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Superconductivity

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Contents:

Top of Superconductivity Web21

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Reporting on The 2012 Forum on Superconductivity Technology Trends

Satoru Miyazaki, Director
Public Relations Division, ISTEC

Keynote lecture by Yuh Shiohara

The International Superconductivity Technology Center (ISTEC) held the 2012 Forum on Superconductivity Technology Trends at the Toshi Center Hotel, (2-4-1 Hirakawa-cho, Chiyoda-ku, Tokyo), at 9:30~17:00, on 21st May 2012.

The forum reported the research output from an array of projects, including the technological development of the Yttrium-based superconducting power equipment project entrusted and advanced by ISTEC. Companies, universities and research institutions, all of whom have been advancing research and development related to superconducting technology reported their latest topics. This annual forum is sponsored by Keirin Race of JKA to facilitate discussions for the future prospects for superconductor technology industrialization, as well as the strategic future direction of research and development in this area.

This year's forum kicked-off with opening remarks from Yutaka Kiyokawa, Executive Director of ISTEC, and was followed by congratulatory messages by guests including Hiroshi Fukushima, R&D Manager, Industrial Science and Technology Policy and Environment Bureau of Ministry of Economy, Trade and Industry, and Yoshiteru Sato, Director General, Energy and Environment Policy Department of New Energy and Industrial Technology Development Organization. A total of eleven lectures made up the forum - five delivered during the morning session with the rest delivered during the afternoon. The lecture theme was "25 years since the discovery of YBCO-based high temperature superconductors, and further development of superconductors", and reflected the fact that 2012 marks the 25th anniversary since the discovery of YBCO-based high temperature superconductors. The lectures touched upon historical aspects and future technological prospects of YBCO-based high temperature superconductors.

The authors will publish full details of their lectures in the Japanese version of the July edition of *Superconductivity Web 21*. This article provides a brief overview of those lectures.

A keynote lecture delivered by Yuh Shiohara, Director General of SRL/ISTEC, entitled *"Anticipating the realization of Yttrium-based superconducting wires and their applications"*, highlighted research and development trends in superconducting wire technology, stressing the fact that wire technology is one of the key fundamental technological drivers for development in this area. Its potential application to wind turbine generators and heavy-ion medical accelerators was reported.

Sato, a Research Fellow from Sumitomo Electric Industries presented, "*Superconducting system development under the JST/S-Innovation program*". He reported its R&D activities, an area where he propelled as program officer, such as the implementation of R&D themes, research outcomes and future R&D prospects (the aim being the creation of an advanced energy/electronics industry utilizing superconducting systems).

Professor Kiss from Kyushu University presented a lecture entitled *"The anticipation of 3G superconducting wires"*, Senior Researcher, Kandori of Hitachi, presented *"Medical measurements using superconducting quantum interference devices (SQUIDs)"*, Professor Nitta of Meisei University presented *"The expectations of superconducting power equipment"*, Director Tomita from the Railway Technical Research Institute presented *"Superconducting technology applications for the next generation railway systems"*, and Research Fellow Osamura from the Research Institute for Applied Sciences presented "*Progress in the international standardization of superconducting wires, and the future standardization of superconductivity-related applications*". SRL/ISTEC Deputy Director General, Tanabe, presented a lecture entitled "*Research trends in Fe-based superconducting materials*", whilst Director Izumi (Superconducting Tapes and Wires Division) presented an overview of "*The current status and future of superconducting wire development*". Director, Ohkuma (Electric Power Equipment Division) presented "*The current status and future of Yttrium-based superconducting power equipment technology development*", and Director, Hidaka (Low Temperature Superconducting Devices Laboratory, Electronic Devices Division) presented "*The flourishing world of multi-element superconducting detectors*".

The forum concluded with closing remarks from Ryohei Kondo, Managing Director of ISTEC. There were around 140 participants. We would like to take this opportunity to express our appreciation.

ISTEC plans to continue this forum, which contributes to the promotion and realization of the industrialization of superconductor technology. We would like to ask you for your continuous support in future.

The next forum will be held at Tower Hall Funabori (4-1-1 Funabori, Edogawa-ku, Tokyo) on 20th May 2013.

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Top of Superconductivity Web21

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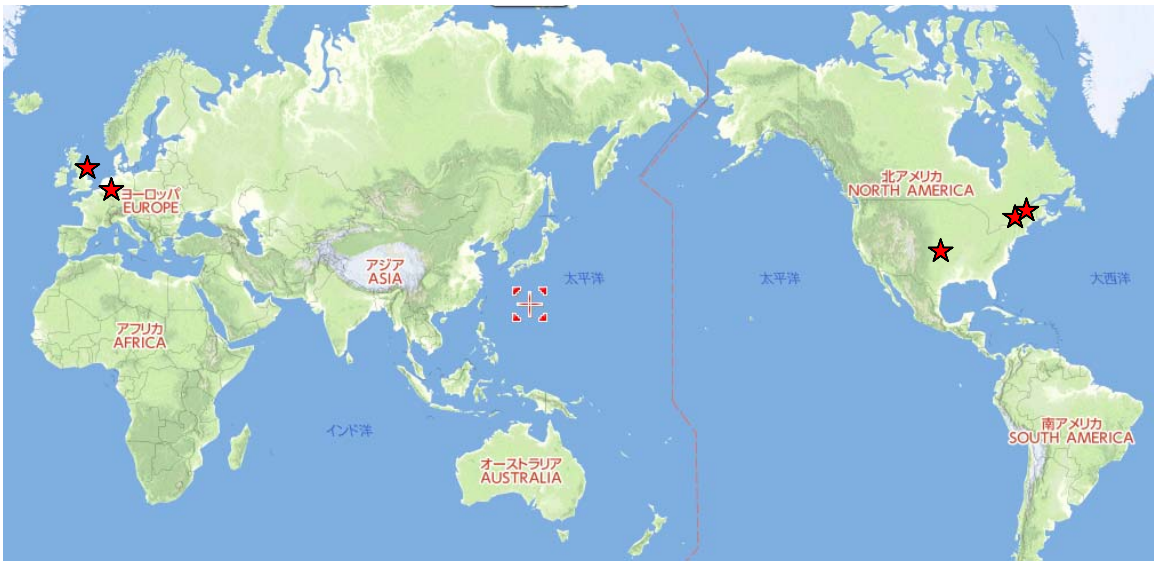
What's New in the World of Superconductivity (August, 2012)

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

▶Accelerator 가속기 加速器 [jiāsùqì]_

LHC Experiments

CERN (August 13, 2012)

The ALICE, ATLAS, and CMS collaborations at CERN's Large Hadron Collider have made new measurements of the kind of matter that most likely existed in the first instants of the universe. The new findings are based mainly on a four-week LHC run using lead ions, performed in 2011. By colliding lead ions, the LHC was able to recreate for a fleeting moment conditions that were similar to those of the early universe—a quark-gluon plasma. By performing a billion or so collisions and analyzing the resulting data, collaborators were able to make more precise measurements of the properties of matter under these extreme conditions. The new data, which was presented at the Quark Matter 2012 conference in Washington D.C., characterizes the densest and hottest matter ever studied in a laboratory—100,000 times hotter than the interior of the Sun and denser than a neutron star.

Source: "LHC experiments bring new insight into matter of the primordial universe"
CERN press release (August 13, 2012)
URL:http://press.web.cern.ch/press-releases/2012/08/lhc-experiments-bring-new-insight-matter-primordial-universe
Contact: CERN press office, press.office@cern.ch

University of Southampton

High-field Superconducting Magnet for Synchrotron

University of Southampton (August 24, 2012)

Researchers from the University of Southampton were among the first to use the new high magnetic-field beamline at Diamond Light Source (the new national synchrotron facility in the United Kingdom), to search for 'hidden magnetic states'. The researchers are examining a type of magnet that has been identified as an ideal candidate for data storage. The composition of this magnetic film provides a sufficient energy barrier that prevents thermally activated data loss, which could allow the present limit on the storage density of hard disk drives to be overcome. To date, the researchers have identified at least three different classes of exchange-spring magnetic states in this magnet.

The Diamond beamline (BLADE: Beamline for Advanced Dichroism Experiments), which was developed through a partnership of several UK universities including the University of Southampton, is capable of producing a magnetic field that is 300,000 times the strength of the earth's magnetic field. The beamline uses a 14-T Oxford Instruments superconducting magnet. Regarding the Southampton group's work, Dr. Peter Bencok, a Senior Beamline Scientist at BLADE, commented, "The first results on the new high-field superconducting magnet represent an important milestone, not only for the beamline, but for the whole of Diamond. Its magnetic field of 14 Tesla is about six times stronger than the saturation magnetization of high purity iron."

Source: "Southampton physicists join search for hidden magnetic states"
University of Southampton press release (August 24, 2012)
URL: http://www.southampton.ac.uk/mediacentre/news/2012/aug/12_149.shtml
http://www.eurekalert.org/pub_releases/2012-08/uos-spj082412.php
Contact: Glenn Harris g.harris@soton.ac.uk

▶ Basics 기초 基础[jīchǔ]

AMERICAN FRIENDS TEL AVIV UNIVERSITY

Controlling Superconductors with Light

American Friends of Tel Aviv University (August 27, 2012)

Researchers at Tel Aviv University's Department of Physics and Center for Nanoscience and Nanotechnology have discovered an innovative was of manipulating superconducting materials. By manipulating different types of light, including ultraviolet and visible light, the researchers have been able to

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alter the critical temperatures of superconducting materials. The researchers placed a thin layer with a thickness of only one organic molecule on top of a 50-nm superconducting film. When light was shined on these molecules, the molecules stretched and changed shape, altering the properties of the superconducting film. Importantly, these changes in the material properties altered the critical temperature of the superconductor. Three separate molecules were tested for the surface layer. The first molecule increased the critical temperature of the superconducting film, while the second increased the critical temperature when an ultraviolet light was shined on the material but decreased the critical temperature when visible light was used. With the third molecule, the critical temperature increased when a light was turned on and decreased when the light was turned off. This discovery provides another means of controlling and improving superconducting materials, serving as an alternative to chemical doping and potentially acting as a "knob" to control the temperature of superconducting materials. Potential applications include a "non-dissipated memory" that would be capable of saving data and running continuously without generating heat and wasting energy. The group's findings have been published in *Angewandte Chemie* and were featured in Nature Nanotechnology.

Source: "Controlling superconductors with light"
American Friends of Tel Aviv University press release (August 27, 2012)
URL: http://www.aftau.org/site/News2?page=NewsArticle&id=17109
http://www.eurekalert.org/pub_releases/2012-08/afot-csw082712.php
Contact: George Hunka ghunka@aftau.org

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

Second Quarter 2012 Results

Superconductor Technologies Inc. (August 9, 2012)

Superconductor Technologies Inc. (STI) has reported its financial results for the second fiscal quarter ending June 30, 2012, and has achieved a technical milestone in the commercialization of its Conductus® HTS wire. The company's net revenues for the second quarter were US $596,000, compared with a net revenue of $1.1 million for the same period in the previous fiscal year. The net loss for the second quarter was $3.4 million, compared with a net loss of $3.2 million for the same period in the previous fiscal year.

Additionally, STI reported ongoing progress in the technical and process development of its second-generation HTS wire program. Jeff Quiram, STI's president and chief executive officer, explained, "A large global cable manufacturer provided independent validation of our 2G HTS wire performance. At current densities greater than 500 Amps per centimeter width at 77 Kelvin, our wire is uniquely positioned to improve superconducting power device performance and economic. Our primary focus is the supply of 2G HTS wire for a committed superconducting high power transmission cable demonstration project. When completed, it is anticipated that this cable will establish a new industry performance benchmark for HTS power transmission cable." Preparations to receive the production equipment required for the production of longer wire lengths have been completed at STI's new Advanced Manufacturing Center of Excellence (AMCE) facility, and an Ion Beam Assisted Deposition machine has been installed and is now operational. The installation of additional machinery is anticipated to occur in the third quarter.

For the six-month period ending June 30, 2012, STI's total net revenues were $1.0 million, compared with

$2.7 million for the same period in the previous fiscal year. The net loss for this period was $6.4 million, compared with $6.9 million for the same period in the previous fiscal year.

Source: "Superconductor Technologies Reports Second Quarter 2012 Results"
Superconductor Technologies Inc. press release (August 9, 2012)
Contact: Investor Relations, Cathy Mattison or Becky Herrick, invest@suptech.com;
HTS Wire, info@suptech.com, mbeaumont@suptech.com

New Spinoff Company

HYPRES, Inc. (August 15, 2012)

HYPRES, Inc. has announced the creation of a new spinoff company, +n (PlusN, LLC), which will focus on the development of intelligent capacity management solutions for data communications. The new spinoff company is being backed by HYPRES lead investors Franklin "Pitch" Johnson of Asset Management Corp., Chris Brody of Vantage Venture Partners, and John Levy, chairman of the board at HYPRES. The spinoff company will continue to develop and create products utilizing innovative signal processing techniques based on pioneering algorithms and software. Meanwhile, HYPRES will continue to focus on superconductor technology, with promising new developments in medical imaging, high-performance computing, and high-performance RF systems on the horizon.

Source: "Digital Superconductor Leader HYPRES Completes Spinoff of +n, A Developer of Capacity Management Solutions for Data Communications" HYPRES, Inc. press release (August 15, 2012)
Contact: technology@hypres.com

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Top of Superconductivity Web21

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Feature Article: Refrigeration and Cryogenic Technologies - The Progress in Refrigeration and Cryogenic Technologies Required for Superconducting Electric Power Equipment

Norihisa Nara
Cryogenic Development Group, Tsukuba Laboratories
Development and Engineering Division
Taiyo Nippon Sanso Corporation

Superconducting technology is considered vital for the next generation energy saving technologies. The research and development of high temperature superconducting (HTS) power equipment and its cryogenic system are aiming at practical applications. The requirements of refrigeration systems for HTS power equipment include, 1) operating temperatures and cooling capacities, 2) long-term continuous operational reliability, 3) cooling efficiencies (low running costs), 4) system compactness (having a compact footprint) and 5) low maintenance costs.

Currently, operating temperatures of refrigeration systems employed for cooling HTS power equipment ranges from 40 to 80 K, with refrigeration capacities ranging from 2 to 10 kW at 80 K operation. Cyocoolers currently available in the market provide cooling capacities of 1 kW or less at 80 K, and additionally have rubbing parts that require regular maintenance once per year. On the other hand, large-scale cryogenic systems such as cryogenic air separation units and helium liquefiers have adopted expansion turbines that have a proven track record of large cooling capacities and reliability. However, the cooling capacities of such systems far exceed that required by HTS power equipment. To address this, in 2007, a prototype expansion turbine refrigerator was fabricated to meet the cooling capacities required by HTS power equipment, using neon as the working fluid.

Later, the development of a new turbo-compressor, a key refrigeration component, performance enhancement of the expansion turbine, and refrigerator process studies has been undertaken. Trials revealed it to have a 2.2 kW cooling capacity at 65 K operation. Furthermore, the adoption of magnetic bearings in the compressor and in the expansion turbine eliminates any rubbing parts and results in a maintenance-free refrigerator. Controlling a turbo-compressor rotational speed allows an adjustable cooling capacity, corresponding to heat load changes of practical HTS equipment. The cooling capacity of the refrigerator was measured as a function of compressor rotational speed, and compressor stability was checked. We confirmed that the cooling capacity was adjustable by varying the compressor rotational speed, namely, varying from its 2 kW-rated value down to 0.5 kW at 65 K operation. Future investigations are planned and involve verifying the possible range of cooling capacity adjustments together with an automatic control system. Considering the footprint of this system we highlight that a refrigerator comprising of a small turbo-compressor is far more compact than an equivalent system with conventional reciprocating or screw-type compressor, thus realizing the compact requirements of a cryogenic system. Figure 1 shows a commercial model of our neon refrigerator package.

For practical cooling systems intended for HTS equipment applications it is important that future research focuses on the entire cryogenic system, including heat transfer between our refrigerator and HTS equipment. Thus, studies have begun to investigate the heat exchanger (sub-cool heat exchanger) which cools liquid nitrogen by cold neon gas. In order to utilize neon gas enthalpy, our investigations have focused upon the flows in the heat exchanger and its make-up, which have resulted in the design and fabrication of a highly efficient heat exchanger. The sub-cool heat exchanger utilizes the enthalpy of neon up to 69 K, when cooling liquid nitrogen from 70 K to 67 K.

