Fall, 2010 Date of Issue: October 12, 2010

Superconductivity Web21

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From Forum on Superconductivity Technology Trends 2010

Masaharu Saeki, Director
Public Relations Division, ISTEC

Lecture by Director General Shiohara

On May 24 (Mon.), ISTEC held a Forum on Superconductivity Technology Trends 2010 at Toshi Center Hotel, Tokyo. There were about 200 participants, including people from the industry, academia, government, mass media, and the general public. Reports on the results, challenges, and trends of superconducting technology development aiming at the industrialization were delivered; and enthusiastic discussions took place.

Ryoji Doi, Director, Research and Development Division, Industrial Science and Technology Policy and Environment Bureau, Ministry of Economy, Trade and Industry, and Mr. Tomoya Ichimura, Director General, Department of New Energy Technology Development, New Energy and Industrial Technology Development Organization (NEDO), delivered congratulatory speeches. They mentioned that superconductivity is positioned as an important technology of the country and projects such as Y-based Power Device Development are making good progress. They also offered words of encouragement saying that ISTEC has been playing a role as the core laboratory and they expect the achievement of these projects and practical applications at an earlier date in collaboration with the people gathered here from the industry, government, and academia.

In the keynote lecture entitled “Development of Y-based Superconducting Wires and their Applications - Contributions to the Environment and Energy,” Yuh Shiohara, Director General, Superconductivity Research Laboratory (SRL)/ISTEC, took up the overview of the NEDO project “Technology Development of Y-based Superconducting Power Devices” and a wind turbine generator using superconducting wires as examples to explain their meaning, and emphasized that superconducting technologies can contribute to drastic CO_2 reduction toward the solution for global environment issues.

Teruo Izumi, Director of Superconducting Tapes and Wires Division, SRL/ISTEC, delivered a lecture entitled "Current Status and Future Prospects of Technology Development for Performance Improvement and Length extension of Y-based Superconducting Wires," and on the basis of the results of the fundamental technologies for superconductivity application project, he reported on the development status and the future challenges toward the performance improvement and cost reduction of wires that support individual power devices in the technology development of Y-based superconducting power devices.

Hiroaki Kumakura, National Institute for Materials Science, delivered a lecture entitled "Development of Bi- and MgB_2-based Wires and their Applications," and explained about the crystal structures and characteristics, wire fabrication methods, their applications and the challenges for the future regarding Bi-based wires and MgB_2 wires.

Noboru Fujiwara, Director of Electric Power Equipment Division, SRL/ISTEC, delivered a lecture entitled "Development Status of Y-based Superconducting Power Devices (cable, transformer, SMES)," and reported on the development status and the plans for the future regarding the SMES (electric power storage), superconducting cables, and superconducting transformers currently under development in the NEDO project.

Tsukushi Hara, General Manager of R&D Center, Tokyo Electric Power Company, delivered a lecture entitled "Demonstration of Bi-based Superconducting Cables and Expectations for the Future," and explained the meaning of superconducting wire development, progress of the demonstration project on bismuth-based high-temperature superconducting cable, and plans for the future expansion toward practical applications.

Mutsuo Hidaka, Director, Low Temperature Superconducting Device Laboratory, Electronic Device Division, SRL/ISTEC, delivered a lecture entitled "Application of Superconducting Devices to Mixed Signals" and reported that higher speed and higher accuracy are required for mixed signal circuits such as AD converters and DA converters that simultaneously process analog and digital signals and high-performance and high-reliability devices can be realized with simple configurations by effectively utilizing the high speed and quantum effect of superconducting circuits.

Keiji Enpuku, Kyushu University, delivered a lecture entitled "HTS-SQUID (S-Innovation)," and introduced the research content of "Development of Advanced Biotech/Nondestructive Sensing Technology using High-temperature Superconducting SQUID" that had been adopted as one of the programs for the JST project "Strategic Promotion of Innovative Research and Development (S-Innovation)." This program aims at developing bio-sensing technologies for medical diagnosis or regeneration medicine and nondestructive testing techniques for analysis and evaluation by establishing a high-performance, high-reliability SQUID system that can be used for industrial applications.

Koichi Nakao, Fellow of Advanced Materials & Physics Division, SRL/ISTEC, delivered a lecture entitled “Progress in Y-based Wire Processing/Evaluation Technologies for Power Devices” and reported on the development status and results of narrow-wire processing technologies for AC loss reduction of Y-based wires applied to power devices, and the progress in the evaluation technologies and the future challenges.

Keiichi Tanabe, Deputy Director General, SRL/ISTEC, delivered a lecture as a co-proponent on behalf of Hideo Hosono, Tokyo Institute of Technology, entitled “Overview of the FIRST Program * – Exploration of New Superconductors and Related Functions, and Applications to Wires.” After explaining how they discovered iron-based superconductors and the subsequent progress, he referred to the framework in which they would promote this project. The materials/functions exploration team explores new high-temperature superconductors that are physically potential for expansion, and then–in response to the exploration results—the wire applications team evaluates the superconductors.

Teruo Matsushita, Kyushu Institute of Technology, delivered a lecture entitled "Global Environment Issues and Superconducting Power Device-related International Standardization" and indicated the passage to the international standardization, and assuming that the introduction of superconducting power devices will start in the near future, he appealed that international standardization must be started immediately and that superconductivity is an important technology for our country; therefore, Japan should lead the world as a managing country.

Koichi Kitazawa, President of Japan Science and Technology Agency (JST), delivered a lecture as a summary entitled "Low-carbon Society realized by Superconductivity," and stated that what went down in the history were symbolic monuments (civilizations such as Horyu Temple and Izumo Shrine) but not cost performance or diligence, and insisted that there are stages where superconductivity can play an active role in resolving global energy issues, by taking up examples such as the GENESIS Project and Sahara Solar Bleeder Plan. He further stated that Japan is said to have been filled up with the sense of stagnation and has become less energetic; however, there is no other country like Japan with such a huge trade surplus, and that Japan could do anything if motivated. In addition, he proposed that from now on, Japan should take the road toward living for the world, leaving monuments for future generations, and retaining resources and the environment for our descendants.

On the basis of the robust achievements of research and development in each field of superconductivity, new steps have been taken toward practical applications and the results started to come within sight; and the debriefing forum turned out to be a place for renewing our awareness of the meaning and importance of further collaborations among industry, government, and academia.

A scene of the venue

*Funding Program for World-Leading Innovative R&D on Science and Technology

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Change of ISTEC President

Katsumi Tajima, Managing Director
ISTEC

At the 46th ordinary Board of Directors' meeting and the 36th Board of Councilors' meeting held at Shiba Park Hotel on June 14, 2010, International Superconductivity Technology Center (ISTEC) unanimously appointed Mr. Tsunehisa Katsumata, Chairman of Tokyo Electric Power Company, as the new president in place of Mr. Hiroshi Araki.

New president Mr. Katsumata (right) and ex-president Mr. Araki delivering their speeches

President Araki had assumed the post in March 2000 as the successor to the then-president Mr. Nasu and served as the president for over 10 years, while greatly contributing to the progress of superconducting technology development and the growth of ISTEC. After the Board of Directors' meeting, the new and old presidents delivered speeches. Mr. Araki said, "I am filled with deep emotion because the development of superconducting technology has greatly advanced over the last 10 years, and the practical applications of superconducting devices are foreseeable. Even so, I would like to ask you to continuously strive for the technology development under the new president Mr. Katsumata, as we are still halfway to the goal." The new president Mr. Katsumata said, "I will do my best toward practical applications realization of superconducting devices at an earlier date, and I would like to ask all the concerned people for continued support and cooperation."

In addition to the above, draft proposal such as "Activity Report and Settlement of accounts for FY2009" were passed at the Board of Directors' meeting and Board of Councilors' meeting.

When the proceedings were completed, Mr. Doi, Director, Research and Development Division, Ministry of Economy, Trade and Industry, delivered a lecture titled "Trends of Research and Development Policies for Green Innovations."

