokamak, a typical ITER. The difference between the tokamak is that the helical is essentially a steady reactor since it does not require huge current flows in the plasma. Amongst helical systems, Japan specifically utilizes heliotron magnetic configuration, which was selected for NIFS's Large Helical Device (LHD). NIFS has advanced the conceptual design of helical reactor FFHR-d1, having 4-times larger LHD. Greater stabilities can be attained when using HTS conductors since helical magnetic configurations do not utilize pulses as part of their operation. This concept could potentially be an alternative to the general approach of currently employing multi-filamentary wires (strands), twisting, transposed conductor structure, all of which have been conventionally applied to LTS conductors. The entire conductor is thus mechanically and greatly reinforced.

A HTS conductor prototype was fabricated and has undergone demonstration trials at NIFS utilizing a 9 T large-scale conductor testing facility. Employing a total of 54 GdBCO tapes manufactured by Fujikura (FYSC-SC10, critical current~600 A@77 K, s.f.), a simple-stacking tape has been embedded in copper and stainless steel jackets (Figure 1(a)). A 3 m-long HTS conductor has been fabricated as a racetrack, single-turn short circuit coil, which has undergone inductive current loading tests by modulating external magnetic fields. The conductor was connected by a bridge-type mechanical lap joint at one side of the straight region, having been developed at Tohoku University. Test findings showed that a current of 100 kA was successfully applied at 20 K with an external magnetic field of 5.3 T, and 100 kA was successfully sustained over one hour at 4.2 K (Figure 1(b)). Based upon the critical current characteristics in a single tape, the critical current of the entire conductor can be explained by self-consistent analysis of the self-field and current distribution within a conductor. The joint resistance was determined to be 2 nΩ. We have proposed that by employing this joint architecture, fabrication speeds of helical coils exceeding 30 m-diameter can be greatly improved. Tohoku University is currently undertaking the mechanical testing for this joint winding and studying the development towards practical applications. NIFS is currently in the middle of preparing a large-bore high-field conductor testing facility with a max field of 13 T and a bore diameter 700 mm, and temperature control (4.2-50 K). Further short-conductor testing and coil testing of HTS conductors is planned in the near future.

The author briefly introduced the trends in HTS conductor applications aimed at nuclear fusion reactors, and further expectations and support towards their future progress is most appreciated.

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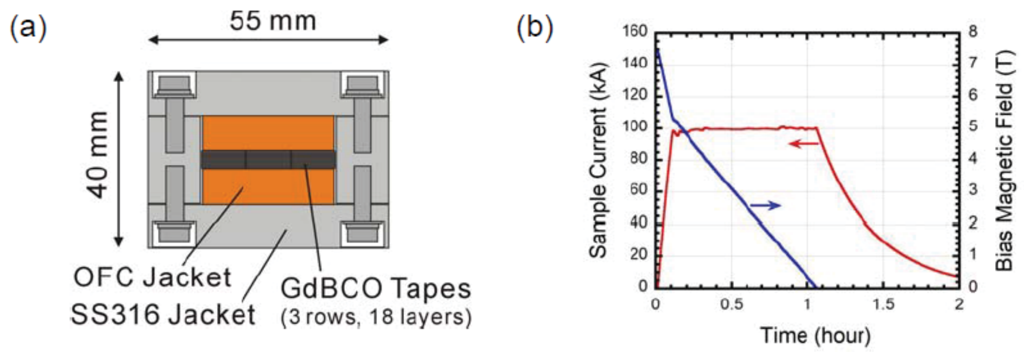

Figure 1(a) Cross-section of 100 kA-class STARS prototype conductor, and (b) an example of testing results (100 kA × one-hour current loading)

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