A test run of the refrigeration unit is planned together with a transformer cryostat, followed by an evaluation test of the HTS transformer system.

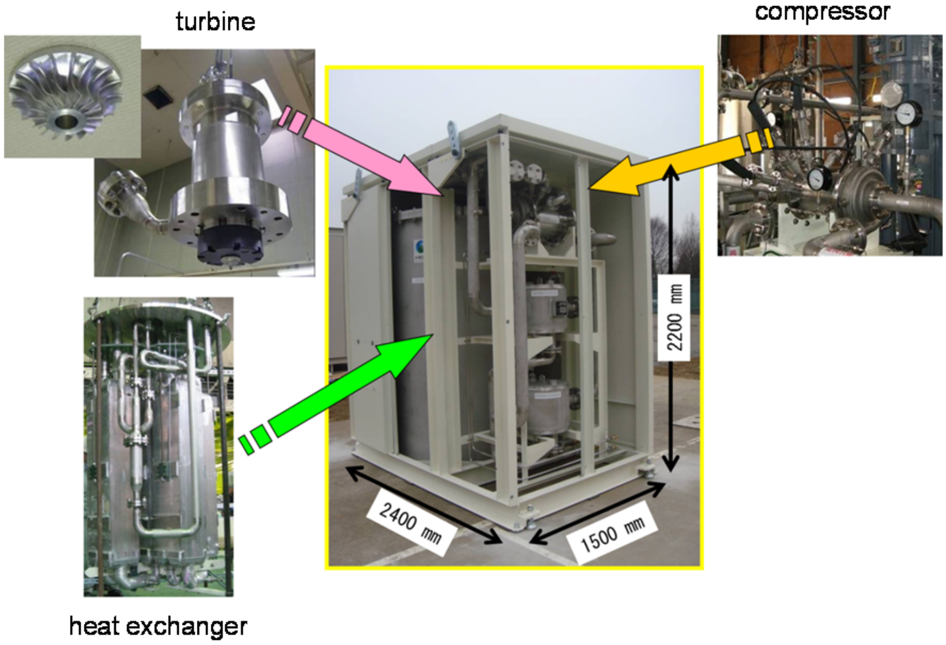

Fig. 1 The building blocks of a prototype neon refrigerator designed for commercial use

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Top of Superconductivity Web21

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Feature Article: Refrigeration and Cryogenic Technologies
- The Current Status of Magnetic Refrigeration Technology

Tsutomu Tamada, Assistant Research Chief
Superconductivity Group, Electric Power R&D Center
Chubu Electric Power Co., Inc.

Cooling via magnetic refrigeration does not involve the classical refrigeration cycle utilizing compression and expansion of a gas, but instead the refrigeration cycle involves the heat generation via the magnetization of certain magnetic materials (hitherto: magnetocaloric materials), which is then adsorbed once the magnetization is removed. Figure 1 provides a comparison of the refrigeration cycles of both gas refrigeration and magnetic refrigeration.

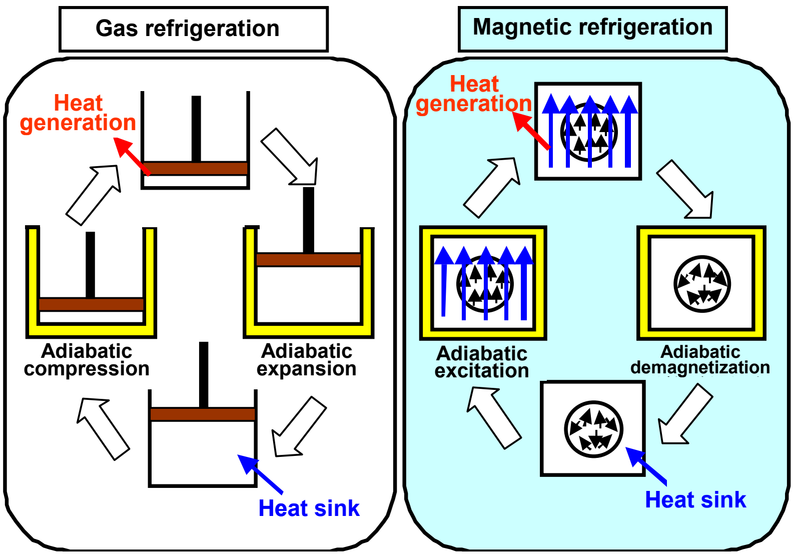

Fig.1 A comparison between refrigeration cycles

The efficiency afforded by gas refrigeration cycles is limited because of the compression and expansion of the gas coolant. Magnetic refrigeration cycles on the other hand utilize changes in the temperature of solid-state magnetocaloric materials offering the possibility to realize operational efficiencies close to theoretical limits, and therefore greater energy savings. Additionally, as chlorofluorocarbons and alternatives to chlorofluorocarbons are not required for magnetic refrigeration, it is environmentally friendly technology that does not contribute to the depletion of ozone and the associated effects of global warming.

Magnetic refrigeration technology used to be known to achieve cryogenic temperatures of less than 4 K. It now offers the possibility of a refrigeration system that can readily realize 20 K, a key requirement for a future hydrogen economy. It is this intention in Japan, under the project of NEDO, that the National Institute for Materials Science and Kanazawa University have been advancing their research and development of hydrogen manufacturing, transportation and storage systems. When conventionally operated as simple stand-alone units, magnetic refrigeration technologies cannot achieve large temperature differences because of the magnetocaloric materials characteristics, however it has been determined that greater cooling capacities could be effective for cryostat cooler systems. By combining different magnetocaloric materials, it is now possible to employ such cooling systems in applications such as air-conditioning units and where there are large temperature differences.

Chubu Electric Power Co. Inc. has addressed the potential prospects of greater energy savings afforded by magnetic refrigeration technology, and participated in both JST and NEDO projects aimed at realizing an array of magnetic refrigeration-related applications. Our research activities have focused on combinations of different magnetocaloric materials that offer large temperature differences, and all aimed at improving system efficiencies. The activities involve exploring magnetic refrigerants that have a large magnetocaloric effect in response to cooling temperatures, as well as the development of a system able to efficiently take in the temperature difference of such magnetocaloric materials. The realization of such a system will provide highly-efficient air-conditioning systems for cars, ultimately leading to the market expansion of electric vehicles, air-conditioning systems for trains, refrigeration and air-conditioning facilities for industrial use, vending machines, and all intended for the realization of a low-carbon society (Figure 2).

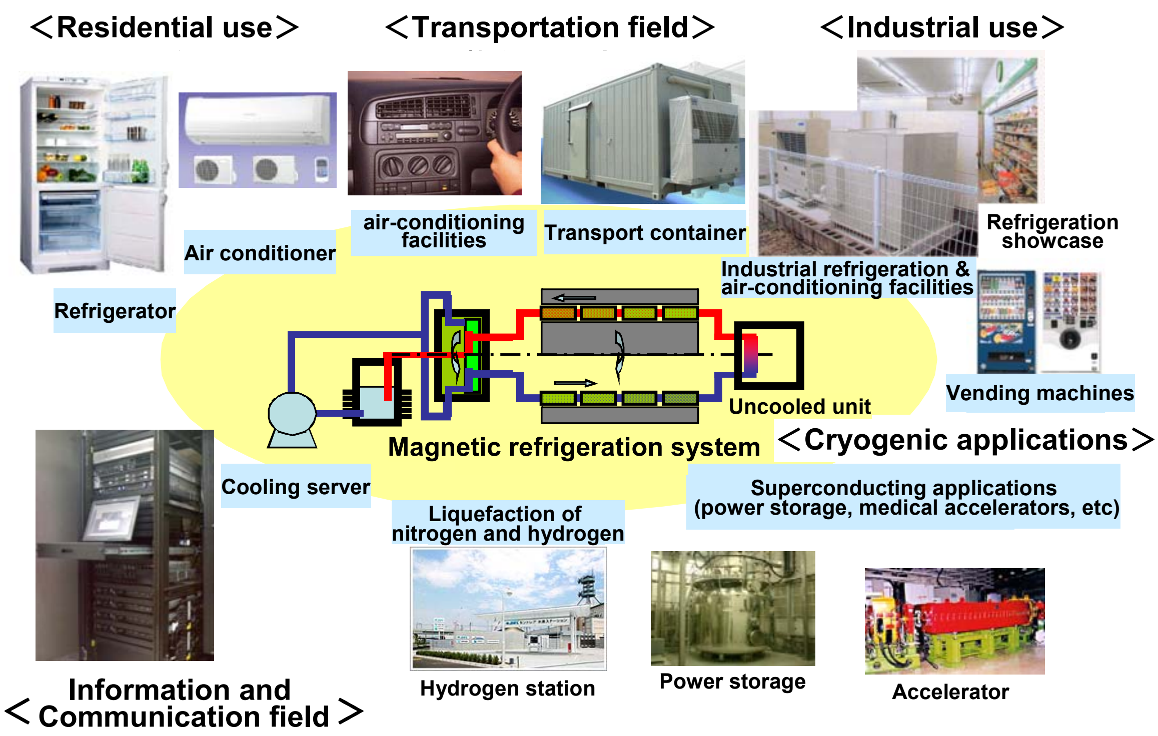

Fig. 2 Expected applications with the diffusion of the magnetic refrigeration cycle

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Top of Superconductivity Web21

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Feature Article: Refrigeration and Cryogenic Technologies
- Multi-stage and Gas-cooled Current Lead for Low Thermal Leakage

Sataro Yamaguchi, Professor, Director
Center of Applied Superconductivity and Sustainable Energy Research
Chubu University

1. Introduction

When cooling superconducting magnets almost 90 % of thermal load losses occur at the low temperature current leads. Also the majority of losses in superconducting transmission systems are due to thermal leakages at terminals, which in cases can be located as far as 2 km away. At large currents the thermal leak volume at the terminals increases proportionally, which increases the terminal thermal leakage from low-voltage equipment with high current capacities. A significant impact upon the economic viability of superconducting-based systems can be therefore realized by reducing this thermal leakage. Realizing this via material characteristics then requires a material with high current transmission characteristics and low thermal conductivities. This causes a contradiction from a physics point of view. To investigate the likelihood of such a material, the author, who has transferred to Chubu University, and his research team launched an experimental study looking at Peltier materials as alternatives to reduce thermal leak volumes. The study looked into solving the physics paradox by utilizing the adiabatic Peltier effect, and resulted in limiting the current lead thermal leak volume per unit current by half of what it originally was.

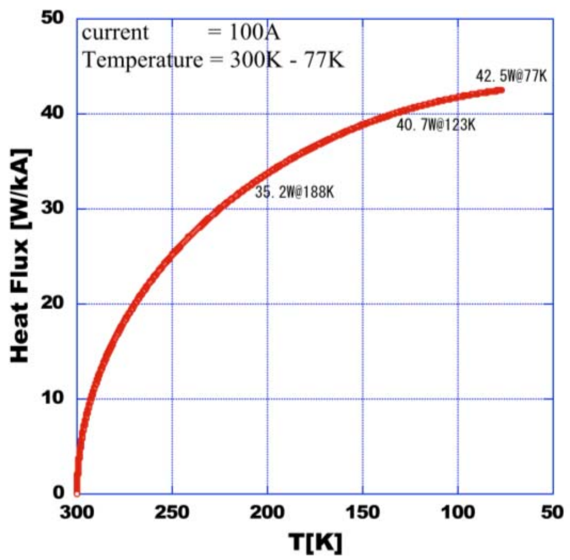

Fig.1 The relationship between the heat flux and the temperature of an optimally-designed current lead

2. Multi-stage current leads

Do alternative methods to reduce current lead thermal leak volumes exist? This forms the basis of our research. Since the final goal is to reduce the refrigerator's power consumption, it is possible to reduce the actual thermal leakage at the terminal by improving the refrigerator COP. Figure 1 shows a plot of the measured heat flux per unit current of a copper current lead (carrying 100 A, with a temperature drop of 300 K to 77 K). The copper lead

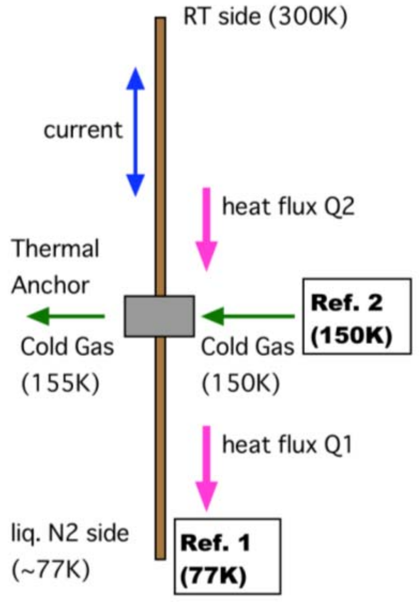

Fig. 2 The fundamental structure of a multi-stage current lead

generates heat that flows towards the low temperature areas, which increases the heat flux on the low temperature side. The graph shows that the electrical resistance of copper falls as a function of temperature, increasing rapidly at high temperatures but becoming moderate at lower temperatures.

Figure 2 shows th at the use of a nother refrigerator allows a fixed tem perature to be maintained at a point along the current lead. This part is called thermal anchor. Thus, employing this method allows the heat flux below this fixed tem perature to be absorbed by the refrigerator at 77 K, whilst the second refrigerator absorbs the heat flux above the fixed temperature. The addition of these two heat fluxes remains constant for the current, however the refrigerator COP improves with an increase of the temperature attained. The resulting power consumed by the two refrigerators is less than the consumption of a single-unit refrigerator operating at 77 K. Assuming that the COP is set at 0.1 for a refrigerator at 77 K, and 0.4 for a refrigerator operating at 188 K and used to maintain the fixed temperature, the power consumed for a current of 100 A by the refrigerator at 77 K is, 4 2.5/0.1=425[W]. The total power consumed by these two refrigerators is, 35.2/0.4+(42.5-35.2)/0.1=161[W], which is equivalent to 37.9 % con sumed by a sing le unit, a 60 % reduction in power consumption.

3. Multi-stage gas-cooled structure current lead

Another method to reduce thermal leak volume from current leads is to employ a gas-cooled current lead. This method involves utilizing the coolant that is used to cool the curr ent lead conductor. The coolant is vaporized by thermal leakage and this low temperature gas is guided towards the normal temperature side via the current leads. Since the low temperature gas exchanges heat with the current lead, which is then transported to the normal temperature side, the thermal leak volume from the current lead can therefore be reduced, making this method the norm.

Figure 3 shows the refrigeration cycle of the refrigerator. The gas exiting the heat exchanger at the low temperature side remains at a low temperature and is transferred to the compressor. Since the compressor is operating above normal temperatures, the temperature of the cold low-pressure gas increases, which attributes to the loss.

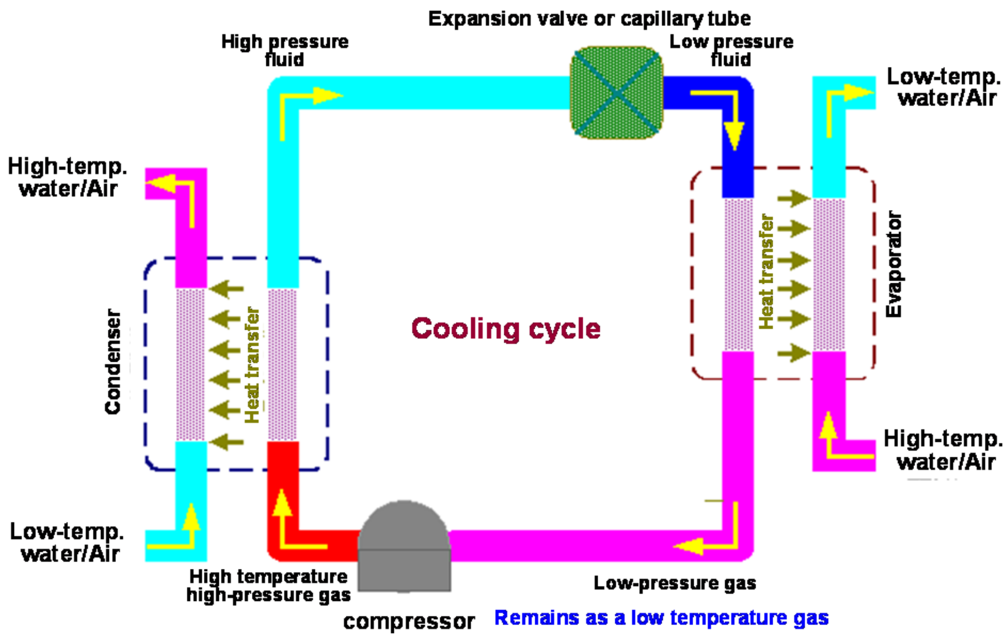

Fig. 3 Cooling cycle of refrigerator

Here we assume the current lead to have the structure shown in Figure 4 i.e. the current lead is combined with the refrigerator coolant cycle. The losses related to low temperature gases, attributed to increased compressor temperatures as shown in Figure 3, can be eliminated.