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What's New in the World of Superconductivity (August, 2010)

Akihiko Tsutai
International Affairs Division, ISTEC

Award

SuperPower (August 2, 2010)

SuperPower, the Oak Ridge National Laboratory (ORNL), and the University of Houston (UH) have been awarded an R&D 100 Award for their collaborative efforts in the production of higher-performing HTS wires. The award is part of an annual competition sponsored by *Research and Development Magazine* that recognizes the "100 most technologically significant new products of 2010." The award was presented for the development of a 3-D self-assembly process that enables the production of ultra-high-performance superconducting wires. This process creates non-superconducting nanoscale columnar defects with nanoscale spacing within HTS wires, thereby improving the performance of high-temperature superconductors by enabling large currents to flow in the presence of high applied magnetic fields. Arthur P. Kazanjian, general manager of SuperPower, Inc., commented, "The higher performance characteristics of this 'advanced pinning' wire are providing important benefits in HTS applications that operate at lower temperatures and in various background magnetic fields, including various type of motors, generators, transformers and all types of high field magnets. The demand for HTS in the electric power, medical, transportation, industrial and military sectors demonstrates this product's importance and widespread commercial viability." Dr. Dominic F. Lee, Superconductivity Program Manager at the Oak Ridge National Laboratory, added, "The close collaboration between team members is a perfect example of how R&D should be done – with a national laboratory serving as the bridge between academia and private industry. I am particularly impressed by the short length of time required by SuperPower to bring this nanotechnology into large-scale production." This is the third R&D 100 Award that SuperPower has received in its 10-year history.

Source:
"SUPERPOWER WINS R&D AWARD WITH ORNL AND UH"
SuperPower press release (August 2, 2010)
http://www.superpower-inc.com/content/superpower-wins-rd-100-award-ornl-and-uh

Power

American Superconductor Corporation (August 17, 2010)

American Superconductor Corporation has acquired a 25 % ownership position in Blade Dynamics Ltd., a designer and manufacturer of advanced wind turbine blades using proprietary materials and structural technology. The wind turbine blades produced by Blade Dynamics are designed to increase the efficiency and performance of very high power (multi-megawatt) wind turbines while reducing costs. The Dow Chemical Company has also made a minority equity investment in Blade Dynamics. Greg Yurek,

AMSC founder and Chief Executive Officer, commented, “Blade Dynamics presents us - and the entire wind industry - with a game-changing wind turbine blade technology that enhances performance and reduces weight and cost for high power wind turbines. We view this as a compelling investment and expect many wind turbine manufacturers, including our own AMSC Windtec™ licensees, to quickly migrate to the Blade Dynamics solution to avail themselves of these competitive advantages. In fact, AMSC Windtec and Blade Dynamics engineers have already been working in close collaboration to optimize blades for AMSC Windtec turbine designs." AMSC anticipates that the Blade Dynamics technology will provide a promising blade platform for AMSC’s 10-MW SeaTitan™ superconductor wind turbines in addition to providing AMSC Windtec licensees with a differentiated blade offering.
Source:
“AMSC Acquires 25 Percent Stake in Blade Dynamics Ltd.”
American Superconductor Corporation press release (August 17, 2010)
http://www.amsc.com/pdf/Blade%20Dynamics%20-%20Final.pdf

American Superconductor Corporation (August 24, 2010)

American Superconductor Corporation has received an in initial order for 17 wind turbine electrical control systems from Inox Wind Limited (India). The electrical control systems will be installed in 2-MW doubly-fed induction wind turbines that Inox is manufacturing under a license from AMSC’s wholly owned AMSC Windtec™ subsidiary. Inox recently installed and commissioned its first 2-MW wind turbine and has already begun volume production.
Source:
“AMSC Receives Initial Wind Turbine Electrical Control Systems Order from India’s Inox Wind”
American Superconductor Corporation press release (August 24, 2010)
http://www.amsc.com/pdf/inox_ecs_08_24_10.pdf

LS Cable (August 30, 2010)

LS Cable (South Korea) and the Korea Electric Power Corporation (KEPCO) are collaborating on the development of a several gigawatt-level high-voltage, direct current (HVDC) superconducting cable. LS Cable has already initiated the development of the core element technology for this project as part of a national policy task organized by the Ministry of Knowledge Economy. In particular, LS Cable will be responsible for the design and manufacture of the technologies required for the DC HTS cable, termination, and joint box as well as the performance evaluation of all insulating materials used in the system. Meanwhile, KEPCO will determine potential application sites for superconducting power transmission lines in Korea and will analyze the impact of reductions in harmonics flow through power converters and the resulting reduction in power loss. The initial deployments of the cable system are anticipated to include the 80-kV DC Jeju smart grid demonstration site in Korea and the Tres-Amigas Project in the U.S. Mr. Son Jong-ho, president of LS Cable, commented, “The HVDC superconducting cable system offers transmission performance superior to that of the AC system. Interest in this technology has been building up in the U.S. and Europe, where new power network implementation is urgently needed. We will actively promote entry into these markets once we have completed the development of the HVDC superconducting cable system.”
Source:
“K-Consortium (KEPCO and LS Cable) to develop a high-voltage DC Superconducting cable system”
LS Cable press release (August 30, 2010)
http://www.lscable.com/pr/news_read.asp?idx=2582&pageno=1&kType=&kWord

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SuperPower (August 31, 2010)

The Advanced Research Projects Agency – Energy (ARPA-E), a division of the U.S. Department of Energy, has awarded SuperPower, the University of Houston (UH), ABB Inc. and Brookhaven National Laboratory $4.2 million for the development of an advanced superconducting magnetic energy storage system with a direct power electronic interface. The money will be used to develop a 20-kW ultra-high field SMES device with a capacity of up to 3.4 megajoule, a field of up to 30 T at 4.2 K, an instantaneous dynamic response, and a nearly infinite cycle life. Arthur P. Kazanjian, general manager of SuperPower, commented, "In addition to providing essential backup power during outages, the SMES can be an important addition to the use of intermittent renewable resources such as wind and solar energy and we look forward to realizing the potential of 2G HTS in this promising application." In particular, SuperPower will receive $2.1 million of the grant money to support the wire development work of its R&D group at the Texas Center for Superconductivity at the University of Houston and to supply the 2G wire for the fabrication of the SMES coil at BNL. SuperPower will also support the coil technology development and fabrication activities of BNL. ABB will act as the project leader to develop the SMES device at an affordable price.

Source:
"SUPERPOWER WINS ARPA-E AWARD WITH ABB AND BNL"
SuperPower press release (August 31, 2010)
http://www.superpower-inc.com/content/superpower-wins-arpa-e-award-abb-and-bnl

Quantum Computer

University of Pittsburgh (August 3, 2010)

Researchers based at the University of Pittsburgh and working in collaboration with several other universities have received a five-year, U.S. $7.5 million grant from the U.S. Department of Defense to tackle some of the greatest challenges preventing the development of quantum computers. The grant was part of the Multi-University Research Initiative (MURI) program, which has distributed a total of $227 million in grants to universities across the United States. The research team will attempt to combine the properties of semiconductors and superconductors into a single material suitable for the developing new types of quantum memory, performing quantum simulations, and creating new methods for transferring quantum information from one medium to another. All of these functions are essential for realizing quantum computers.

Source:
"Pitt-led researchers to build foundation for quantum supercomputers with $7.5 million federal grant"
University of Pittsburgh press release (August 3, 2010)
http://www.news.pitt.edu/news/LevyMURI2010_supercomputers

Communication

Superconductor Technologies Inc. (August 3, 2010)

Superconductor Technologies Inc. (STI) has reported its financial results for the second fiscal quarter ending July 3, 2010. Total net revenues for the second quarter amounted to U.S. $2.4 million, compared with $2.6 million for the same quarter in the previous fiscal year. Net commercial product revenues for the

second quarter were $1.7 million, compared with $1.8 million for the same period in the previous fiscal year. Government and other contract revenue totaled $631,000, compared with $854,000 for the same period in the previous fiscal year. Jeff Quiram, STI's president and chief executive officer, commented, "During the second quarter, our wireless customers continued to invest in performance improvement projects for their existing networks that provided demand for our core products. As expected, government revenues declined as the SURF 2 program nears completion… Our 2G HTS wire program for emerging power applications remains on schedule. Building on our success in producing wire in one-meter lengths, we are on track to complete the design of our wire deposition machine to produce 50-meter lengths by the end of this year. We are focusing our efforts on three HTS wire designs to address the unique performance requirements for large wind turbine, AC power cable and fault current limiter applications. We expect to begin delivering samples of our wire for testing by our prospective customers before year end." Net loss for the second quarter was $3.1 million, compared with $4.1 for the same period in the previous fiscal year. As of July 3, 2010, STI had $5.5 million in cash and cash equivalents and a commercial product backlog of $679,000.
Source:
"Superconductor Technologies Inc. Reports Second Quarter 2010 Results"
Superconductor Technologies Inc. press release (August 3, 2010)
http://phx.corporate-ir.net/phoenix.zhtml?c=70847&p=irol-newsArticle&ID=1455503&highlight