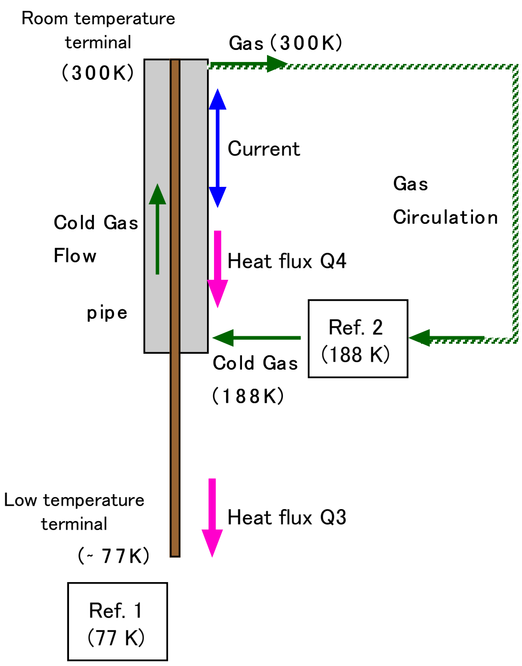

Fig. 4 Principle schematic of a multi-stage gas-cooled current lead

If this structure of current lead is realized then the total power consumption of these two refrigerators is 118.1[W], which results in 27.8 % power consumption compared to the initial stage. The effective thermal leak volume is therefore reduced considerably.

There are several ideas proposed for the design of these structures. Furthermore, as their principle of operation differs from Peltier current-leads, their structural combination is possible in principle. With further research development activities, the author anticipates that the thermal leak volume from current leads will be reduced considerably in the future.

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Top of Superconductivity Web21

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Feature Article: Refrigeration and Cryogenic Technologies - The Development of Low Thermal Leak Peltier Current Leads for Superconducting Equipment

Masahiro Minowa
Advanced Technology Development Section
R&D Center
SWCC Showa Cable Systems Co., Ltd.

The cost of cryocooling superconducting equipment will need to be reduced further in order to ensure its economic viability. Thus, the development of refrigerators with greater efficiencies and low temperature vessels with superior adiabatic characteristics has been progressing. Additionally, reducing conductor thermal loss from parts electrically connecting the power supply, which usually operate at room temperature, to parts operating at cryogenic temperatures becomes important when the cross-sectional area of the conductor increases.

It is the function of the current leads installed in a superconducting device to supply power to equipment (at cryogenic temperatures) derived from a power supply (at room temperature). Metallic copper is typically employed for the conductor owing to its high conductivity characteristics. However, despite this, the high thermal conductivity of high conductivity materials generally leads to greater thermal leakages, which become an issue for equipment with high current carrying capacities. Thus, the design of current leads addressing these conflicting characteristics is required.

One solution is to utilize a high temperature superconducting current lead in place of a conventional conductor. Current leads in contact with superconducting equipment operating at less than 10 K have temperatures of around 70 K, thus allowing the prospects of employing Bi-based high temperature superconductors as an alternative current lead conductors. Since Bi-based high temperature superconductors are a complex metal oxide, their thermal conductivities are much lower compared to copper and therefore thermal leakages due to heat transfer are greatly reduced. Furthermore, during operation, high currents can be transmitted without Joule heating and therefore exhibiting the ideal characteristics of current leads required for superconducting equipment. Higher current capacities requirements in recent years have seen the rise and development of current leads employing Y-based superconducting wires.

These superconducting current leads are however not suitable for applications such as superconducting cables that employ Y-based wires and practical equipment utilizing high temperature superconducting materials, since the temperature of the areas connecting current leads to equipment are close to room temperature. In order to address this, a Peltier current lead (PCL) has been developed[1)] with the current-carrying parts having a Peltier element sandwiched by copper conductors. The thermal conductivity of the Peltier element is small compared to that of the copper conductor thus minimizing thermal leakage due to heat transfer. When operational, although there is greater Joule heating compared to copper conductors, it is the Peltier effect that is responsible for transferring heat from the low temperature side to the high temperature side, thus minimizing the heat leak volume towards the low temperature side. Figure 1 shows the outline schematic structure of a PCL[2)].

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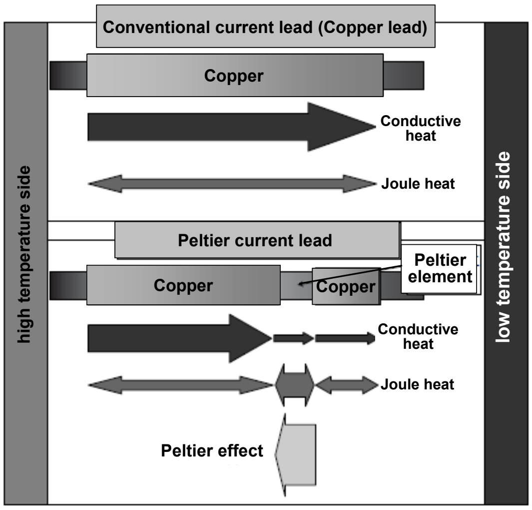

Fig. 1 Schematic structure of a PCL [2)]

Since 2009, SWCC has made efforts in a joint research and development programme with Chubu University aimed at developing high current capacity PCLs. The research team has evaluated the performance characteristics of a PCL with a 200 m-class superconducting DC transmission test device (CASER-2), installed at Chubu University [3)]. The system is equipped with 23 PCLs connected to positive and negative poles, respectively. Several different copper leads were evaluated and comparisons made. Figure 2 shows the results from temperature distributions measured from PCLs and copper leads[3)]. The results from the PCLs established large temperature differences at both terminals of the Peltier element, confirming that the electrode with a temperature gradient lower than the Peltier element had a smaller thermal leakage towards the low temperature parts of the system. At the same time, the thermal leak volume per current lead was measured as 3.6 W for PCL compared to 4.3 W for a copper lead[2)]. Also, the thermal leak volume, which was calculated from the measured electrical resistance during operation, was confirmed as being sufficiently low with a value of approximately 32 W/kA [2)].

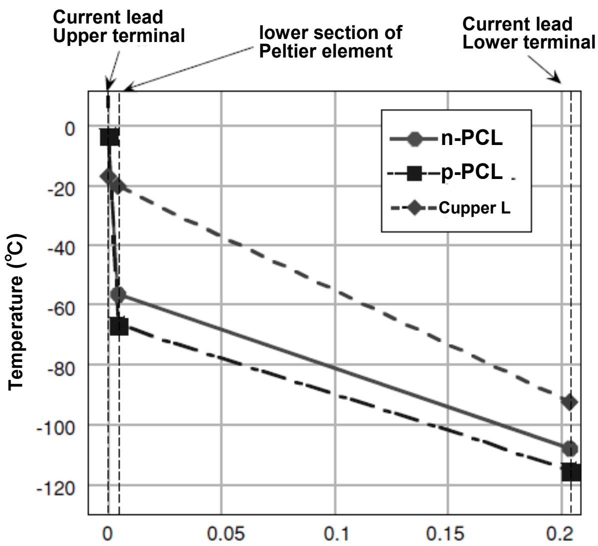

Fig. 2 Current lead temperature distribution with no current applied

Having evaluated the PCLs using CASER-2, a principle test involving 100 A-class PCLs was undertaken. Despite this, in order to realize practical PCLs the current carrying capa cities still require improvement in accordance with specific equ ipment capacities. The fabrication of 20 0 A-class PCLs has been aimed towards the optimization of shape, orientations and connections of the elements, the results of which involve evaluating the current transmission characteristics and are shown in Figure 3. As the c urrent carrying capacity increases the temperature of the element on the side of the lower temperature gradually declines because of t he Peltier effect. Thus, evaluating the 200 A-class PCL confirmed its effective performance attributes with th e minimum current value measured on the low temperature side shifting towards the high current region[4]. This result paves the way for the future development of a PCL that is planned to have a current carrying capacity greater than 1 kA.

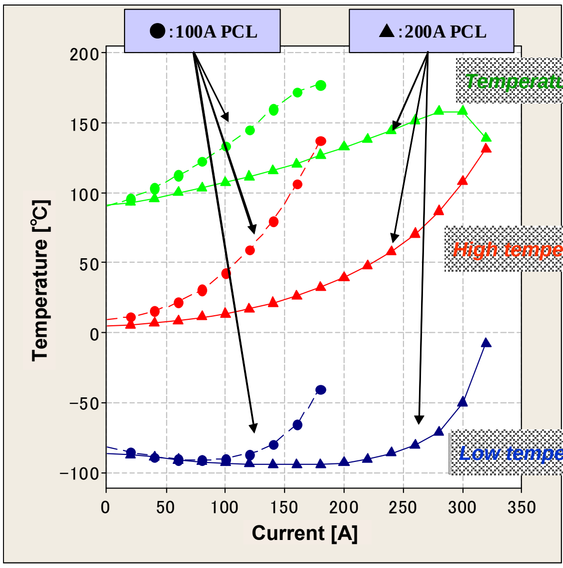

Fig. 3 PCL current application test results

The author considers that a reduction of thermal leaks from power supply parts is a significant issue to ensure the economic viability of advancing high power and large-scale superconducting equipment in the future. The development of a PCL is regarded as an important aspect in solving this issue. For the future the author would like to advance PCL product development aiming for enhanced performance of superconducting cables and equipment applications as well as compact power terminal parts by combining PCL with electric insulating technology.

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Top of Superconductivity Web21

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Feature Article: Forum on Superconductivity Technology Trends - Expectations of Yttrium-based Coated Conductors and Their Applications

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SRL/ISTEC

Introduction

The Great East Japan Earthquake that struck on 11th March last year triggered a sequence of events of a huge Tsunami and a nuclear power station accident that forced Japan to face difficulties the likes of which it has never experienced before. An urgent recovery from this triple disaster is required. However, the strong yen and the economic stagnation due to the worldwide financial crisis since the Lehman shock still continue and measures to stimulate economy and employment, social security and global environment issues remain unsolved. Whilst recovery efforts remain of primary concern, the introduction of energy saving equipment and renewable energy are strongly anticipated more than ever. A strategy involving superconducting technology was drawn up by the Agency for Natural Resources and Energy, which falls under the Ministry of Economy Trade and Industry, and New Energy Industrial Technology Development Organization (NEDO), entitled "Energy Saving Technology Strategy 2011". This plan influences the future development of Japan in the rapid implementation of superior energy saving technologies, stating that "*a strategic approach is desired to ensure Japan's world leading superconductor technologies be a core technology for the implementing practical energy saving systems*". It is therefore anticipated that Japan's superconducting technology will be at the forefront of energy saving technology initiatives and will formulate part of the strategy for Japan to recover from the earthquake devastation.

This year marks the 25th anniversary since the discovery of Y-Ba-Cu-O superconductors (hereafter YBCO), by Professor C.W. Paul Chu of the University of Houston in February 1987, having superconducting transition temperatures exceeding the liquid nitrogen temperature. In 1962, B.D. Josephson, a graduate student at Cambridge University at that time, theoretically predicted the occurrence of Josephson effects in superconductors and this year marks the 50th anniversary since P.W. Anderson and J.M. Rowell, from Bell Laboratories provided experimental verification.

The "2012 Forum on Superconductivity Technology Trends," which was held this year commemorated the theme of "25 years since the discovery of YBCO and further development of superconductivity". The professors and research scientists working at the forefront of superconducting applications in fields involving high temperature superconducting tapes and wires, energy applications such as electric power equipment and thin film electron devices presented their expectations of the future of superconductivity.

1. The progress of tape/wire development since the discovery of the superconducting phenomenon

Looking back over 25 years since the discovery of YBCO high temperature superconductors, which have a superconducting critical temperature exceeding the boiling point of liquid nitrogen (77 K) at atmospheric pressure, stirred a worldwide fever of high temperature superconductors. Initially, fabricating silver-sheath tapes/wires was attempted in order to circumvent the fragile ceramic characteristics of these oxide-based materials. The disappointing low critical current densities of the YBCO system made many apprehensive regarding the future potential for applications. Despite this, research into wire/tape development utilizing YBCO superconducting materials has progressed with increased acknowledgement of the importance

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played by high in-plane grain alignment technology. Research studies showed that employing high in-plane grain alignment technology could solve issues associated with weak inter-grain coupling. This again ignited a worldwide fever pitch leading to intensified competition in full-scale research and development of YBCO superconducting tapes. Recently, technologies including Ion Beam Assisted Deposition (IBAD) and Rolling Assisted Bi-axially Textured Substrate (RABiTS^{TM}) have been adopted as the processes for achieving high in-plane grain alignment. In particular the IBAD method developed by Fujikura Ltd., has paved the way for ISTEC to develop technology that is quick and leads to high in-plane grain alignment, by combining IBAD with PLD. This has led to further developments in the fabrication of longer tapes. A recent research report from Fujikura details a PLD film fabrication technology that employs a Hot Wall RTR (Reel to Reel) heating method leading to an improvement in the uniformity of superconducting characteristics, achieving an I_C of ± 1.35 % in the longitudinal direction.

Using the benchmarking characteristics of the product of critical current (I_C) and conductor piece length (L), Figure 1 shows the progress development of BSCCO and YBCO superconducting wires/tapes after the initial discovery of high temperature superconducting materials. It is apparent that since the discovery of high temperature superconductors there was a rapid advance in the development of BSCCO silver-sheath superconducting wires. However, since then rapid advances in YBCO superconducting coated conductors (hereafter; c.c.) have overtaken these initial BSCCO materials. In particular, recent remarkable research advances into YBCO c.c. development comes from a group based in Korea, who have been depositing superconducting layers using Reactive Co-Evaporation Deposition and Reaction (RCE-DR) method onto IBAD template. A comparison between the characteristics of both BSCCO and YBCO c.c. was measured at a critical current (@77K, self-field), with each wire or c.c. having approximately a 1.1mm^2 cross-sectional area (BSCCO wire 4.4 mm wide and 250 μm thick, YBCO c.c. 10mm wide and 110 μm thick).

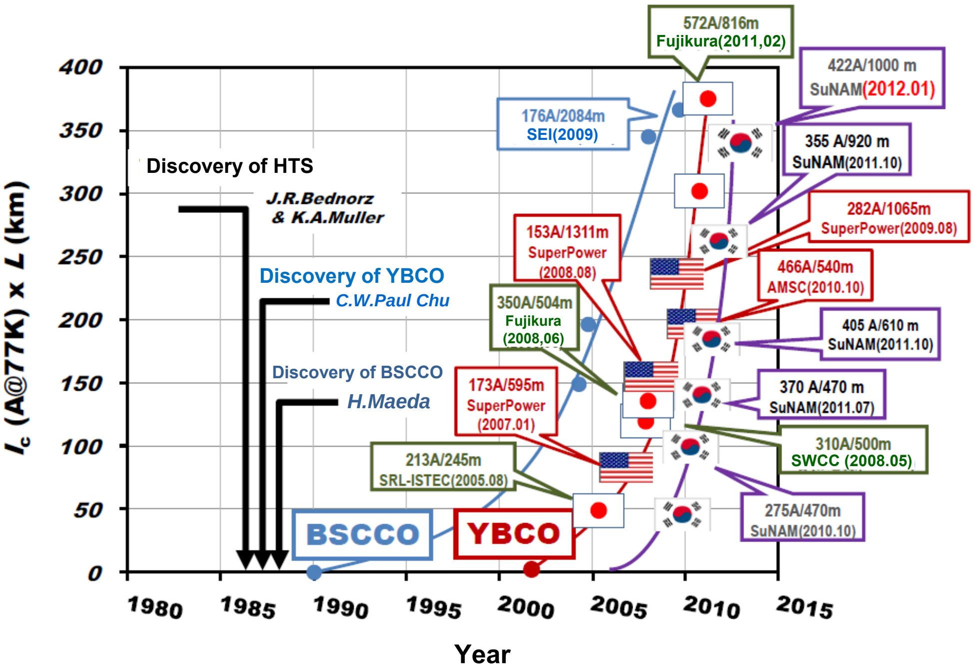

Fig. 1 R&D history of high-temperature superconducting wires

Currently the highest ever reported value of the product of critical current (I_C) and piece length of conductor (L), is held by Fujikura based in Japan, and is presently the world leader in coated conductor development.