Superconductor Technologies Inc. (August 26, 2010)

On August 25, 2010, Superconductor Technologies Inc. (STI) announced the pricing of an underwritten public offering of 4,000,000 shares of its common stock at a price of $1.50 per share, for gross proceeds of $6.0 million. After deducting underwriting discounts, commissions, and estimated offering expenses, the net proceeds of the offering are expected to total approximately $5.3 million. STI expects to close the sale of its common stock on or about August 31, 2010. Jeff Quiram, STI's president and chief executive officer, commented, "I am proud of the solid progress we are making on our HTS wire program. We believe the enormous potential for the 2G HTS wire market creates a compelling investment opportunity. We intend to use this raise to contribute to funding this major initiative as well as to working capital for our ongoing business serving our wireless customers as they continue to invest in performance improvement projects for their networks."
Source:
"Superconductor Technologies Inc.® (STI) – Press Release"
Superconductor Technologies Inc. press release (August 26, 2010)
http://phx.corporate-ir.net/phoenix.zhtml?c=70847&p=irol-newsArticle&ID=1455503&highlight

Astronomy

Cornell University (August 17, 2010)

The National Research Council has named a planned $110 million telescope in Chile as the top construction priority for mid-sized, ground-based telescopes for the coming decade. The 25-meter, far-infrared and submillimeter telescope, known as CCAT, is being constructed by two major partners—Cornell University and the California Institute of Technology—and three other American, Canadian, and German universities. Upon completion, the telescope will be the largest, most precise, and highest (at an elevation of about 5,600 m above sea level) astronomical facility of its kind in the world. The technology required for the CCAT instruments is already being developed, including a state-of-the-art camera containing an array of 2,400 superconducting detectors. Fundraising for the telescope's construction is ongoing.

Source:
"Telescope project involving CU-Boulder selected as top priority for construction"
Cornell University press release (August 17, 2010)
http://www.pressoffice.cornell.edu/releases/release.cfm?r=49313&y=2010&m=8

Basic

Oak Ridge National Laboratory (August 9, 2010)

Researchers at the Oak Ridge National Laboratory have developed a supercomputer application for examining nanoscale inhomogeneities in superconductors. The application consists of a rewritten version of computational code for the numerical Hubbard model that previously assumed cuprates to be have the same electron density from one atom to another. Two years ago, this application was awarded the Association for Computing Machinery Gordon Bell Prize. The supercomputer application has now been used to examine nanoscale inhomogeneities in superconductors that have long been noticed but not explained. Jack Wells, director of the Office of Institutional Planning and a former Computational Materials Sciences group leader, explained, "The goal following the Gordon Bell Prize was to take that supercomputing application and learn whether these inhomogeneous stripes increased or decreased the temperature required to reach transition. By discovering that striping leads to a strong increase in critical temperature, we can now ask the question: is there an optimal inhomogeneity?" The group's findings were recently published in *Physical Review Letters*.

Source:
"Award-winning supercomputer application solves superconductor puzzle"
Oak Ridge National Laboratory press release (August 9, 2010)
http://www.ornl.gov/info/press_releases/get_press_release.cfm?ReleaseNumber=mr20100809-00

Carnegie Institution (August 18, 2010)

Researchers at Carnegie Institution's Geophysical Laboratory, in collaboration with the South China University of Technology and the Max Plank Institute for Solid State Research in Germany, have unexpectedly found that two transition temperatures of Bi2223 can be induced under two different intense pressures, with the higher pressure producing the higher transition temperature. This unusual phenomenon is thought to arise from the competition of electronic behaviors in different copper-oxygen layers of Bi2223 crystals. Under normal pressure, the transition temperature of optimally doped Bi2223 is 108 K. In the present study, the researchers subjected doped crystals to a pressure of 36.4 gigapascals (GPa) and observed an initial higher transition temperature at 10.2 GPa. At higher pressures, the transition temperature began to decrease until the reduction of superconductivity stopped at about 24 GPa. At 36.5 GPa (the highest pressure that the group's measuring system could detect), the transition temperature was 136 K. As other research has shown that some multilayered superconducting crystals such as Bi2223 exhibit different electronic and vibrational behaviors in different layers, the researchers believe that 24 GPa may represent a critical point where the pressure begins to suppress one behavior and enhance superconductivity. The findings provide a new perspective on attaining higher transition temperatures in multilayered cuprate superconductors. The group's research was published in the August 19, 2010, issue of *Nature*.

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Source:
"Roller coaster superconductivity discovered"
Carnegie Institution press release (August 18, 2010)
http://carnegiescience.edu/news/roller_coaster_superconductivity_discovered

National Institute of Standards and Technology (August 31, 2010)

A new material, known as YLBLCO, has been measured and tested using neutron diffraction at the National Institute of Standards and Technology and has been described as an "ambipolar" material": a material that can only be made to superconduct by removing electrons but, when electrons are added, exhibits some properties only seen in materials that superconduct with an electron surplus. This material is unique in that all previously described superconductors are made by either adding or removing electrons, but not both. The new measurements may help researchers to develop a clearer understanding of high-temperature superconductors. The group's results were described in a "News and Views" article in the August 2010 issue of *Nature Physics*.

Source:
"New Material May Reveal Inner Workings of Hi-temp Superconductors"
National Institute of Standards and Technology press release (August 31, 2010)
http://www.nist.gov/ncnr/htc_083110.cfm

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Feature Articles: Refrigeration/Cryogenic Technologies - Progress in Refrigeration/ Cryogenic Technologies for Superconducting Power Devices -

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

High-temperature superconducting power machines have entered the stage of researches for practical applications, and the development of refrigerators is also accelerating toward practical applications. Currently, it is assumed that the operating temperature range of refrigerators used for cooling high-temperature superconducting power machines is approximately 40 K to 80 K, and the refrigeration capacity is 2 kW to 10 kW at 80 K. Maintainability and compactness are also important issues. The refrigeration capacity of compact refrigerators, which are currently on the market, is 1 kW or less at 80 K. For structural reasons, these refrigerators contain sliding parts and usually require maintenance about once a year. While expansion turbine systems, which have a proven track record in refrigeration capacity and durability, are adopted in large-scale cryogenic refrigerators such as cryogenic air separation units and helium liquefiers, these systems are too large in terms of refrigeration capacity to be used for cooling high-temperature superconducting power machines. For that reason, we prototyped an turbine refrigerator by using neon gas as the working fluid with the aim of developing a refrigerator suitable for this area.

For the first prototype refrigerator, the flow rate of neon gas was 1,200 Nm^3/h and the system pressure was 2 MPa/1 MPa. This refrigerator achieved a refrigeration capacity of 2 kW at 70 K and the refrigeration efficiency (refrigeration capacity/power consumption) was about 0.05 at 80 K. The refrigeration efficiency is an index that indicates the performance of a refrigerator, and it is a very important value because it directly affects the economic efficiency of the operation of high-temperature superconducting power machines. It is also a major goal for refrigerator development to increase this value as high as possible. With turbine refrigerators, an expansion ratio of approximately 2 delivers the maximum value of refrigeration efficiency. Based on this knowledge, we performed simulations of a refrigerator using neon gas as the working fluid, and found out that a system pressure of 1 MPa/0.5 MPa provides the maximum refrigeration efficiency.

Given this finding, last year, we altered a reciprocating compressor and converted an expansion turbine to a low-pressure type, and then carried out a performance test. The performance test was done using a neon-gas flow rate of 1,200 Nm^3/h and a system pressure of 1 MPa/0.5 MPa. The test result showed a refrigeration capacity of 2.0 kW at 65 K, 2.5 kW at 80 K. Further, adiabatic efficiency of the expansion turbine was from 68 % to 70 %, and we achieved the target value of 65 %.

The prototype refrigerator used an expansion turbine without any sliding parts. However, it used an existing reciprocating compressor with sliding parts; therefore, this refrigerator could not be applied to practical cooling of high-temperature superconducting power machines with regard to the maintainability as well as the efficiency. Thus, we are promoting the efficiency improvement of the expansion turbine and development of a compact turbo compressor without any sliding parts with the aim of improving the refrigeration efficiency and eliminating the maintenance of the refrigerator. No wear-out components exist in refrigerators that do not have any sliding parts both in the compressor and in the expansion turbine, leading to the realization of maintenance-free refrigerators. In addition, the adoption of compact turbo compressors will result in a smaller installation area compared with refrigerators that use existing reciprocating or screw compressors; therefore, we can achieve the compactness required for refrigerators used in the cooling of high-temperature superconducting power machines.

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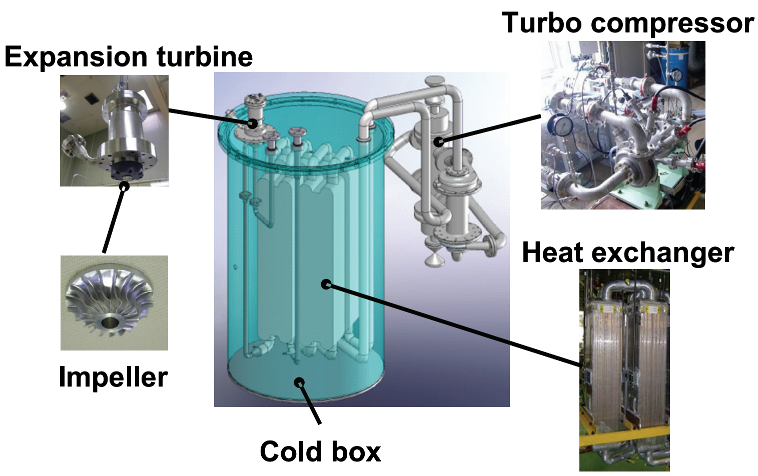
Currently, the development of the compact turbo compressor has completed the measures for harmonic noise from inverters, consideration of the accuracy of magnetic bearings assembly, detailed design, and assembling, and we are carrying out performance tests with nitrogen gas. We have obtained test data up to the maximum rotation speed of 31,500 rpm with nitrogen gas (equivalent to the rotation speed of 36,000 rpm with neon gas), and the compact turbo compressor has achieved adiabatic efficiency of approximately 67 %.

The high-efficiency compact compressor has not yet been incorporated into the prototype refrigerator. We can foresee, however, that our final target will be achieved as planned – a refrigeration capacity of 2 kW at 65 K and a refrigeration efficiency of 0.06 at 80 K.



Prototyped turbine refrigerator

The above figure shows the image of the prototyped turbine refrigerator that incorporates a turbo compressor. When looking at each component, you can see that the heat exchanger takes up a large cubic capacity in the cold box of the refrigerator. Optimization of heat exchangers is an important factor when considering the downsizing of refrigerators. On the other hand, scale-down of heat exchangers will decrease the refrigeration efficiency; therefore, it should be carried out with caution. For that reason, we are considering the dimension of heat exchangers by using a refrigeration process simulator that was developed for turbine refrigerators. According to the simulation results, the heat exchanger can be scaled down from five blocks to three blocks. As the next step, we are planning to perform experiments with a reduced number of heat exchanger blocks and improve the accuracy of the simulator by comparing the experiment data with the simulation results.

In addition, the research of the refrigeration system is important for the future, such as how to remove heat from high-temperature superconducting power machines and transfer heat to the refrigerator.

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Feature Articles: Refrigeration/Cryogenic Technologies
- Research of Slush Nitrogen Refrigeration System -

Masamitsu Ikeuchi
R&D Center
Mayekawa MFG. Co., Ltd.

"Slush nitrogen" is an unfamiliar term, and it may be hard to grasp the image. Slush originally refers to snow that has thawed partially. Slush nitrogen (hereinafter "SN_2") is a mixed fluid in which solid nitrogen and liquid nitrogen are blended with each other, and it provides a lower temperature and larger thermal capacity than conventional liquid nitrogen refrigeration by utilizing the latent heat of fusion in solid bodies. For that reason, it has a potential to improve the cooling effect for superconducting cables (hereinafter "cables") etc. if the large thermal capacity can be utilized effectively.

Researches until now have used a simple vacuuming (freeze-thaw) method to generate SN_2, partly because they had been fundamental researches and have been clarifying the carrier properties and heat characteristics while keeping the cooling of superconducting cables in mind. The researches revealed, however, that the freeze-thaw method does not allow continuous generation and it is hard to control the particle diameter of the generated solid nitrogen. They also revealed that the average particle diameter is 1.4 mm (Fig. 1) and the particles settle out under the influence of gravity in the low flow rate range (1 m/s or less).

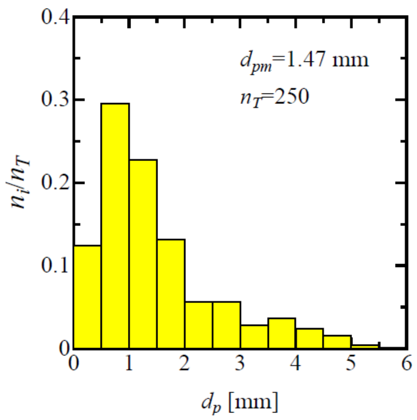

Fig. 1 Grain-diameter distribution of solid nitrogen generated by the freeze-thaw method

When considering the cooling of superconducting cables, the cooling effect improves as the flow rate of liquid nitrogen (hereinafter "LN_2") flowing inside the cables increases. On the contrary, pressure loss increases with the square of the flow rate; therefore, a flow rate of approximately 0.2 to 0.3 m/s is considered suitable for cable cooling. As mentioned above, however, the SN_2 generated by the freeze-thaw method will cause solid–liquid separation at this flow rate. Given these factors, we assumed that the SN_2 could be transported at a low flow rate if the solid is broken down into fine particles, and our simulations showed a possibility that it would flow through the conduit line without settling out if the particle size is 100 μm or less.

Until now, as part of our miniaturization research, we have confirmed the generation of solid particles of diameters of approximately 100 μm by using the ejector-nozzle method, which is different from the freeze-thaw method.[1)] This method, however, holds the possibility that the helium gas, which was used for miniaturizing and solidifying LN_2 droplets, may melt into SN_2 and separate out inside the conduit line as a vapor phase during transportation[2)]; therefore, we considered yet another generation method.


Fig. 2 Generation-testing device (Auger method)

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As a result, we turned our attention to the scraping method (Auger method) that separates fine solid particles from the cooled surface using a rotating impeller. We fabricated a testing device (Fig. 2) and are now carrying out researches for continuous generation methods.

The features of this device include the capability to generate continuously as well as the capability to adjust the particle diameters. Fig. 3 shows the solid nitrogen generated by this testing device. Fig. 4 shows example histograms of solid particle diameters when the rotating speed of impeller is changed. These results showed that the particle diameters can be controlled by changing the rotating speed, and we confirmed the generation of fine solid nitrogen particles with diameters of approximately 100 μm.[3)]

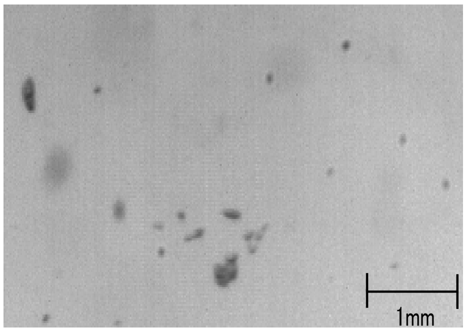

Fig. 3 Status of particles (100 rpm)

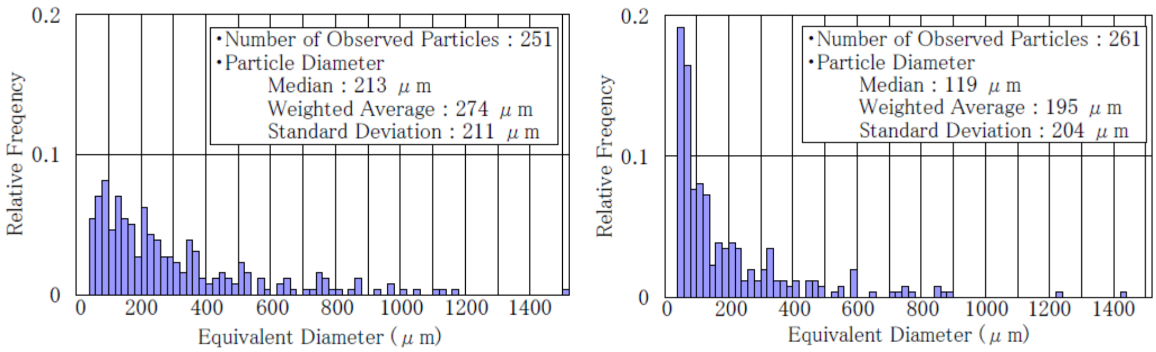

Fig. 4 Particle-diameter histograms of generated solid nitrogen (left: 17 rpm, right: 100 rpm)

On the basis of this generation-testing device, we are currently considering a testing device that allows cycle operation, while carrying out researches on the cooling characteristics.