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Further enhancements in the characteristics of coated conductors are expected along with the production of longer conductors, increasing production yields, lower costs and mass production.

2. Development of Y-based superconducting power devices

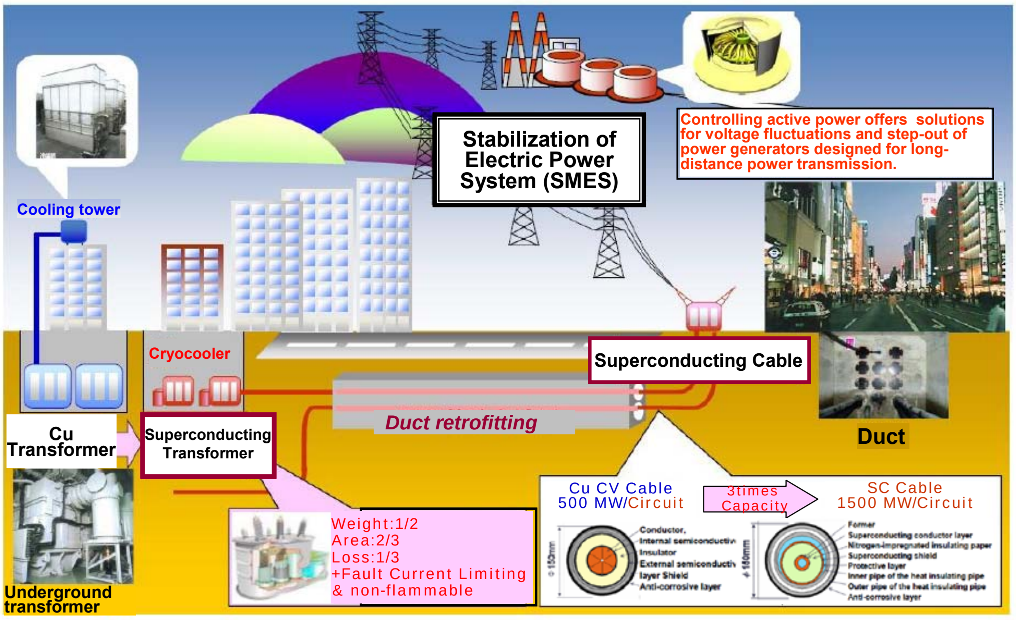
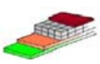


Fig. 2 A schematic of a stable, large-capacity power supply system using superconducting electric power

A five year national project supported by the New Energy and Industrial Technology Development Organization (NEDO) has been running since 2008, entitled "Materials and Power Applications of Coated Conductors; M-PACC". Figure 2 shows that research and development efforts have focused upon Superconducting Magnetic Energy Storage (SMES), power transmission cables and transformers utilizing YBCO superconducting materials, all with the aim of delivering a stable and large-capacity power supply in an urban environment. Additionally, the project aims to research and develop YBCO coated conductors employed for such power equipment and establish an international standardization of such devices. This year welcomes the final year of the project and the research aims are progressing to achieve the final goals shown in Table 1.

Table 1 R&D targets of the " Materials and Power Applications of Coated Conductors (M-PACC)" Project

R&D themes		R&D targets
SMES		The feasibility of improving coil strength and design are verified with the development of a 2GJ-class SMES having high magnetic fields and compact coil architecture technology, as well as easing maintenance with the development of coil conduction cooling technology.
Cable		Fabrication of a high capacity cable system (66kV-5kA, 3-phase in one, 15m, 150mm diameter can be accommodated in a duct, terminal junction), as well as a high voltage cable system (275kV-3kA, single-phase single-core, 30m, 150mm diameter, midpoint junction, terminal junction). Performance verification tests are performed, including transmission loss trials (1/2~1/3 reduction compared to currently available cables).
Transformer		A model of a 2MVA-class superconducting transformer is fabricated and its performance characteristics are verified to assess the feasibility of a 66/6kV 20MVA-class superconducting transformer system. The fault current limiting function is also verified by employing a several hundreds kVA-class transformer.
Wire development for power devices		After project completion the development of Y-based coated conductor fabrication technology, which meets the specifications required for practical equipment development will be undertaken. Developments aimed at advancing stable wire manufacturing technologies as well as the development of wire fabrication technology required for commercialization and market penetration of each power device planned for around 2020.

2.1 R&D activities of Superconducting Magnetic Energy Storage System (SMES)

SMES coil component technology with high functionality and excellent tolerance has been progressed in order to foresee the development of a 2GJ-class SMES. To solve the phenomenon of degradation in coil current transport properties, a compact coil was used in order to evaluate and study the characteristic degradation at each stage of the coil fabrication process. The findings revealed that wire insulation and coil impregnation needed to be optimized and therefore a new method was established, which significantly reduced the internal stress of the coil, which was a trigger that led to coil degradation, allowing the design of a coil with greater functionality and high tolerance without a degradation in current transport properties.

2.2 R&D activities of superconducting power cables

To foresee the future development of a 66 kV, 5 kA large-current cable and a 275 kV, 3 kA high voltage cable, research and development has focused on 1) technology of large-current capacity/low AC loss cables, 2) high voltage insulation/low dielectric loss cables, 3) compatible YBCO c.c. applied to superconducting power cables, 4) verification of a 66kV, large-current cable system, and 5) verification of a 275 kV high voltage cable system.

With regards to large-current/low AC loss cables, a remarkable reduction of AC losses has been achieved with the structural design of a four-layer conductor, with a 2 mm width for the outermost layer, producing a significantly low AC loss of 0.8 W/m-phase@5 kA at 74 K. Technological development of a high-voltage insulation/low dielectric loss cable has been investigated using the fabricated short cable-core model, allowing the system design feasibility to be verified by measuring AC loss and operational performance at the midpoint junction of the superconducting cable when excess current was applied. Furthermore, a facility designed to undertake current tests to verify superconducting power cable systems is currently underway with tests planned in the final year of the project.

2.3 R&D activities of superconducting transformers

To foresee the development of a 66/6 kV, 20 MVA-class superconducting transformer employed for a distribution system, research and development has been progressing for 1) superconducting transformer tape winding technology, 2) cooling system, 3) transformer with fault current limiting function, 4) YBCO c.c. applicable to superconducting transformers, and 5) verifying the performance of a 2 MVA-class superconducting transformer model.

A prototype model designed to test low-loss tape winding was fabricated and verified, along with the fabrication of a prototype refrigerator and cooling system that combined a compact/high efficient expansion turbine and turbo type compressor. The fault current limiting functionality was verified using excess current tests by employing a 400kVA fault current limiting model.

2.4 R&D activities of superconducting coated-conductors for power devices

Technology has focused on stable manufacturing methods for practical YBCO c.c. required for long-term reliability tests for superconducting power equipment as well as the development of YBCO c.c. fabrication technology required for commercialization and market penetration, planned for around 2020. The development has aimed at 1) understanding c.c. characteristics, 2) the fabrication of YBCO c.c. with high in-field (magnetic) critical currents (I_C), 3) the fabrication of YBCO c.c. with low AC loss, 4) the fabrication of YBCO c.c. having high strength/high industrial critical current density (J_e), and 5) low cost/yield enhancement.

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Specific research and development outcomes thus far are as follows:

A better understanding of point 1, which involves the YBCO c.c. characteristics, and is based upon hearing surveys regarding the fabrication and operating environment such as voltage impression, as well as excess current characteristics relating mainly to the transformer. Issues associated with c.c. delamination have been overcome through a better understanding of the relationship between the strength and the origin where delamination occurred, and the delamination strength of the bed layer formed by MOD improved.

For point 2, YBCO c.c.'s having greater in-field high I_C has been realized with short c.c. achieving 85A/cm-width (@77 K, 3 T), by using pulse laser deposition (PLD) of materials with $BaHfO_3$ acting as artificial pinning centres. An intermediate heat treatment process of a Y(Gd)BCO superconducting film deposited by metallorganic decomposition (MOD) allowed for the insertion of $BaZrO_3$ as artificial pinning centres, realizing 56 A/cm width (@77 K,3 T) in short c.c.'s.

Point 3 involved the development of low AC loss c.c.'s, which was realized by employing a PLD method and then scribing 5mm-width short c.c. into 10 filaments. The results confirmed a homogeneous c.c. filament I_C (16~19 A@77 K, s.f.) and a measured AC loss $1/10^{th}$ compared to that of a non-scribed c.c. Furthermore, developing a new MOD coating process in order to control film thickness fluctuations at the edges allowed the realization of greater film thickness homogeneity along the width. Homogeneous filament width was also confirmed with c.c.'s scribed into 10 (0.31~0.38 mm) for 5 mm-width c.c.

The development of YBCO c.c. with high strength/high J_e set in point 4, have been attempted in order to develop high I_C (greater than 550 A/cm-width @77 K, s.f.) as the final goal requirement. Measurements of c.c.'s fabricated by PLD and MOD methods have realized 700 A/cm-width and 636 A/cm-width (@77 K, s.f.), respectively in short c.c.'s.

The technology development stated in point 5 involves enhancing production yields and reducing costs. The PLD method realized 460A/cm-width (@77K, s.f.), at a speed of 30 m/h, producing a 71 m-long c.c., and therefore achieving a cost of 2.4 yen/Am in technological terms. On the other hand, the MOD method realized c.c. characteristics of 432 A/cm-width (@77 K, s.f.) for 50 m-long c.c., equivalent to 1.9 yen/Am. The stable manufacturing technology required for commercialization has achieved a 100 % production yield for a total production length of 5.6 km-long c.c.'s. having single piece length of 240~318 m with c.c. characteristics of 300 A/cm-width @65 K, 0.02 T, an intermediate target set for transformer applications.

3. The future prospects of R&D

Projects involving superconducting power equipment utilizing YBCO c.c.'s have entered their final year, achieving set targets at a much earlier stage of the project for each theme (SMES, cables, transformers, YBCO superconducting c.c.'s). Research and development efforts are now focused on establishing the fundamental technology to commercialize superconducting power equipment, which are expected to diffuse into the marketplace from 2020 onwards.

The development of an array of equipment that utilizes the high critical current characteristics at high temperatures/high magnetic fields, which is typical of YBCO c.c.'s, is greatly anticipated.

The USA and Europe are beginning the acts for deploying alternative renewable energies, natural energy sources and the reduction of CO_2 emissions, with the development of superconducting wind turbine generators, which makes possible compact/lightweight and high capacity devices. Japan's shorelines are

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not shallow and therefore alternative floating wind turbines are anticipated to solve issues related to Japan's wind power generation (large-scale, utilization/operation rate, offshore use, cost reduction etc.), the R&D progress of which is summarized in Figure 3. Considering the cost of floating-type support architecture, an ultra large-scale (>15 MW) wind turbine generator is necessary, which is difficult to realize both economically or via a conventional normal conducting wind turbine route. Here being lightweight is one of the important factors and can be realized by employing an iron-core free generator. Also, efficiency will be improved by utilizing a synchronous generator and maintenance cost reduced by eliminating speeder gears (speed-changer). To address these issues, worldwide efforts acknowledged on going efforts to replace field-winding coils by Y-based superconducting electromagnets. Figure 4 shows highly efficient, ultra-large and lightweight superconducting wind turbines synchronous generators, which are being realized without the need for iron cores and gears, and their potential advantages are currently foreseen. Therefore, the combinations of high temperature superconductors with floating wind turbine technology are greatly anticipated, with Japan being the world leader in this field.

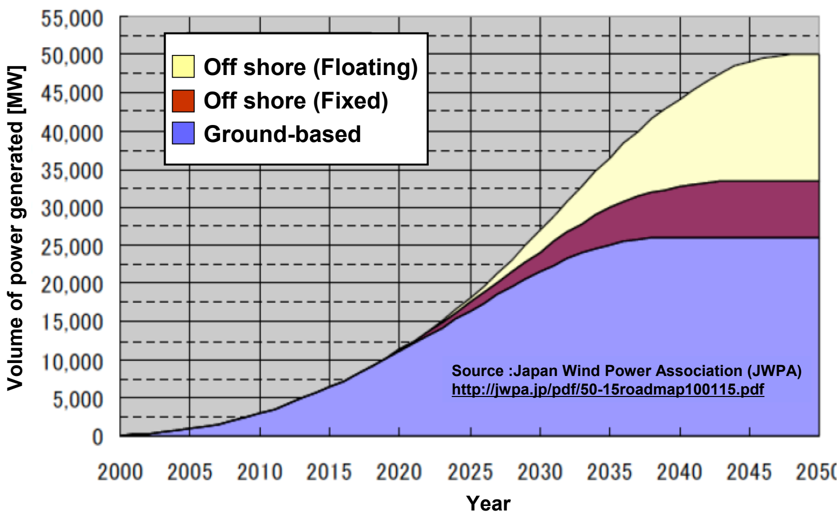

Fig. 3 Road Map of Wind Turbine Generators in Japan

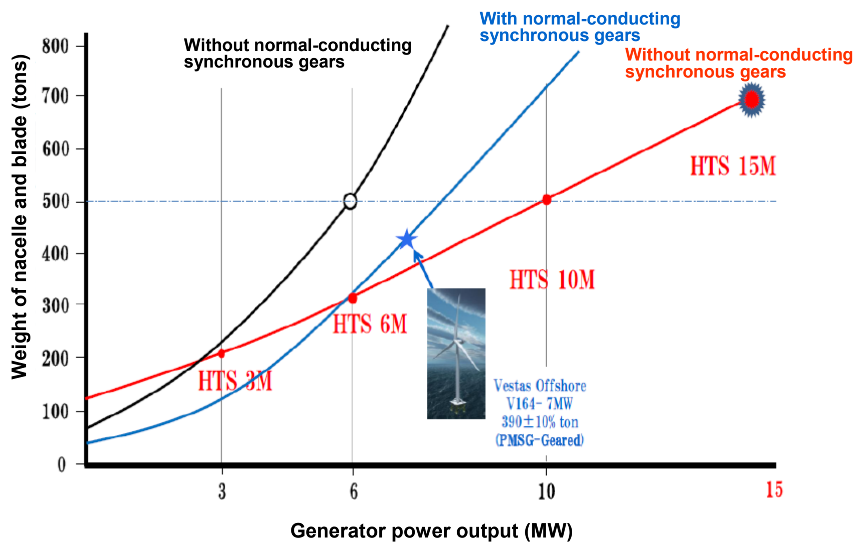

Fig. 4 Effectiveness of High-temperature Superconducting Wind Turbine Generators

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As well as an ageing society, changes in diet are behind increases in numbers of cancer patients and deaths related to cancer. However, the numbers of patients receiving radiation therapy in Japan is at a lower rate (around 25 %) compared to western countries. The Japanese government has in place a cancer control policy that promotes and undertakes research and development of equipment needed for treatment of patients as well as promoting radiation therapy methods.