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1) Ikeuchi *et al.*, "Fundamental Research on the Generation of Slush Nitrogen," Abstracts of CSJ Conference 68 Cryogenic Association of Japan (2003), p. 159.

2) Department of Technology, Superconductive Generation Equipment and Materials, "Result Report on Commissioned Tasks for FY 2004 - R&D on fundamental technologies for superconducting AC power equipment," NEDO (2005), p. 171 (portion of Furukawa Electric Co., Ltd.)

3) Komagome *et al.*, "Particle System Measurement of Slush Nitrogen (Auger Method) by High-sensitivity Camera," Abstracts of CSJ Conference 81, Cryogenic Association of Japan (2010), p. 209.

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Feature Articles: Refrigeration/Cryogenic Technologies - Development of High-efficiency Coil-conduction Cooling Technology Using Heat Pipes -

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

Chubu Electric Power Co., Inc. and the National Institute for Fusion Science are developing a cooling structure as a new cooling technology for superconducting magnets, which can effectively remove the heat generated inside the magnets by incorporating sheet-like oscillating heat pipes (OHPs). By carrying out operational experiments on the OHPs at low temperatures, we confirmed the operation in a wide temperature range between 17 K and 80 K, while also observing a high thermal transport property that was comparable to the high thermal conductivity of high-purity metals at low temperatures. On the basis of these experiment results, applications of superconducting magnets to high-efficiency cooling are described in the following.

Generally, an OHP has a structure such that a single narrow tube is folded many times between the heating part and the cooling part. Inside the pipe, an appropriate amount of working fluid is charged so that a state of gas-liquid two-phase mixture is obtained on a vapor pressure curve. When the mixture is heated, the liquid evaporates in the heating part and condenses in the cooling part. An oscillating flow occurs by the pressure change associated with the phase transition, and the heat is transported. Fig. 1 shows the fabricated OHP, and Fig. 2 shows the operating concept of OHP.

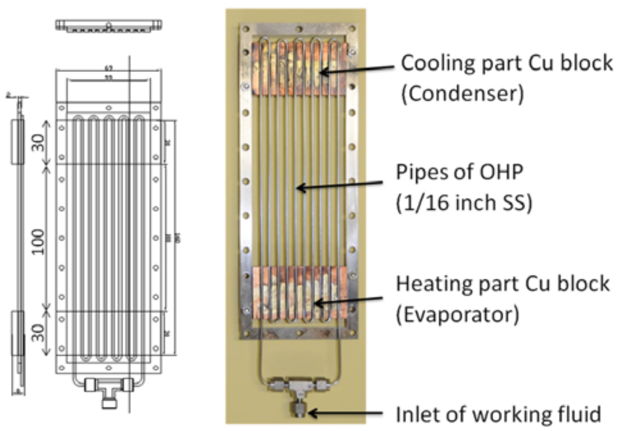

Fig. 1 Design drawing and picture of fabricated OHP

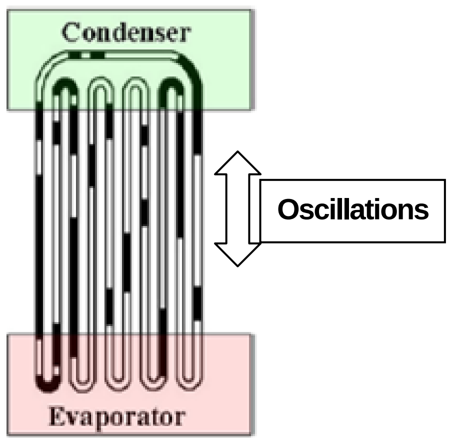

Fig. 2 Conceptual diagram of OHP operation and self-exited oscillation

We fabricated the OHP using an SUS tube with an inner diameter of 0.78 mm (outer diameter: 1/16 inch) before carrying out the experiments. Table 1 lists the experiment results in the arrangement where the lower section is the heating part and the upper section is the cooling part. In the installation direction, where the upper section of the oscillating heat pipe is cooled and the lower section is heated, we observed stable operations with each of the three working fluids: nitrogen, neon, and hydrogen.

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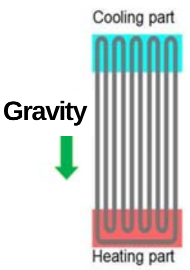
Table Result of heat pipe operation



Working fluid	Temperature of cooling part [K]	Amount of charged fluid [Volume %]	Amount of heat input [W]	Operating temperature range [K]	Effective thermal conductivity [W/m*K]
N_2	67 – 69	17 – 70	0 – 7	67 – 91	5,000 – 18,000
Ne	26 – 27	16 – 95	0 – 1.5	26 – 34	1,000 – 8,000
H_2	17 – 18	31 – 80	0 – 1.2	17 – 27	500 – 3,000

As arrangements of OHPs in various directions are required for coil cooling, we conducted an experiment with reversed direction.

As a result, self-excited oscillations did not occur in the reversed direction where the upper section is the heating part and the lower section is the cooling part.

To solve this problem, we tried a technique in which OHPs with different installation directions were connected and interlocked. Fig. 3 shows the schematic diagram of the interlocked OHPs.

As shown in Fig. 4, by connecting two heat pipes in series, we successfully induced self-exited oscillation in the heat pipe of which the upper section is heated and the lower section is cooled, allowing both heat pipes to operate simultaneously. On the basis of this result, we confirmed the possibility of operating OHPs as a whole unit by the serial operation of heat pipes, in the case of superconducting magnets that need to incorporate multiple OHPs with various installation directions.

Further, Fig. 5 shows an example of cooling configuration for a superconducting magnet that incorporates multiple OHP cooling panels. We are planning to carry out the verification in the future.

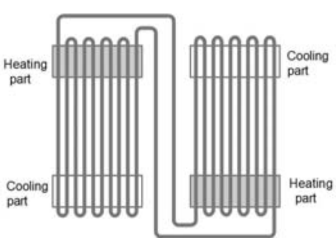


Fig. 3 Schematic diagram of interlocked OHPs

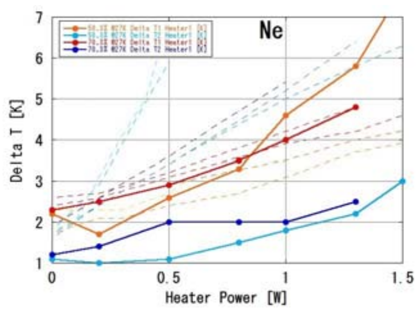


Fig. 4 Temperature difference between the heating part and cooling part

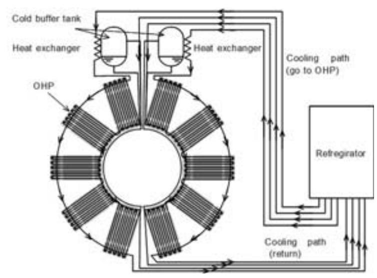


Fig. 5 Configuration example of OHP cooling

This development was carried out in the NEDO-consigned project "Technology Development of Yttrium-based Superconducting Power Devices."

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Feature Articles: Refrigeration/ Cryogenic Technologies
- Helium Re-condenser for Magnetoencephalograph -

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Taiyo Nippon Sanso Corporation

Helium is an inactive monatomic gas that has the lowest boiling point among all the elements; and it only solidifies under increased pressure. The content of helium in the air is only 0.0005 % (5 ppm). A tiny amount of helium gas, which is produced along with natural gases, is collected and refined to provide it as a gas product; therefore, it is also a valuable gas as an earth resource. Helium gas is well known as a lifting gas for balloons and small airships, and it is also used as a refrigerant gas for cryogenic devices. In addition, liquid helium is indispensable for superconducting devices since it is a low-temperature freezing mixture.

This device collects and re-condenses the helium gas (GHe) evaporated from a liquid helium (LHe) container for magnetoencephalograph (MEG). The SQUID (Superconducting Quantum Interference Device) magnetic sensor of the MEG needs to be cooled to the LHe temperature (4.2 K) and to be set inside the LHe dewar of the MEG. We have developed a helium re-condenser for the MEG in order to reduce the running cost associated with the consumption of LHe by a MEG measuring system.

This helium re-condenser comprises the main unit, console panel, and two compressors (see Fig. 1, 2). The main unit consists of a cold box (vacuum heat-insulating container). The main unit is equipped with two compact refrigerators and a lifting machine. The main unit (300 kg) is 740 mm (W) × 740 mm (D) × 1,790 mm (H) and the console panel is 800 mm (W) × 700 mm (D) × 1,600 mm (H). The re-condensed helium gas passes through the transfer section extending from the main unit before it is stored in the LHe container. The main unit supports any commercially available LHe containers (60 or 100 L) to be installed as long as they are equipped with φ15-mm connection ports.

Fig. 1 Appearance of helium re-condenser for magnetoencephalograph

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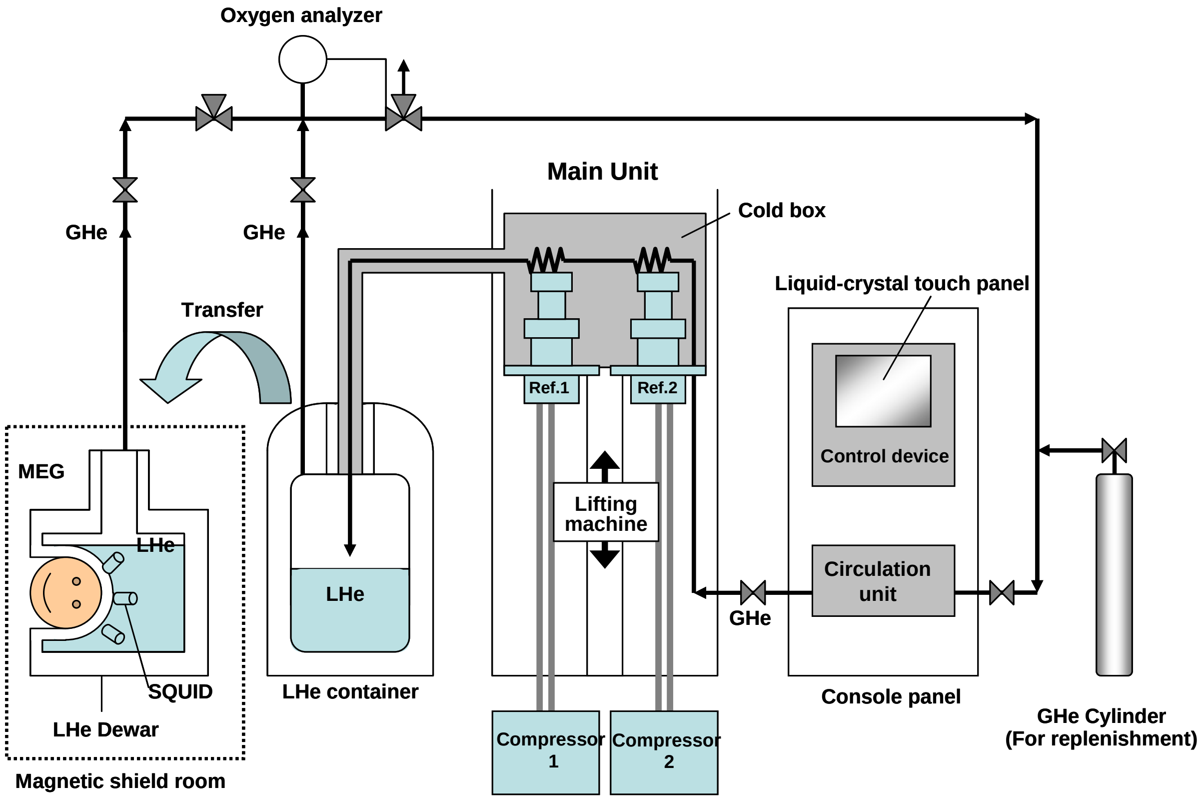

Fig. 2 Flow diagram

Fig. 2 shows the flow diagram of the entire system. The MEG is a device that accurately inspects the brain by externally measuring the extremely weak magnetic fields emitted from brain neurons. The device is installed in a magnetic shield room to prevent external noises, and it is separated from the main unit that is a potential noise source. The system is structured so that the GHe evaporated and collected from the MEG passes through the circulation unit in the console panel, and it is cooled and re-condensed in the cold box (heat exchangers installed at the cooling stage of the compact refrigerators), before it is temporarily stored in the LHe container. The LHe stored in the LHe container is periodically transferred to the LHe dewar of the MEG. The amount of GHe, which has been discharged to the atmosphere because of the transfer loss, is introduced from the GHe cylinder (for replenishment) connected to the gas line.

The console panel incorporates a liquid-crystal touch panel that allows the monitoring of the operation status of the device on the liquid-crystal screen. Further, a sequence program controls the circulation unit to achieve an automated operation of the device. In addition, the oxygen analyzer installed halfway through the gas line continuously monitors the GHe concentration of the collected gas to achieve stable operation of the device.

Table 1 shows the specification of the helium re-condenser. The helium re-condensing capacity is 10 L/day (standard type), (18 L/day type is also available). The compressors for compact refrigerators are selectable from water-cooled and air-cooled types (maintenance intervals: 10,000 h for refrigerators; 20,000 or 30,000 h for compressors).

Normally, continuous operation over an extended period without any LHe loss is possible by directly inserting the transfer section of this device into the LHe container to integrate both components; however,

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the helium re-condenser for the MEG developed this time is configured to collect and re-condense the GHe evaporated from the LHe dewar, which cools the MEG, and to store the liquefied gas in the LHe container.

The helium gas as a natural resource is scarce, and the price is gradually increasing, making it expensive. Therefore, it is important to operate superconducting devices without dispersing the valuable helium gas resource in the future.

Table 1 Specification of helium re-condenser

Re-condensing capacity	10 L/day
Utility	Power capacity: 24 kVA Cooling water: 14 L/min or more
Installation space	3,000 mm (W) × 2,500 mm (D) × 2,600 mm (H)
Periodical maintenance	Refrigerator: every 10,000 h Compressor: every 20,000 or 30,000 h
Weight of main unit	300 kg

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Feature Articles: Refrigeration/Cryogenic Technologies
- Development of Compact Hydrogen Liquefier using GM Refrigerator -

Akihiro Nakano
Socio-economics and Policy Study Group, Energy Technology Research Institute (ETRI)
National Institute of Advanced Industrial Science and Technology

Our group has been promoting researches on the Totalized Hydrogen Energy Utilization System (THEUS) that produces, stores, and utilizes hydrogen, and we are currently working on the system development for commercial building equipment. This system comprises a Unitized Reversible Fuel Cell (URFC) and a metal hydride tank. During nighttime, this system produces hydrogen gas by operating the URFC in water-electrolysis mode, and it stores the gas in the metal hydride tank. During daytime, it operates the URFC in fuel-cell mode by utilizing the stored hydrogen to supply electricity to the building; this is the basic concept of this system. We are advancing the development of THEUS not only for the purpose of load leveling, but also with an eye to introducing renewable energy and utilizing by-product hydrogen. Our eventual goal is to establish a robust energy system that can contribute to the stabilization of system power and supply energy to electric and hydrogen vehicles. Regarding the utilization of by-product hydrogen supplied from hydrogen stations, we select liquid hydrogen considering the utilization in urban areas and from the standpoint of safety. In that case, a liquid hydrogen tank is installed on the premise and all the boil-off gases generated from the tank are utilized by collecting and storing them in the metal hydride tank. The boil-off gases from liquid hydrogen, however, are almost entirely composed of para-hydrogen, and the constituent is different from the hydrogen that we usually use (normal hydrogen: approx. 75 % of ortho-hydrogen + approx. 25 % of para-hydrogen). Ortho-hydrogen and para-hydrogen differ in the spin direction of atomic nucleus; the one with two spin directions parallel to each other is called ortho-hydrogen, and the other one with two spin directions opposed to each other is called para-hydrogen. While their densities are identical, they produce differences in thermo-physical properties such as thermal conductivity. Thus, we need to understand the absorption/desorption properties of the metal hydride alloy for para-hydrogen in the future utilization form of this system; therefore, we designed and fabricated a compact hydrogen liquefier using a two-staged GM refrigerator as a para-hydrogen supplying device for the experiment to determine the properties.