The treatment of patients with radiation therapy is equivalent to or has a greater effect than surgical treatment as it localizes radiological dosage and focuses only on the cancer (tumor) region, at the point where treatment is actually required thereby reducing the burden of radiation absorption in a body, especially from the skin as shown in Figure 5. For the areas of treatment highlighted in Figure 6, a heavy-ion cancer therapy method has already a track record involving more than 5,000 clinical events. Medical accelerators currently employed in the treatment of patients have been undergoing changes that involve the development of low cost heavy-ion accelerators, which are significantly compact in size and energy-efficient, utilizing the benefits afforded by high temperature superconducting technologies. Further investigations are on going to enhance radiation treatment methods and strengthen the international competitiveness of the industry as a whole. A heavy-ion synchrotron based at the National Institute of Radiological Sciences houses the world's most

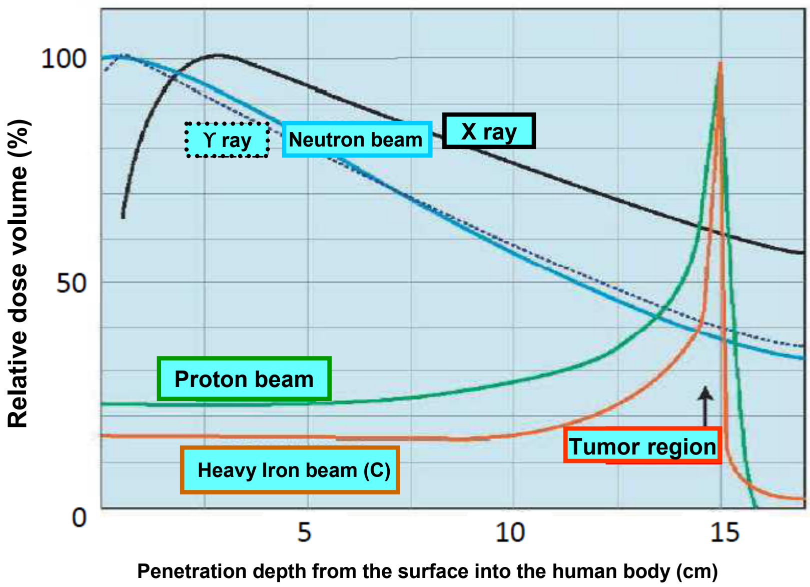

Fig. 5 Distribution of dose in humans (SOBP: Spread out Bragg Peak) with various types of radiations

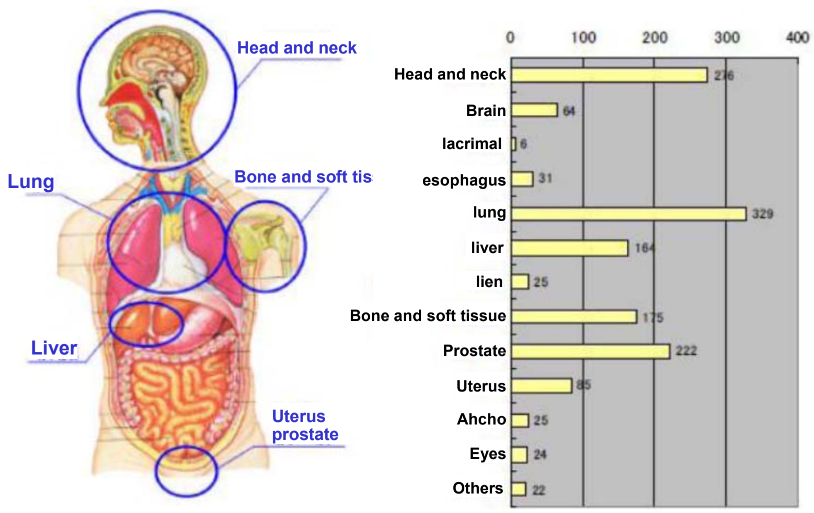

Fig. 6 Parts of the body treated by Heavy Iron Medical Accelerator Treatment System

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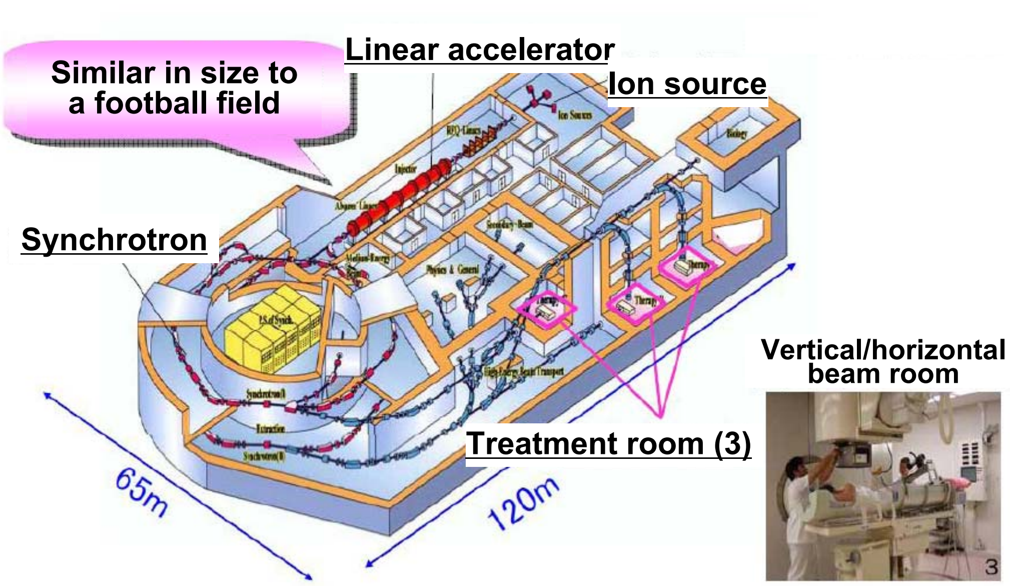
advanced heavy-ion cancer therapy facility, named Heavy Ion Medical Accelerator in Chiba (HIMAC), and comparable in size to a football field and costing around ¥0.5 billion per year of electricity consumed to operate and provide air conditioning and excitation to the electromagnet, as shown in Figure 7. If, instead, a superconducting electromagnet replaces the conventional normal conductor electromagnet then calculated electricity consumption costs are expected to fall by around 25 %.



Source: National Institute of Radiological Sciences

Fig. 7 Heavy-ion cancer therapy facility installed at the National Institute of Radiological Sciences

It is therefore Japan's world leading role in uniting high temperature superconducting technology and accelerator technology that has allowed the development of high magnetic field superconducting electromagnets for use in heavy-ion accelerators. Rapid progress has also been made in significantly reducing the size of the incident accelerator parts, the acceleration tube, beam outgoing parts (lines) and gantry. Therefore, the combination of these component parts has allowed the development of beam acceleration control technology with studies progressing towards a plan to realize a more compact and lower cost heavy-ion medical accelerator than a conventional system.

The development of high temperature superconducting YBCO c.c.'s has advanced so far, targeting critical currents and piece length as well as cost to determine c.c. performance characteristics. Additionally, the functionality of superconducting-based equipment that can substitute normal-conducting equipment has been progressively investigated. Based upon the functional verification trials undertaken thus far it is clear that future c.c. research and development is a key requirement to establish absolute superiority of superconducting-based equipment and at the same time remain competitive to other equipment and technology. Furthermore, whilst temporal and spatial homogeneity of the generated magnetic field are required from now, unique c.c. characteristics required involve a remarkable enhancement as well as homogeneity of in-field performance, production yield improvement as well as low-cost manufacturing - a requirement that is different from power equipment applications.

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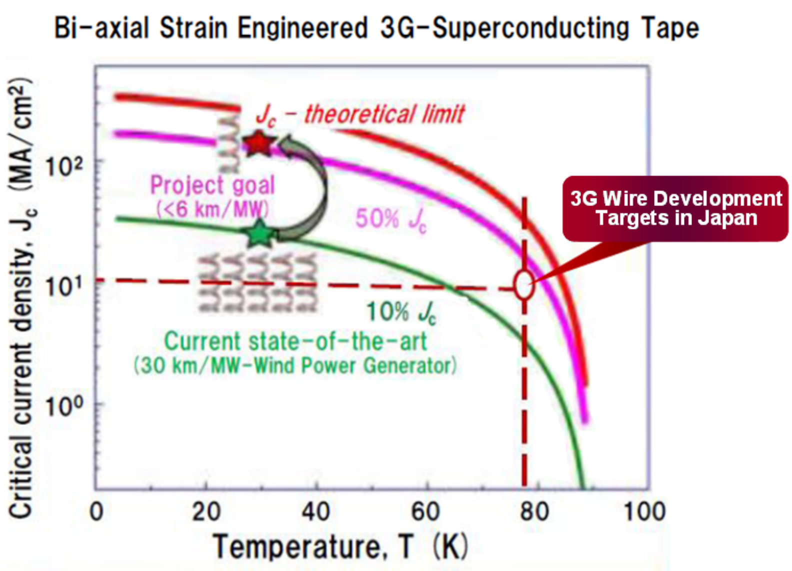
The aim is to have wire manufacturing costs set around ¥2,000~3,000/m because of limitations due to materials and equipment costs (installation/maintenance costs), and it is, of course, necessary to improve c.c. performance to achieve low manufacturing costs per Am (Ampere meter) unit price. The future development of so-called third generation (3G) superconducting c.c.'s that meet the following targets proposed for the first time by Japan at last year's ISS 2011, are anticipated to lead to the prosperity of world-leading superconductor technology.

. Ultra high critical current capabilities: I_C, e.g. 2,000 A/cm–width, 2 μm thickness, (J_c>10MA/cm^2)@77K, s.f.
. Ultra high critical current in high magnetic fields: $I_{C,\ min}$-B, high B_{c2} c.c. e.g. 500A/cm-width @65K, 5T
. Grain boundary inclination angle: $\Delta\phi < 2^\circ$
. Operational performance homogeneity: a variation of less than 0.5 % along the width and longitudinal length of c.c., and less than 1 % variation in performance between c.c.'s.
. Low cost: ¥1/Am@65 K, 4 T

A research programme aimed at the fabrication of 3G wires, supported by the U.S. Department of Energy (DOE), entitled ARPA-E, publicised this year the development of Bi-axial Strain Engineered 3G-Superconducting Tape for the development of large-scale wind turbine generators (Figure 8). In the USA, the aim is to have critical current densities around 50 % of their theoretical limitation (superconductor pair-breaking current), and to exceed the target set by Japan for the development of their 3G wires, which is about 30 %. New YBCO c.c. development project plan set by Korea will achieve fruition, and the competition for the development of superconducting c.c.'s is expected to intensify between Japan, USA and Korea in the future.



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http://www.l.eere.energy.gov/manufacturing/pdfs/critical materials workshop presentations.pdf

Fig. 8 Future Targets for Superconducting Wire Development set by the U.S. Department of Energy (DOE) (ARPA-E; Advanced Research Projects Agency – Energy)

It is superconductor technology that holds the key in realizing the benefits of greater system efficiencies with a compact architecture, which will result in the development of technologies that lead the way to solving global environmental issues such as reducing CO_2 emissions and producing greater energy savings. Such technology is highly anticipated to significantly contribute to the medical field. Additionally, technological development is expected to sustain the superiority of Japan as the world leader in this field as well as becoming an area of strategic growth in the future. Moreover, by 2020, it is equally important to establish an all-Japan research and development structure in order to advance technological development aimed at the commercialization of superconductor industry with successful, practical applications.

This article partly includes the research achievement of the "Materials and Power Applications of Coated Conductors (M-PACC) project" supported by the New Energy and Industrial Technology Development Organization (NEDO).

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Top of Superconductivity Web21

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Feature Article: Forum on Superconductivity Technology Trends - Current Status and Future Development of Superconducting Tapes/Wires

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SRL/ISTEC

Until now an important benchmark in the development of Y-based coated conductors has been I_CxL, with the current world record of 467 (kAm) being held by Fujikura, Japan. The I_CxL value has progressed steadily amidst fierce competition between Japan and USA. However a remarkable change in this competition table is afoot with a Korean company, SuNAM, joining the race recently. Since last autumn, SuNAM has rapidly progressed its development of long wires and in January this year reported an I_CxL of 422 (kAm), placing it in second place to Fujikura. There is a report suggesting that wire development now forms part of Korea's national policy and it is likely that Korea will be a third-party in what has usually been a two-horse race between Japan and USA.

On the other hand, Japan and USA have recently shifted focus towards the technological development of enhancing wire performance applicable to various types of practical equipment. Specifically, whilst low AC loss is required for transmission cables and transformers, high magnetic field characteristics and mechanical strength are required for SMES/NMR and rotating machines, respectively. However, addressing low cost manufacturing routes remains a common factor for both. Efforts in technological development are being centred on performance enhancements for specific components. Recent improvements in in-field characteristics have been due to the discovery of $BaHfO_3$, which is a more effective artificial pinning material than conventional $BaZrO_3$. PLD fabrication of superconducting wires using targets containing $BaHfO_3$ additives has no degradation in in-field J_c characteristics in the thickness dependence, a feature that is usually observed in thicker films when utilizing other materials. Such wires confirm very high in-field characteristics of 85 A/cm width@77 K, 3 T for a 2.9 μm thick wire. The origin of these characteristics derives from the relatively isotropic structure of $BaHfO_3$ with the short rod lengths, accounting for the observed minor changes in the structure of thicker films. The progress in fabrication and process technology of wire scribing has had a significant impact on the development of low AC loss technology. An example of this can be found where a 5 mm-width, 50 m-long MOD wire scribed into five filaments demonstrated the ability to control its degradation characteristics allowing a reduction of AC loss by 1/5 compared to non-scribed wires. For short wires, successful results have been obtained by scribing into 10 filaments, achieving a 1/10 reduction in AC loss. Moreover the delamination strength issue of Y-based wires has recently been the focus of systematic analysis. Delamination trials involving wires fabricated by various materials and processes have been undertaken in order to determine their origin, concluding that three factors were responsible. The bed-layer formed by MOD has been determined to be one factor contributing to relatively poor delamination strength, and process improvements have been undertaken to improve this. Removing the origin of delamination in this layer has yielded greater delamination strengths exceeding 60 MPa.

Equipment development has also advanced in parallel with the above-mentioned wire development and has reached the stage where the advantages offered by Y-based wires are becoming apparent for

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equipment applications. However, amidst the development and progression of alternative competing technologies, a rapid enhancement in superconducting wire characteristics is required in order to realize and showcase many superconductor-based equipment (i.e. superconductor world) that clearly display their superiority. The development of these so-called 3rd generation wires are well positioned to be the epoch in the required performance enhancements with high performance attributes and low cost manufacturing that would significantly exceed the possible future prospects imagined from current development thus far. This concept was in fact the message delivered from Japan for the first time at the ISS conference held last autumn and was reiterated again this year. The USA has also proposed the necessity of similar ultra-high performance wires by setting developmental targets required. Specific characteristic levels are $I_c \geqq$ 2000A@77K,s.f. and $I_c \geqq$500A@65K, 5T. A word of caution to note here is that the developmental aims are not to use a 2000 A operating current. The operating current considerations are based upon energy recycling characteristics and limitation in J_e and it is highly expected that I_C improvement can significantly reduce load factors, which will lead to an effective reduction of AC loss. Additionally, the added advantage related to improvements in in-field characteristics will result in thermally stable current values at high temperatures requiring less cooling loads. A potential future application in mind involves a medical accelerator, and this desires an ultra-homogeneous wire fabrication process in order to deliver the necessary homogeneous magnetic field. Furthermore, rapid improvements are highly anticipated together with important aspects of cost reduction for realizing practical applications.

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Top of Superconductivity Web21

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Feature Article: Forum on Superconductivity Technology Trends - Expectations of Third Generation Superconducting Wires

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1. Introduction

Important issues surrounding the development of rare-earth (RE-123) based superconducting wires intended for practical applications mainly involve, 1) problems associated with weak grain boundary coupling, 2) elimination of current inhibition, and 3) introducing effective magnetic flux pinning centres. A major reason for the difficulties is that phenomena need to be effectively controlled over a spatial region spanning 12-digits, i.e., an introduction of well-controlled nano-scale defects acting as magnetic flux pinning centres, a control of grain boundary characteristics over sub-micron to several tens of microns, in addition to eliminating defects affecting current flow. At the same time, the production of wires on an industrial scale with lengths of several 100's of meters to several kilometres require defect detection methods over the entire wire lengths to establish homogeneity from both reproducibility and quality management points of view.

As well as addressing the current status of RE-123 superconducting wires, the so-called second-generation (2G) wires, the forum presented the future potential of third-generation (3G) wires that are expected to offer significantly enhanced practical performance characteristics by the nanostructural engineering of long wires. The detailed performance of 3G wires was studied quantitatively from both theoretical and experimental points of view, with the performance attributes compared to existing wires and the impact on magnet-based applications.