The figure shows the full view and schematic diagram of the fabricated liquefier.
The capacity of the liquid hydrogen container housed inside the radiation shield of the high-vacuum insulated tank is approximately 30 L, and the 2nd stage cold head (spec. value: 5.4 W @ 10 K) of the two-stage 10K-GM refrigerator (Sumitomo Heavy Industries, Ltd.: RDK-408S) cools the hydrogen condenser at the upper part of the container to condense and liquefy the hydrogen gas. As the freezing point temperature of hydrogen is approximately 13 K, the temperature is adjusted by using the temperature controller and the heater, while monitoring the value on the platinum-cobalt (Pt-Co) resistance thermometer attached to the 2nd cold head so that the temperature does not fall below the freezing point during the actual liquefaction. The hydrogen liquefied on the copper plates of the hydrogen condenser will flow down under its own weight, and it is stored in the container. The surface of the copper plates is coated with iron oxide with the aim of facilitating ortho–para conversion. The 1st stage cold head (spec. value: 30 W @ 45 K) is in contact with the radiation shield that surrounds the hydrogen introduction pipe and the container, and it is designed to contribute to the pre-cooling of introduced hydrogen gas and the reduction in radiation heat from the surroundings. Further, an evaporation-facilitating heater is installed beneath the bottom of the container on the high-vacuum insulated tank side to supply para-hydrogen gas to the metal hydride tank.

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The container is designed to withstand a pressure of 0.6 $MPa_{(abs)}$, and the safety valve will operate if the internal pressure exceeds this value. When we liquefied a room-temperature hydrogen gas under an approximately atmospheric pressure condition after having pre-cooled the device overnight, the maximum liquefying speed was 12.1 NL/min in the introduced hydrogen gas volume flow (room temperature), and the maximum value of the liquid hydrogen production capacity was 19.9 L/day. JECC Torisha Co., Ltd. undertook the detailed design and fabrication of this liquefier. As the device falls under the category of high-pressure gas production facility stipulated by the High Pressure Gas Safety Act, it has been authorized by the Ibaraki Prefecture as a movable production facility, and it is installed in a hydrogen test booth that is continuously ventilated. All the devices installed in the booth are of explosion-proof specification or specially designed for use with hydrogen. Refrigerator compressors, temperature controller, heater power supply, PC for data acquisition, etc., are installed outside the hydrogen test booth.

In recent years, researches on applying liquid hydrogen to the refrigerant for superconducting devices are advancing at home and abroad. We are hoping that the demand for such compact hydrogen liquefiers can be anticipated in the places of superconducting device-related development.

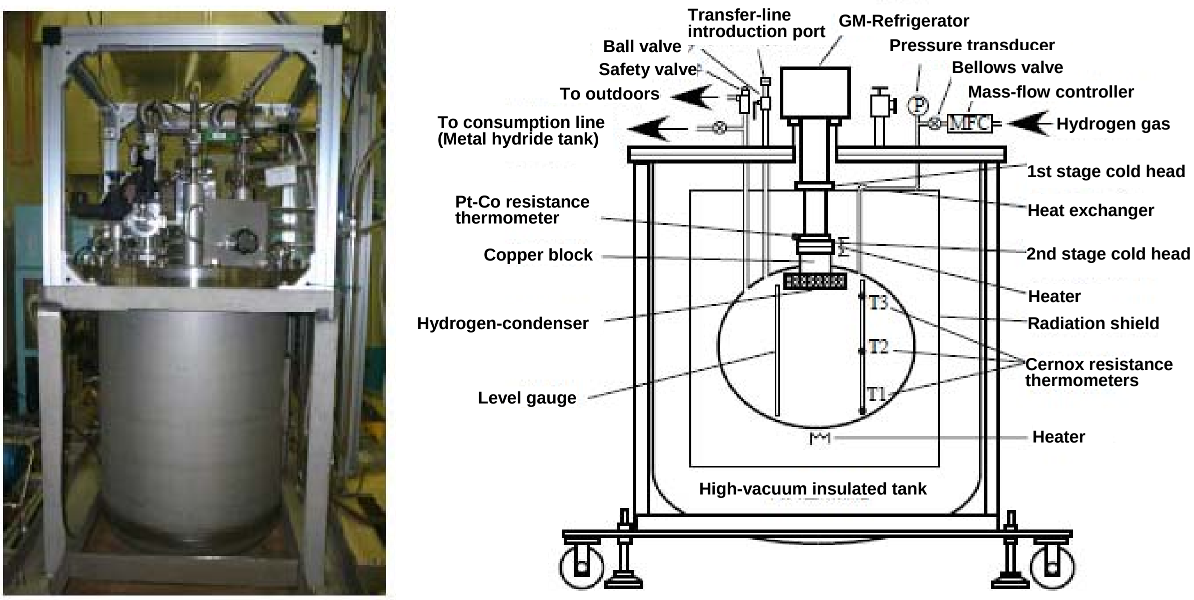

Fig. Full view of liquefier and schematic diagram

This research was carried out in collaboration with Takasago Thermal Engineering Co., Ltd. with the assistance of the "Research and Development of Hydrogen Storage Device and Unitized Reversible Fuel Cell (FY2007 to 2009)," which was based on the consignment contract for the project "Strategic Development of Energy Use Rationalization Technologies" implemented by the New Energy and Industrial Technology Development Organization (NEDO).

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Feature Articles: Forum on Superconductivity Technology Trends 2010 "Development of Yttrium- system Superconducting Coated Conductors and their Applications " - Contributions to the Environment and Energy -

Yuh Shiohara, Director General
SRL/ISTEC

In Japan, the Democratic Party-led administration was born in September, last year, and the then-prime minister Mr. Hatoyama delivered a speech at the United Nations pledging that Japan would set the CO_2 reduction target for 2020 to 25 % less than the 1990 levels, although the figure was with conditions. On the basis of the Copenhagen Accord, the administration officially submitted the reduction target as an interim objective to the Secretariat of UN Framework Convention on Climate Change on January 31, this year. Further, considering that "Environment and Energy Issues" are pressing challenges, the administration takes up the "Promotion of Green Innovations" as one of the policy challenges. To achieve the target, our country must draw on all the technologies and means for responding to such challenges. Since "superconductivity" eliminates electrical resistance and allows for very efficient and compact designs, it is expected to serve as a trump card for preventive measures against global warming, and the world awaits the practical applications at an earlier date. Under the title "Development of Yttrium- system Superconducting Coated Conductors and their Applications," this report reviews the global environment issues and the contributions of high temperature superconducting technologies.

Major issues of the green innovations were set out in the "Action Plan for Important Policies concerning Science and Technology for fiscal 2011" that was established on May 21, 2010, by the Minister of State for Science and Technology Policy and the Council for Science and Technology Policy, Cabinet Office. Among these issues, the action plan considers "Superconducting Power Transmission" as a "Policy Required for Resolving the Issues" toward which the whole government must work strategically and describes that efforts must be made for the research and development as well as for wide-spread utilization in order to facilitate the introduction and expansion of the technologies according to their characteristics.