2. Advances in 2G wire development and progress of 3G wires

2.1 In-plain alignment

It is well established that because of the d-wave symmetry of electron pairs in oxide-based high temperature superconductors the misalignment angle of grain boundary CuO_2-plains increases and the grain boundary critical current density (J_C) decreases exponentially[1]. Grain boundary alignment of less than several degrees is an important factor to obtain the equivalent J_C of grains, i.e., the development of high performance RE-123 wires is dependent upon achieving greater alignment with the metal substrate. The fabrication of biaxially orientated buffer layers in 1991 by Dr.Iijima et al. of Fujikura, allowed for the first time J_C values exceeding 0.1 MA/cm^2 (@77 K, s.f.). These findings led to the accelerated development of RE-123 wires[2]. Later, with improvements of the IBAD layer and the self-orientation process of the CeO_2 cap layer developed by ISTEC, allowed in recent years the fabrication of a long IBAD template with a three-degree in-plain alignment and a quality equivalent to almost a single crystal. As a result of enhancements in in-plain alignment, J_C's measured at a benchmark of 77 K s.f. to determine wire quality have increased, with recent reports stating a measured J_C of 4-5 MA/cm^2.

2.2 Local defects

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As well as grain boundary characteristics, defects also affect current transport, leading to a spatial inhomogeneity in the current distribution. In fact, the *E-J* characteristic of a high temperature superconductor where *E* is the electric field and *J* is the current density, exhibits strong nonlinearity as expressed in n value model: $E=E_c(J/J_c)^n$, as *E* becomes localized near the defect due to the modest distribution of *J*[3]. This results in the significant spatial distribution of the flux flow loss and hot spots being generated within the wire. By focusing efforts in solving each individual factor that contributes to the proliferation of defects as well as improving process feedback has led to rapid improvements in in-plain homogeneity of recent wires. For example, a standard deviation of 1.35 % has been calculated for critical currents (I_C) measured at 70 cm intervals for several 100's-meter class long wires, proving that defect control has realized superior homogeneity[4]. Fujikura currently holds the world record for the performance of a 600m-long 2G wire[5], with an I_C (77 K, s.f.) of 600A/cm-w.

Thus, technological advances in the above-mentioned developments have led to increases in J_C values, which in turn have successfully improved wire performance attributes. However, as Figure 1 illustrates, detailed studies of wire characteristics in high magnetic fields shows that their performance in an irreversible magnetic field has hardly changed despite the many developments. In fact, RE-123 wires exhibit large n values in low magnetic fields and is therefore significantly influenced by current inhomogeneity accompanied by local defect and weak grain boundary coupling. However, the *E-J* characteristics tail-off and the n values drop near the irreversible magnetic fields, producing a broadened spatial distribution of the electric field. Figure 2 shows low temperature scanning laser microscope images of the local electric field distribution[6]. The in-plain electric field localization becomes prominent in the limit of J_C under low magnetic field conditions. Although the same voltage is induced at both terminals of the samples there are significant differences between the inner electric field distributions. It is clear from these findings that electric fields concentrated around local defects produce bottle necks and limit macro J_c values. Whereas under high magnetic fields, even a low bias current is applied locally depinned fluxoids form percolation paths to generate flux flow loss. Here, the concentration of local electric fields becomes moderate and J_C is determined by the properties of the entire superconducting layer even when local defects exist. Therefore, it is understood that current limiting mechanism varies depending on the external magnetic field conditions. Whilst it is considered that a high quality substrate along with improvements in orientation and homogeneity are essential technological issues in mid/low magnetic field regions, in-field performance enhancements of superconducting layer itself with the introduction of pinning centres are essential in high magnetic field regions located close to irreversible magnetic fields.

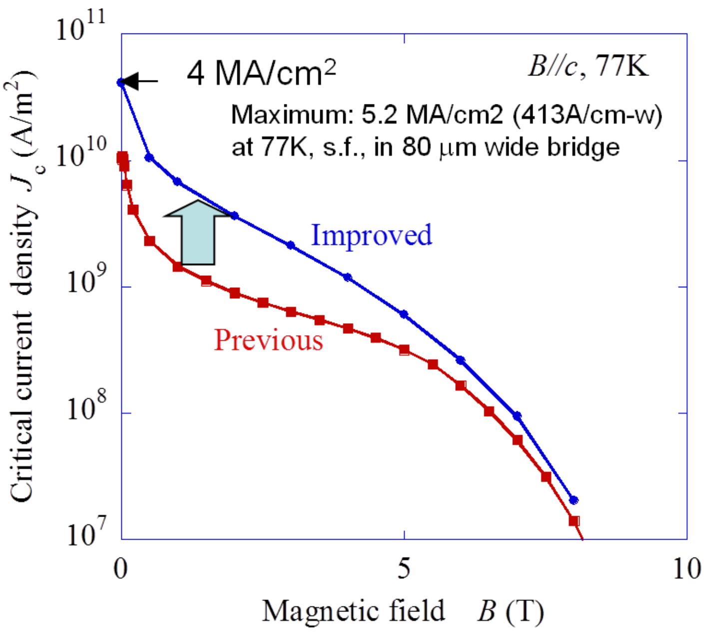

Fig. 1 Improvements in J_C-B characteristics by enhanced in-plain homogeneity.

Fall, 2012 Date of Issue: October 15, 2012

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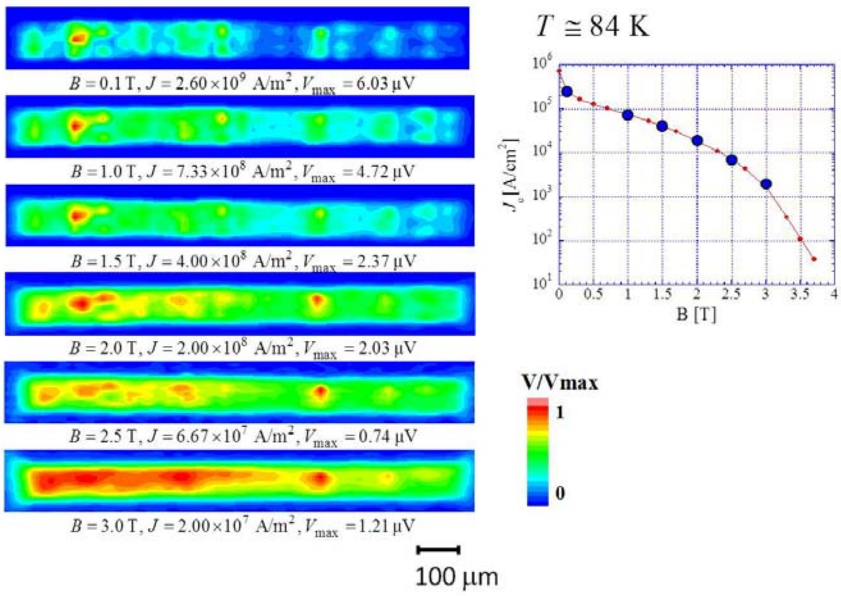

Fig. 2 Low temperature laser scanning microscope images of the local electric field distribution. The in-plain electric field localization becomes prominent in the limit of J_C under low magnetic field conditions. The figure insert shows the observed J_C-B characteristic for each image.

2.3 Enhancement of in-field performance by introducing flux pinning centres

It is known that flux pinning can be achieved with the introduction of nano-sized defects having coherence length dimensions. Metal-based superconductors have now reached a point that enables artificial pinning centres to optimize the nano-structure in accordance with their operating environments. In fact, RE-123 wires have demonstrated that artificial application of nanorods with the addition of nano-particles and additives via PLD, is an effective route to improve in-field performance. Studies attracting attention in recent years are those conducted by ISTEC, who report on a new method of introducing artificial pinning centres involving $BaHfO_3$ (BHO) additions at the time of PLD film deposition. The results from this work on short samples, show that the wires were much less influenced by falls in T_C, and therefore effective in improving in-field J_C and also allowing the fabrication of thicker layers[7]. Figure 3 (a) shows the comparisons in I_C-B characteristics of Gd-123 wires with and without BHO additions. There is an improvement in irreversible-magnetic field characteristics as well as an increase in I_C over the low temperature region, different characteristics to those shown

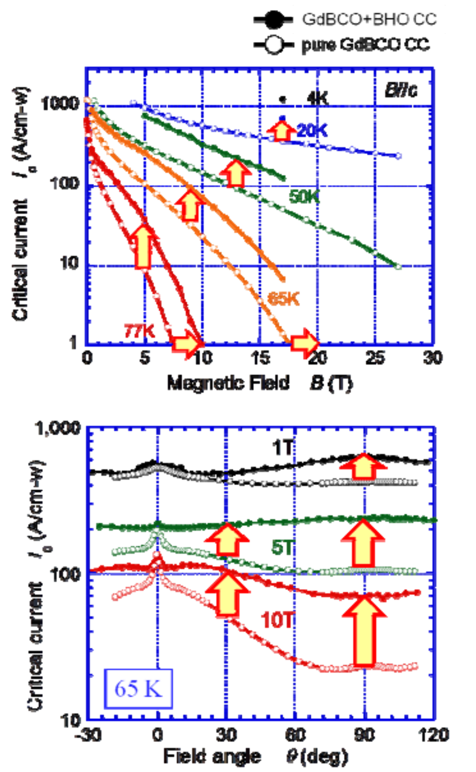

Fig. 3 Critical current characteristics of a sample with BHO artificial pinning. a) I_C-B-T characteristics, b) Angle dependency of I_C.

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in Figure 1. Furthermore, more isotropic I_C dependency for applied field angel θ against the tape surface can be achieved, as shown in Figure 3(b). Increases of I_C are not limited to the magnetic field direction perpendicular to the tape surface, but can been seen over a large angular region. These findings propose the likelihood of realizing practical applications.

3. Performance forecasts of 3G wires

As has been mentioned beforehand in this article, superconducting wires have now reached the stage where we can foresee the possibility of rapid improvements in practical operational performance in long wires by having nano-structure control. The author has investigated the theoretical limitations of present-day wires from a pair-breaking point of view, and the detailed performance attributes anticipated for 3G wires.

The temperature and magnetic field dependency of I_C have been described by measuring the in-field characteristics[8)] and by formulizing current transport properties utilizing the percolation model [9)] of the best performing 2G wires with 600 A/cm-w, 600 m-long as mentioned prior. The results confirmed that the J_C self-field value of 2G wires corresponded to 10 % or less of the pair-breaking current. On the other hand, based on the properties of short-length wire samples with BHO artificial pinning centres as well as the assumption that approximately 30 % of the pair-breaking current will be possible if pinning could be optimized, we've predicted the characteristics of 3G wires. Considering the fabrication cost, a superconducting layer thickness was assumed to be around 2 μm, the estimated I_C of a 3G wire at 77 K self-field was 2000 A/cm-w. Figure 4 shows a map comparing the characteristics of 2G and 3G wires. Here, the overall J_C (J_e) per cross section of wire, 100 μm effective thickness including the substrate, provides a clear assessment of practical wire performance.

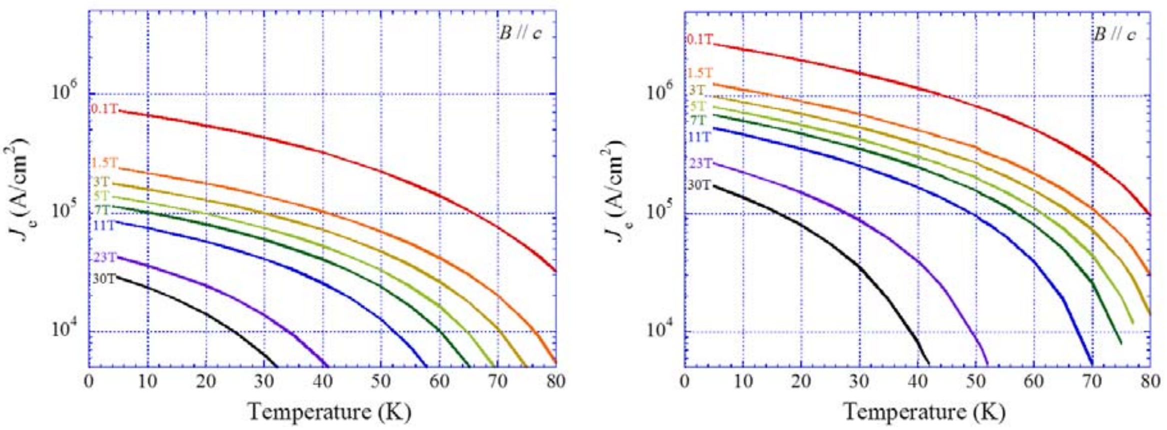

Fig. 4 J_e-T-B characteristics: Comparisons between (a) 2G and (b) 3G wires.

Additionally, the J_e-B-T characteristics of 3G wires are compared with other wires, as shown in Figure 5, which implies a possibility that their in-field performance at 65 K and 50 K is potentially equivalent to NbTi wire (@4.2 K) and Nb_3Sn wire (@4.2 K), respectively. The characteristics of present 2G long wires, as displayed in Figure 5, show that without the introduction of artificial pinning centres cooling down to 4 K is required to realize performances equivalent to NbTi. However if we focus on the performance of wires in high magnetic fields, then for equivalent magnetic fields that exceed 20 T, it is clear that 2G wires have superior performance characteristics than Nb_3Sn wires at 20 K even at present stage.

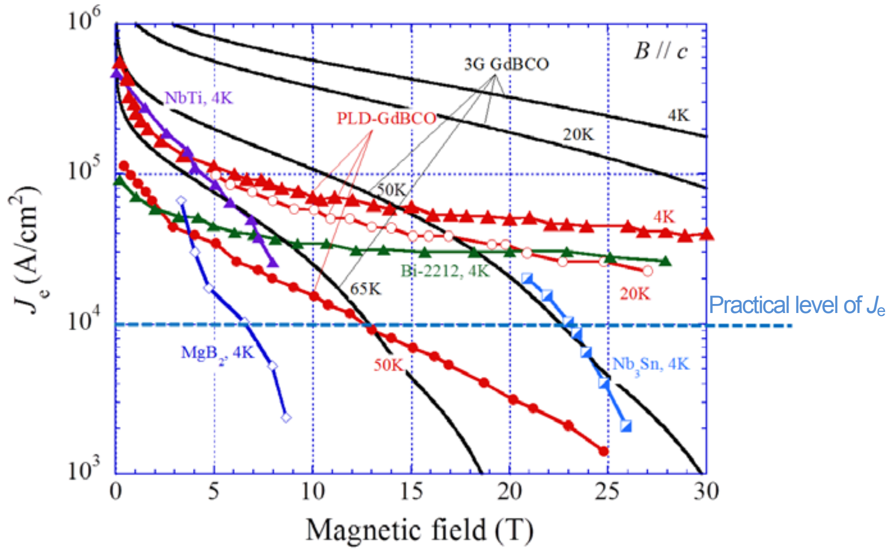

Fig. 5 Comparisons of J_e-B characteristics for each type of wires.

4. Impact in magnetic applications

Based upon the performance attributes discussed above, the wire characteristics when wound into a coil have been investigated. The objective here is analyse the most suitable coil shape and performing coupled analysis[10] of, 1) J (E, T, B, θ, ε) characteristics of wire (here, ε indicates the uniaxial strain in longitudinal direction of wire) with the central magnetic field B_0 and operating temperature T, calculated using the necessary conductor length as the determining factor, 2) structural analysis taking into account electromagnetic coil force considerations, and 3) thermal analysis by considering flux flow losses. The bore of the coil was here set to more than 30 mm with the operating current set less than the minimum I_C within the coil, and furthermore, by taking into consideration the stabilization and insulation layers, with the coated-conductor volume ratio set at 50 %.

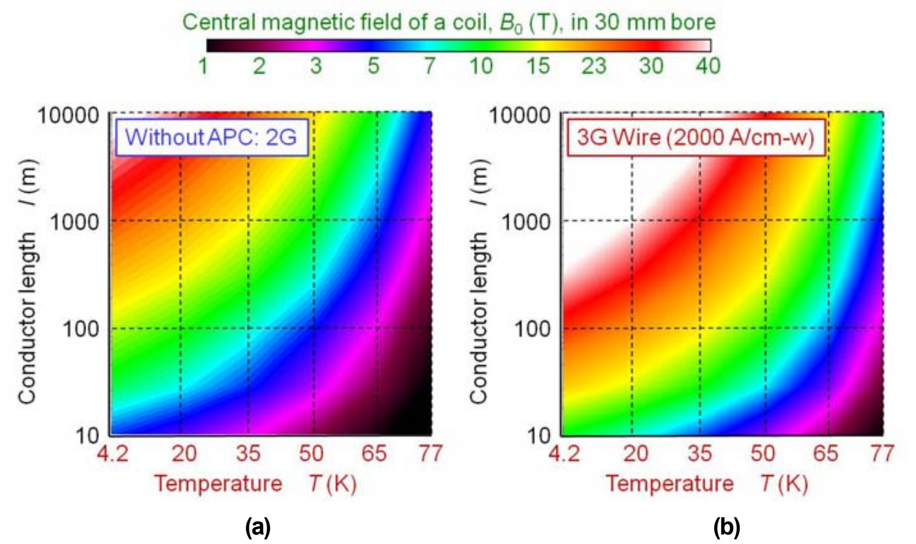

Fig. 6 Magnetic field strength comparisons of wire-winding coils: (a) 2G and (b) 3G wires.

Figure 6 provides a comparison of the strength of magnetic fields possible at a given temperature[11]. It is understood that the next generation 3G wires, with their shorter wire lengths required at remarkable high temperatures will make it possible to generate strong magnetic fields from compact coils. A comparison of this is displayed in Figure 7, which shows the performance of coils fabricated from both 2G and 3G wires based upon an example where the central magnetic field was B_0=5.5 T, operating at 65 K. For equivalent performance attributes, a length of 1800 m is need for a 2G wire, whereas only 100 m are required for the 3G wires. Therefore, the coil compactness is enhanced and the volume significantly reduces to around 1/16th.

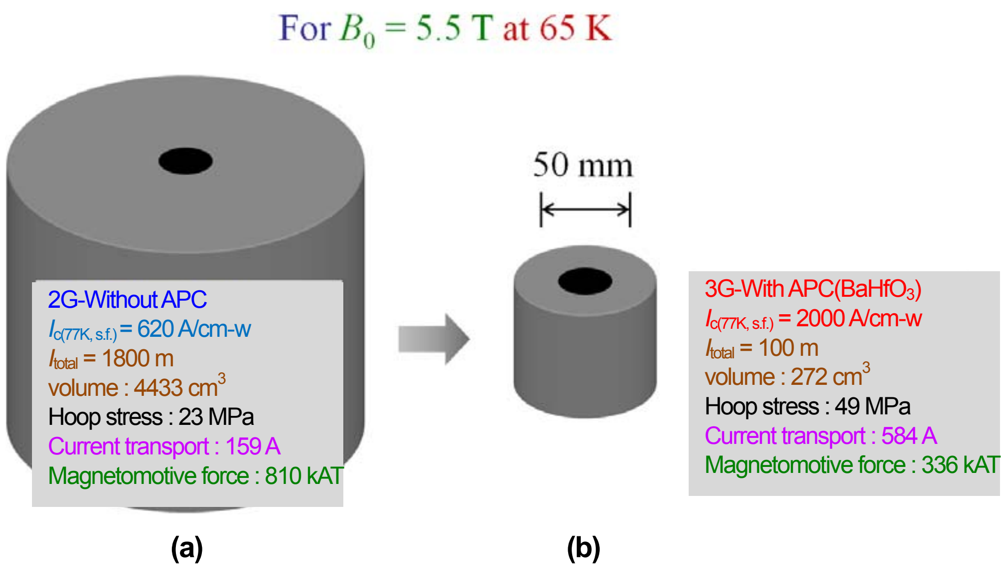

Fig. 7 Comparisons of the coil sizes at a central magnetic field of B_0=5.5 T, operating temperature T=65 K between (a) 2G and (b) 3G wires. It is clear to see its great potential for magnet-based applications where high magnetic field strengths can be realized via a sub-cooled liquid nitrogen environment.

5. Summary

Current 2G wires have J_e characteristics equivalent to NbTi wires at 4.2 K, achieved by high-substrate orientation and high-homogeneity processes, realizing superior characteristics over Nb_3Sn wires (@4.2 K) at 20 K. The self-field J_C is estimated at around 10 % of the pair-breaking current.

Future targets aims at the development of 3G wires are as follows:

1) Realization of J_e characteristics equivalent to NbTi wires (@4.2 K) at 65 K
Replacing NbTi wires currently employed in the majority of superconducting applications with 3G wires suggests a possibility to realize a sub-cooling liquid nitrogen environment. Utilizing such wires are anticipated to lead to significant impacts on lower costs and a reduction in cooling loads, influencing industrial applications utilizing superconducting technology.

2) Realization of J_e characteristics equivalent to Nb_3Sn wire (@4.2 K) at 50 K
Ultra-high magnetic field NMRs, high-temperature operation of accelerators along with shorter wire lengths will reduce the volume required, resulting in compact designs and considerably lower costs.

Those targets can be realized by optimizing pinning centres and achieving around 30% pair-breaking current, and are key in establishing a technology that is effective in introducing artificial pinning centres homogeneously over long wires. The author believes that preparations for the rapid progress of 3G-wire technology are forthcoming because of the accumulation of component technologies in wire developments achieved thus far.

Acknowledgement

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Top of Superconductivity Web21

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Feature Article: Forum on Superconductivity Technology Trends - Expectation of Superconducting Power System Apparatuses

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1. Introduction

Superconducting power system apparatuses have progressed in line with the developments of high temperature superconductors. An outline regarding the effects of superconducting power system apparatuses on power grid applications is briefly summarized herewith. Firstly the fundamental concepts regarding the design and operation of grids are explained and are followed by a brief introduction to the applicability of this technology to superconducting power system apparatuses. The effectiveness of superconducting power system apparatuses in recently featured smart grid technology is also discussed.

2. Electrical Energy System (Power Grids)

Power grid systems consist of power generation-transmission-transformation-distribution, and comprises of a power generator, transformer, transmission cable, switch (circuit breaker, disconnect switch), storage system, and protection system. An important aspect of the design and operation of power grids is the ability to supply stable and high quality electricity economically. However, there is a trade-off between the breaking fault current and power system stability, which are very important issues.

3. Superconducting Power System apparatuses

Superconducting system apparatuses is compatible for currently available power system apparatuses that includes superconducting power generators, superconducting transformers, superconducting transmission cables, superconducting magnetic energy storage systems and superconducting fault current limiters, which are able to suppress fault current.

Common characteristic features applicable to superconducting system apparatuses are compact size/lightweight, high efficiency and high capacities etc. Also, specific characteristics that relate to system apparatuses are briefly mentioned below.

- Superconducting power generators: Improve power system stability and have high partial load efficiency rates.
- Superconducting transmission cables: The line constant is equivalent to overhead transmission lines.
- Superconducting magnetic energy storage systems: High responsiveness
- Superconducting fault current limiters: High responsiveness without the need for sensors. Can also easily resolve issue such as the trade-off between power system stability and suppression of fault current.

- Example:

Substituting conventional generators currently available in the market with superconducting ones can realize far greater stabilities in power systems applications, including wind power generation having varied power outputs.

The employment of superconducting magnetic energy storage systems enables the eigenvalues of power systems to be measured online, (a stability measure related to power systems).

Utilizing superconducting cables as a local bus can solve issues related to high efficiency, high currents and EMC.

4. Smart Grid and Superconducting Power System Apparatuses

The smart grid system needs to be configured for power systems as well as consumers needs. Power generation also occurs via an array of energy sources and therefore it is advantageous to employ superconducting power system apparatuses. For example, the benefits considered here are to enhance the stability of power systems and increase the efficiencies of partial load operation by utilizing superconducting power system apparatuses, the suppression of fault current by employing superconducting fault current limiters, and reduce power fluctuation as well as evaluate on-line stability with the use of superconducting energy storage systems. Further high capacity energy storage systems are also required for Smart Grid operations.

Current battery efficiency is very poor considering power system intelligence. Thus, the high efficiency afforded by superconducting energy storage systems should be taken as an advantage.

5. Conclusions

The development of superconducting power system apparatuses is highly anticipated for not only improvement for current power systems, but also potentially for effective system apparatuses used in Smart Grid systems that serve as part of future power systems.

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Top of Superconductivity Web21

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Feature Article: Forum on Superconductivity Technology Trends - The Current Status and Future of Development for Power Applications using Yttrium-based Wires

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A five-year national project, which stared in FY2008 and runs until FY2012, has been aimed at the technological development of Superconducting Magnetic Energy Storage (SMES), power cables and transformers that utilize Y-based superconducting wires. The project has been endeavoured to develop a high capacity and stable supply of electricity to urban area using superconducting power application. The first three years of the project focused on the development of component technology and wire development in order to enhance the performance of power application. This year marks the final year of the project.

At this forum we present the current status of the technological development of the application, under the title of “Materials and Power Applications of Coated Conductors (M-PACC)” project.

1. SMES

Chubu Electric Power Co. Inc. has been the main body responsible for targeting the development of a 2GJ-class SMES for power grid stabilization. They have progressively conducted component coil verification trials for 20MJ-class SMES. Over the first three years of the project, they attempted to establish coil architecture technologies of high strength and high hoop stress by taking advantage of the Y-based SMES coil wire strength characteristics, together with the required architecture technologies for conduction cooling systems. The latter part has been ongoing for the past two years and it aims to evaluate the properties of conduction-cooled SMES coils and also grasp performance limitations (tolerances, reliability etc.) of coils employing Y-based coated conductor for the future development of 2GJ-class high capacity SMES.

Test results performed in an 11T external magnetic field have so far measured hoop stress tolerances exceeding 600MPa by multilayer coil (250 mm ø). Additionally, high current tests performed using a full-scale coil model (about 600 mm ø) employing 4-bundle conductors measured 2.6 kA. In fact a coil with an electromagnetic force tolerance twice that of conventional coils has been successfully developed by establishing coiling architecture technology to suppress the electromagnetic force that influences superconducting wires, and the formation technology of flexible insulation coatings with greater bend strengths.

2. Superconducting power cable

The technological development has been undertaken for 66kV/5kA large-current cables and 275kV/3kA high-voltage cables, which make possible compact and high capacity transmission. The first three years of the project, component technologies that involve large current/low AC loss cable technology and high voltage insulation/low dielectric loss cable technology have been established. The latter 2 years of the project will see system verification trials undertaken for each cable system with operational test.

In regards to AC loss reduction which is important for superconducting cable development, the fabrication technology of thin wires of 4 mm and 2 mm widths for large current cable was employed in order to suppress the generation of vertical magnetic field by shaping wire concentric cross section of a cable closer to a circular shape. This verified AC losses of 1.5 W/m/phase. Furthermore, a short-circuit test of model cable was undertaken and confirmed that there was no problem in performance deterioration and temperature increase caused by excess current of 31.5 kA - 2 sec.

For the development of electrical insulating materials for high voltage cable, AC withstand voltage test, impulse withstand voltage test, partial discharge inception electric field strength test, and long-term life testing have been undertaken. The cable design was carried out employing the selected Polypropylene laminated paper (PPL paper) as insulating materials with withstand voltage/low dielectric loss properties. With the results of 0.6 W/m of dielectric loss and 0.8 W/m of total cable loss, a cable was acquired satisfying electrical properties required. Furthermore, short-circuit test of a model cable and its intermediate cable joint have been undertaken and verified that there was no problem in performance deterioration and temperature increase caused by excess current of 63 kA - 0.6 sec.

This year, and based upon the results acquired so far, we are going to fabricate a model system of a 66kV/5kA three-in-one large current cable (15 m) and 275kV/3kA single phase high voltage cable (30 m) and verify the feasibility of system by each type of characteristic tests and long-term operational test.

3. Superconducting Transformer

Kyushu Electric Power Co. Inc. is the main body responsible for developing component technology and system technology for the realization of 66kV/6.9kV-20MVA class superconducting transformer with compact, high efficiency and incombustibility. During the first three years of the project, establishment of low loss, high current capacity, wire winding technology such as strong short-circuit withstand, cooling system technology, and technology with fault current limiting function have been undertaken. System verification is planned for several hundreds of kVA-class model transformers with fault current limiting functions and a 66kV/6.9kV-2MVA-class model transformer in final two years of the project.

Wire winding technology, which is important for superconducting transformer development, have so far verified a successful AC loss reduction to 1/5 by 5-scribed processed thin wire compared to non-scribed wire, short-circuit withstand strength of wire winding with six-time short-circuit current more than rated current, and homogeneous current distribution between each wire by homogeneous model with phase transition for multilayer parallel conductor (12 layers, 2 parallel). Also, excess current test of 400 kVA transformer model with fault current limiting function have verified fault current limiting function to suppress excess current within less than three times as rated current. Furthermore, in regards with cooling system technology development, expansion turbine as well as compact turbo compressor without sliding part have been developed aiming efficiency improvement by employing neon coolant, high reliability and long-life and verified more than 65 % of efficiency. Combined this with heat exchanger, cooling system was designed and fabricated.

This year, the feasibility of 66kV/6.9kV-20MVA class superconducting transformer systems will be verified by performance test of 2 MVA class superconducting transformer model.

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Top of Superconductivity Web21

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Feature Article: Forum on Superconductivity Technology Trends - Expanding Applications of Superconducting Detectors by Multi-Pixel Multiplexing

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Low Temperature Superconducting Devices Laboratory
SRL/ISTEC

Superconducting detectors utilize specific characteristics of superconductors to detect γ-rays, X-rays, photons and other particles, with resolutions and sensitivities much superior to other conventional technologies. Superconducting detector research has heated up in recent years, which is reflected at the world's largest conference related to superconducting application research, the Applied Superconductivity Conference (ASC), whose electronics region is consisted of two main categories as traditional superconducting electronics and the detectors.

There exist several types of superconducting detectors in which the most typical is the Transition Edge Sensor (TES). It utilizes the superconducting/normal-conducting transition in a superconductor, and is able to detect changes in temperature when X-rays impinge on it. Another is the Superconducting Tunnel Junction (STJ), which detects the broken superconducting electron pairs causing an increase in sub-gap current at the superconductor/insulator/superconductor junction. The Superconducting Single Photon Detector (SSPD) is consisted of an ultra-thin superconducting film with meander geometry. Detection occurs when an incident photon disrupts the superconductivity in the meander. The superconducting electron pair energy gap in a STJ is, for example, three digits smaller than that of a semiconductor, resulting in not only higher sensitivity, but also superior high-energy resolution due to greater numbers of electron pairs breaking with incident photons.

Superconducting detectors are anticipated for a vast array of applications to meet individual specifications where high resolution and greater sensitivity are required, and where this cannot be realized with other materials. Examples can be found in X-ray astronomy to explore mysteries of the universe, radiation analysis to readily identify atomic nuclei, terahertz imaging which is proving effective in airport security screening, mass spectroscopy applications directly measuring mass as well as the mass to charge ratio, material analysis applications to identify atoms that are quite difficult to detect by buried in other peaks, as well as quantum information communications with guaranteed absolute safety.

However, the limitations associated with superconducting detectors are the prolonged data acquisition times. This limitation is due to an unavoidable small sensing area which is necessary by small measurement volume required for greater sensitivity. Despite this, the data acquisition times can be improved without affecting the resolution and sensitivity by increasing the sensing area in a so-called multi-pixel arrangement. Current research efforts have therefore been focused upon multi-pixel superconducting detector arrangements rather than individual units. However, simple multi-pixel arrangements increases the numbers of input/output electrical lines, which in turn increases thermal inflows through those lines that result in an unacceptable cryocooling requirement that is greater than the cooling ability offered by the current cryocooler.

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In order to solve above-mentioned issues, time-division multiplexing, frequency-division multiplexing, code-division multiplexing and multiplexing using resonance phenomena have been so far developed in an attempt to reduce the numbers of outputs. In particular, multiplexing using resonance phenomena has recently been gaining attention. The method utilizes in a Microwave Kinetic Inductance Detector (MKID) to detect variances in the kinetic inductance by a LC resonant frequency shift due to photons arriving in a superconductor. Such a method allows a 1000-detector read-out with a single output line. ISTEC, together with the National Institute of Advanced Industrial Science and Technology (AIST) began research into TES last year. Methods to detect LC resonant frequency shifts by using changes in SQUID inductance have been developed for combining high resolution TES and resonant frequency methods in anticipation for multi-pixel detectors.

Superconducting detectors will not lead to large industries straightaway, however the research and development in this field is required to maintain Japan's science and technology at world-top class. As the developmental projects in this field are still small-scale, it is difficult to surmise that the efforts of all researchers are united. Also, stable supplies of devices are required to steadily advance research in this field. Once established, will position each research institution with the prospect of focusing resources into individual fields of expertise. The time has now arrived to launch the full-scale development of multi-pixel superconducting detectors by having access to stable supply bases as well as establishing projects that are united with the research efforts in Japan.

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Top of Superconductivity Web21

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Feature Article: Forum on Superconductivity Technology Trends - Research Trends in Fe-based Superconducting Materials

Keiichi Tanabe, Deputy Director General
SRL/ISTEC

It has been approximately four years since a research group based at Tokyo Institute of Technology, led by Professor Hosono, discovered a second group of high temperature superconducting materials after Cu oxides, but based on Fe. Within several months of their initial studies, they recorded a T_c of around 55 K, which has yet to be improved. However, since their discovery several programs in Japan such as JST's "TRiP"(2008-2010), JSPS's "Exploration of Novel Superconductors and Related Functional Materials, and Development of Superconducting Wires for Industrial Applications"(2009-2013), and JST's "Japan-EU Cooperative Research Project" (2011-2013) have launched and progressed in an attempt to evaluate potential applications utilizing Fe-based materials in addition to exploring other new materials. This forum introduced recent research trends related to Fe-based materials, which included recent advancements in thin film fabrication technology and potentially important application-related grain boundary characteristics, as well as trials involving wire fabrication technology. Towards the end of the forum recent topics on Fe-based materials and the exploration of new materials were presented.

Fe-based superconducting materials have a multilayered structure of superconducting charge carrier layers such as Fe-*Pn* (*Pn* is a pnictogen element, e.g. P ad As) or Fe-*Ch* (*Ch* is a chalcogen element, e.g. S, Se, Te) with other atomic layers. Such layered material systems can typically be categorized into the 1111,122 and 11 systems, and so on. Amongst these, the 1111 system, represented by NdFeAs(O,F), has the highest recorded T_c of 55 K, and the 122 system, represented by $(Ba,K)Fe_2As_2$, has a recorded maximum T_c of 38 K, with both material systems exhibiting high upper critical magnetic fields that are equivalent to Y-based Cu oxide materials. Additionally, the 122 system and the 11 system, Fe(Se,Te), with the simple crystal structure, exhibit less anisotropic superconducting parameters such as upper critical magnetic fields when compared to the Cu oxides. Such characteristics are advantageous for wire applications.

Until now, the majority of reports into thin film fabrication of Fe-based superconducting materials have been on the 122 and 11 systems. Initially, a high quality thin film 122 system was fabricated by Tokyo Institute of Technology utilizing $Sr(Fe,Co)_2As_2$ and $Ba(Fe,Co)_2As_2$, (T_c is around 22 K), by partial Co substitution on the Fe sublattice using PLD. Later, a research group based at the University of Wisconsin in USA and a group at IFW Dresden in Germany, both demonstrated the PLD fabrication of high quality epitaxial films utilizing $SrTiO_3$ and metal Fe buffer layers. Of particular note is that the former group reported that by inserting $BaFeO_2$ nanorods into the thin films acted as strong pinning centres that exhibited high in-field J_C. Research groups at Tokyo University of Agriculture and Technology and Nagoya University have produced thin films of $(Ba,K)Fe_2As_2$ (T_c=38K) and $BaFe_2(As,P)_2$ (T_c=30 K), demonstrating higher T_c by employing MBE. Recently, ISTEC reported the successful thin film fabrication of $BaFe_2(As,P)_2$ by PLD that exhibited high J_C. Research institutions in both Japan and overseas have mainly employed PLD to fabricate high quality 11-system thin films of Fe(Se,Te), all interestingly reporting a higher T_c of around 16-21 K compared to the bulk, together with less deterioration in in-field J_C characteristics. Realizing a high quality thin film with 1111-system crystal structure that exhibits a high T_c requires a strict control of oxygen content. Research groups based at Nagoya University and Tokyo University of Agriculture and Technology, have

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recently demonstrated the MBE deposition of a high quality 1111-system thin film with a T_c slightly higher compared to bulk. (The details were published in April 2012 issue of Superconductivity Web21).

Last year, the Tokyo Institute of Technology and ISTEC jointly fabricated a $Ba(Fe,Co)_2As_2$ epitaxial thin film onto a bicrystal substrate, verifying that high angle grain boundaries in Fe-based superconducting materials exhibited weak link similar to Cu oxide materials. However the deterioration in J_C accompanied by an increase in misorientation angle was moderate and showed favourable grain boundary characteristics compared to Cu oxide (Refer to September 2011 issue in Superconductivity Web21). Recently, the research group at Nagoya University reported the MBE fabrication of a $BaFe_2(As,P)_2$ thin film deposited on a bicrystal substrate with a misorientation angle of 24°, which exhibited a J_C greater than 1 MA/cm^2 at low temperatures. Further improvements in material quality offer possibilities to improve J_C characteristics between grains. There were several reports on Fe-based superconducting thin films fabricated on biaxially textured IBAD-MgO buffered metal substrates. In particular, it was just last year that Tokyo Institute of Technology and ISTEC established that restrictions in in-plane alignment were moderate compared to Cu oxide-based materials, with the J_C results being equivalent to thin films fabricated on a single crystal substrate having a 7° in-plane alignment. Wire fabrication employing the so-called PIT (Powder-In-Tube) method has recently seen remarkable progress. The research group based at Florida State University sintered a $(Ba,K)Fe_2As_2$ compound having less impurities by reacting refined raw powder at low temperatures. They employed Ag-sheath wires that contained this compact sintered material and demonstrated a J_C of 120 kA/cm^2 (4 K, self-field), one digit higher than the record originally achieved by other groups, clearly demonstrating that further enhancements in J_C are possible by improving composition control. Wire applications desire materials that employ no toxic elements such as As. In response, materials such as $K_xFe_{2-y}Se_2$, exhibiting a T_c greater than 30 K, and containing no As have been discovered. The active exploration of materials with even higher T_c is currently on-going.

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Top of Superconductivity Web21

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Superconductivity

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Feature Article: Forum on Superconductivity Technology Trends - Superconducting Technology Applications for the Next Generation Railway Systems

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Railway Technical Research Institute

A superconducting cable utilized as part of the railway electric traction system was introduced at the Forum on Superconductivity Technology Trends. Research efforts can be classified into four categories, 1) the influence of superconducting cables for railway systems, 2) evaluating fundamental wire characteristics, 3) cooling system for superconducting cables, and 4) fabrication of prototype superconducting cables.

1) The influence of superconducting cables for railway systems

Around 60 % of Japan's railway employs a DC 1,500 V feeder system. Results from simulation studies showed that installation of superconducting DC cables between transformer substations had some operationally advantageous effects such as reducing transmission losses, which significantly exceeded cooling losses, a reduction of non-receptive line conditions, and a reduction of input voltage requirements at transformer substations.

2) Evaluating fundamental wire characteristics

The design of superconducting DC cables has been undertaken by testing excess current characteristics, I_C-B-T and I_C distribution of long wires.

For excess current characteristics, our experiments have repeatedly applied pulse-currents with 100 ms pulse widths. The findings concluded that there was no drop in I_C when the cable was pulsed 100 times, thereby establishing no detrimental effects of repeated pulsing. Additional studies of excess current characteristics with sweep rate dependence have been undertaken. Here, the risk is that bubbles form when immersed in liquid nitrogen, which then nucleate and eventually boil-off, causing rapture straight away. The greater the sweep rates, the greater the current value causing the formation of the first bubble. The results confirmed that in the case of Bi-based superconducting wires, even small destructive currents at a rate greater than 360 A/s cause rapture even before the first bubble occurs.

The low magnetic field dependency of both Bi-based and Y-based superconducting wires has been calculated to be less than 0.1 T, as measured from I_C-B-T characteristics (research conducted jointly with NIMS).

Magnetic microscopy evaluation of long wires has concluded that there was a relatively large local I_C distribution that looked homogeneous if measured using the four-probe method. Furthermore, high-speed magnetic microscopy measurements conducted at 36 m/h allowed the visualization of local defects measuring less than mm in size within the wires. Defects lead to hotspots and employing this technology in the fabrication of long wires will be inevitable (research being undertaken with Kyushu University).

3) Cooling system for superconducting cable

A study of the cooling system has concluded that the combination of a refrigerator and a vacuum pump offers far greater reliability than a refrigerator equipped with a backup system.

4) Fabrication of prototype superconducting cable

A 5 m-long prototype superconducting cable was fabricated and tested. Application tests were performed and confirmed a current flow of 10.1 kA(@77K) and 10.9 kA(@77K) for the conductor layer and shield layer, respectively.

At the Railway Technical Research Institute the technological deployment of superconductors has been investigated for railway system applications. Amongst a number of projects, the development of a superconducting cable for railway systems is partially funded by JST Industry-Academia Collaborative R&D Program - Strategic Promotion of Innovative Research and Development (S-Innovation). Intensive research and development efforts are underway. With the results from fundamental experiments conducted thus far, the author's research team will continue their efforts to design and fabricate a suitable superconducting DC cable for railway systems.

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Top of Superconductivity Web21

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Feature Article: Forum on Superconductivity Technology Trends - Progress in the International Standardization of Superconducting Wires, and the Future Standardization of Superconductivity-related Applications

Kozo Osamura, Research Fellow
Research Institute for Applied Sciences

It has been 101 years since the discovery of the superconducting phenomenon. Since that time academic progress has advanced, producing more specific superconductor-based technological applications from 1960 onwards. The discovery of high temperature superconducting materials in 1986 strengthened the opportunities for even greater arrays of superconducting applications. Generally speaking, the development and distribution of industrial products inevitably leads to some form of standardization that applies to each stage of the product, ie. manufacturing, distribution, and consumption. This equally applies to new industrial materials in particular superconducting wires, and the author considers that the standardization of superconducting wires will play an important role in fulfilling the awareness of wire characteristics and its methods of use.

The structure and fabrication methods of commercially supplied superconducting wires made from Nb-Ti, Nb_3Sn, MgB_2, BSCCO, or REBCO have thus far been established as industrial technologies. The Japan National Committee for the IEC-TC90 superconductivity has recognized that for superconducting wires to be categorized and employed as industrial products their structural characteristics, superconductivity and industrial characteristics need to be systematically identified.

At the IEC-TC90 Berlin meeting held in June 2008, a Japanese proposal was put forward to standardize superconducting wires. In response an Ad-hoc3 group was founded to deliberate the justification for standardization. The discussions led to recommendations that were reported and acknowledged at the IEC-TC90 Seattle meeting held in October 2010. A WG13 was newly founded to discuss NWIP, which was proposed at the same time. At the Berkeley meeting held in June 2011, a policy directive divided NWIP into two parts, however committee members have repeatedly debated this issue. At the Okinawa meeting held in December 2011, a CD draft outline for the division of NWIP was agreed. It is through these channels of discussions that summaries of the general requirements for superconducting wires specifications are presently circulated around the world. Following the successful outcomes from these discussions, it is expected that by April 2014 these will be established as international standards. A summary of these discussions is presented here.

The first section pertains to the category of practical superconducting wires – general characteristics and guidance, which has been registered as project-reference IEC 61788-20. This registration only applies to superconducting wires, outlining their characteristics and structure, which cannot be realized by utilizing any other industrial materials. Following this, an awareness of the common structural features for employing the five types of wires mentioned above has been summarized. For international standardization the following are requisite requirements for manufacturers to detail their products, 1) "Superconductor", either the material names or trademark name or both, 2) manufacturer name, 3) origin of product, and 4) shipping information, such as lot number or serial number of manufacturer to ensure traceability. The second section, (IEC 61788-21), is a document concerning test methods for practical superconducting wires to measure the wire characteristics. The document briefly summarizes essential factors such as critical temperature, AC loss, critical magnetic fields and irreversible magnetic fields, mechanical/electromagnetic properties, critical currents and n-values, inhomogeneity and stability that need to be addressed when applied practically. Since there are 11 international standards in Reference Test Methods pertaining to superconducting-related characteristics as well as the required characteristics of industrial materials, it is therefore compulsory that these international standards are applied to characteristics testing.

It is foreseeable that in the future, superconducting technology will evolve and become established mainstream technology for many products. Therefore, as further products are developed there will be more legislation involving the international standardization of such products. It will become necessary to standardize a greater number of test methods than 11 methods currently available today. Thus, establishing general requirements pertaining to superconducting wires is the “key” in order to systematically arrange complex and wide-ranging international standards of the future. Superconductor technology is yet to be established as a mainstream industry, however the promotion of international standardization and investigations of superconducting industrial technologies have been continuously perused nationally, mainly with the Japan National Committee for the IEC-TC90. From a standards consensus strategy viewpoint, it is the author’s opinion that Japan leads the international standardization activities related to superconductor technology and it is imperative that this remains the case, as well as being able to constantly relay the pioneering research outcomes of superconductivity science and technology.

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Top of Superconductivity Web21

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Feature Article: Forum on Superconductivity Technology Trends - Superconducting System Development under the JST/S-Innovation Program

Kenichi Sato, Program Officer
Japan Science and Technology Agency/Sumitomo Electric Industries, Ltd.

1. Outline and characteristics of the organization

A technological development program entitled "Strategic Promotion of Innovative Research and Development (Abbreviation: S-Innovation)" was launched by the Japan Science and Technology Agency (JST) in 2009, the R&D themes being selected based upon the excellent outcomes from promotion activity of innovative research and development. The characteristics of the program are 1) to support a series of developments ranging from fundamental research to applications, all operating under one R&D program, and running over a maximum period of 10 years (realization of long-term seamless funding), 2) promotion including, a. R&D activities promoted under one R&D theme by several research teams from both industrial and academic partner collaborations, b. building one research team between industrial and academic research partnerships, c. each research team establishing a lead chief Project Manager (PM), and 3) a Program Officer (PO) who would be responsible for issue selection and strategic R&D promotion, as well as promote research and development together with JST.

2. Past research outcomes and future issues for "Superconducting System" R&D themes

Table 1 Technological outcomes

R&D themes	Technological outcomes
High Temperature Superconducting SQUID	. Technology required for the fabrication of high-performing SQUID devices, with noise characteristics that are equivalent to that of low temperature superconducting SQUIDs . Modularization of SQUID sensors, and dissemination of structured themes involving partnership institutions leading to the rapid progress of applications research
High power superconducting rotating machine	. Conceptual design of a 20MW-class rotating machine operated at a targeted efficiency of 99%, and clarifying the component parts specification required . The potential of meeting the required AC loss targets in a superconducting magnetic field coil . Preliminary experiments of an all-in-one rotor cooling system that confirms cooling stability under thermal loads
High efficiency/compact accelerator system	. Completion of a conceptual design for an accelerator and magnet, and clarifying the component technology specifications required (3D winding technology) . Potential component technology solutions obtained from detailed investigations of shield current effects and favourable superconductivity characteristics in a 3D coil winding.
Next generation NMR	. Fabrication of a high-temperature superconducting coil based upon the fundamental characteristic evaluation of superconducting wires and investigations of impregnation methods. Confirmed to be a world-class hybrid magnet generating magnetic fields of 24T at 4.2K. . Ultimately clarifying the high temperature superconducting magnet specifications . Verifying that the metal probe detection sensitivity improves by reducing its temperature
Next generation railway system	. Simulating actual operating routes and model schedules have confirmed that installation of superconducting DC transmission systems on railways realizes a reduction of energy consumed. . An investigation of potential candidates applicable for railway systems that combine transmission (including cable) and cooling systems

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"The creation of an advanced energy/electronics industry with a superconducting system" has been selected as one of the themes. Under a strict candidate selection protocol, five research teams have already begun R&D activities, which have been progressing steady for the past 2.5 years. The acquisition of world-leading technological outcomes are summarised in Table 1 with the patents and external publications shown in Table 2. It is worth noting that there are now in excess of 200 presentations and publications, which the author believes are now forming the foundation of communication channels of high temperature superconductor-related R&D outcomes to Japan and abroad.

Table 2 Patents/external publications

Category		Numbers
Patent (numbers)		12 (Overseas:2)
Conference presentation (numbers)	Japan	129
	Overseas	59
Paper publication (numbers)	Papers written in Japanese	3
	Papers written in English	21
Newspaper, TV		15

Future research and development will enter the stage for establishing component technology further and addressing full-scale issues arising. For this, the author seeks further cooperation and guidance from fellow researchers.

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Top of Superconductivity Web21