Carbon dioxide (CO_2) is the most serious human-made greenhouse gas, and it is reported that world's gross emissions are summed up to approximately 50 billion tons of which Japan's CO_2 emissions are approx. 1.2 to 1.3 billion tons—1/4 of which is accounted for by fossil fuel power generation and 1/5 by automobiles. According to the 2006 statistical results, the CO_2 emission Energy Intensity (hereafter "CO_2 EEI") of Japan, associated with electric power generation, is 0.39 kg-CO_2/kWh, and the ratio of non-fossil power supply to the total of various electric energies is approximately 38 %, which comprises nuclear power (28 %), hydropower (8 %), and renewable energy etc. (2 %). Meanwhile, the ratio of fossil power supply is 61 %, comprising petroleum (11 %), gas (23 %), and coal (27 %). According to the report of the Federation of Electric Power Companies, the power industry is placing expectations on the reduction of power-associated CO_2 EEI by achieving their target, by increasing the ratio of non-fossil power supply, i.e., the ratio of zero-emission power supply, to 50 %.

The CO_2 EEI of other countries are as follows; USA, 0.56 kg-CO_2/kWh; UK, 0.50 kg-CO_2/kWh; Germany, 0.50 kg-CO_2/kWh; Italy, 0.44 kg-CO_2/kWh; China, 0.86 kg-CO_2/kWh; and India, 0.97 kg-CO_2/kWh. Japan's power-associated CO_2 EEI of 0.39 kg-CO_2/kWh is lower than that of Germany, which has about the same ratio of non-fossil power supply (39 %), indicating that our country's technologies, such as generation efficiency improvement, are advanced and matured. The CO_2 EEI of France, which has a high ratio of nuclear power generation (79 %), is 0.08 kg-CO_2/kWh, while Canada reportedly has the CO_2 EEI of 0.19 kg-CO_2/kWh because of the high ratio of hydropower generation (58 %). Our country's greenhouse gas reduction target will impose a further CO_2 reduction on the technologies that have already matured.

When assuming the 25 % reduction below 1990 levels (30 % below 2005 levels), the aggregate sum of credit purchase to achieve the target by emission trading with other countries will amount to about 2 to 4 trillion yen (15–30 Euro/t-CO_2) over the five-year period, if the 15 % portion below 2005 levels is reduced by domestic measures and the remaining 15 % is achieved by credit purchase. As mentioned above, the target that our country has pledged to the world is very challenging. Further, for the 2050 target, researchers must explore each and every potential by collecting all their wisdom.

The power transmission/distribution losses are very low in Japan where the technologies have matured. For power transmission with normal conductive cables, the loss rate has remained at a 5+ % level since about 1980, and we have a report of a 5 % transmission/distribution loss, which is almost the limit under the present circumstances. Introduction of innovative technologies is indispensable for further reduction of transmission/distribution losses, and the research and development is underway with the aim of introducing superconducting power transmission cables. According to an estimate, approximately 740 kW/km of transmission loss is reported with an existing conventional power transmission cables for a 1,500 MVA-class transmission capacity; however, the loss is expected to be reduced to 200 kW/km by using alternate-current superconducting power transmission. Similarly, efficiency improvement is also expected for transformers. As shown in Fig.1, we expect the future power system, which assumes that introduction of renewable energy will have been promoted, will comprise large-scale photovoltaic power generation sites (mega solar), wind power generators (wind farms), and superconducting power transmission systems that link up photovoltaic power generators of individual households by using superconducting power transmission/distribution cables, superconducting transformers, and superconducting magnetic energy storages (SMESs), in addition to nuclear power generation and thermal power generation.

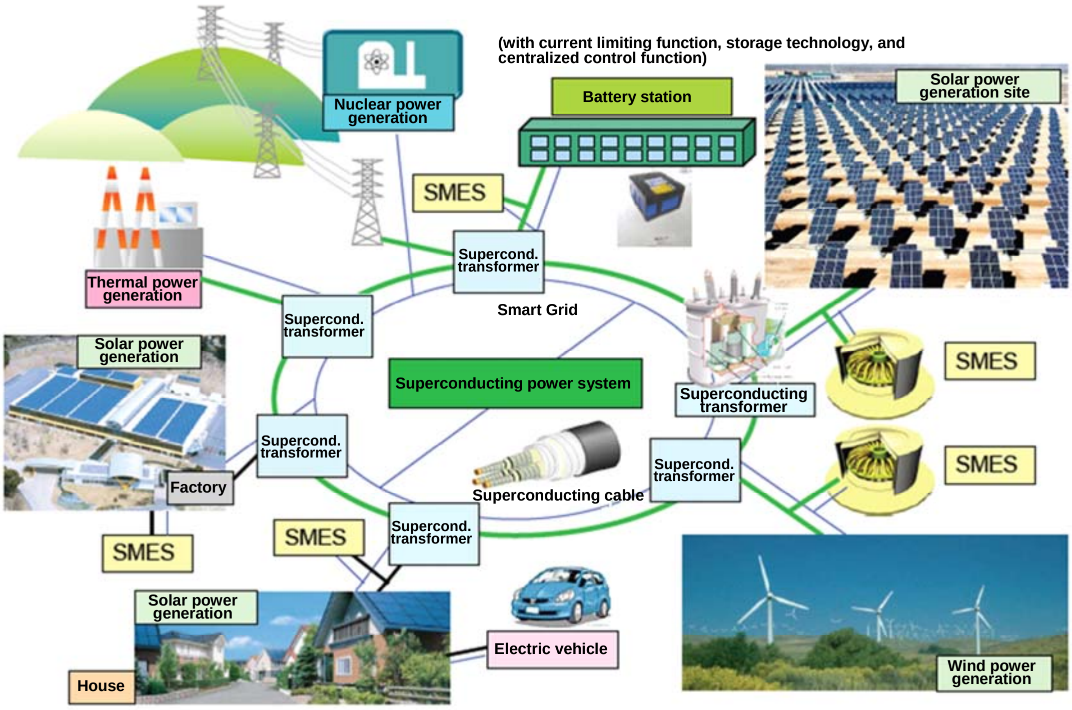

Fig. 1 Schematic diagram of future power system

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At present, the research and development is underway to apply superconductivity to superconducting magnetic energy storages (SMESs), power transmission cables, and transformers by using Y- system high-temperature superconducting materials with the aim of achieving stable, large-capacity power supply to urban areas by means of superconducting power devices. This R&D aims at developing compact SMESs that allow for operations in high magnetic fields and at high temperatures by utilizing the features of Y- system tapes such as the high mechanical strength and high critical current characteristics in magnetic fields. We have already confirmed an electromagnetic stress tolerance of 560 MPa by performing a hoop-stress test under high magnetic fields and a repetitive test of coils in an external high magnetic field of 11 T, while also demonstrating a high-current conduction of over 2 kA by fabricating real-scale coils of about 600-mm diameter using stacked conductors of four tapes of YBCO coated conductors.

For the development of superconducting power transmission cables, technologies are advancing toward the reduction of power transmission losses, which also include cooling losses specific to superconducting cables, down to 1/3 of that with conventional underground power lines, while also expecting CO_2 reduction effects, in addition to achieve large capacity power transmission with compact configurations. As for the power-device applications using superconducting materials, we could expect a drastic reduction of Joule heating losses, which are caused by electrical resistance; however, a big challenge is the reduction of AC losses caused by the fluctuations of magnetic flux in Type II superconductors. Experiments and simulations have indicated that it is effective to bring the cross-sectional shape of cables as close to a perfect circle as possible by the filamentarization of Y-system coated conductor in order to reduce AC losses in alternating-current transmission cables, and we have already fabricated 3 kA-class conductors and successfully reduced the AC losses down to 0.5 W/m. For twisted cables, we have also confirmed that the critical current properties show no deterioration in a bending test performed at a 2-m radius.

The development of superconducting transformers is underway with the aim of reducing the weight to 1/2, installation area to 2/3, in addition to achieving incombustibility and high efficiency. As for the application of superconductivity to transformers, we could expect the downsizing of the transformer itself, thanks to the improvement of critical current density; however, same as superconducting cables, it might be difficult to achieve the compactness and high efficiency of the entire system, including cryocool system, without reducing AC losses. For Y-system coated conductors, the reduction of AC losses, together with coupling loss, is possible, as the oxide intermediate (buffer) layers between the metal substrate and the YBCO superconducting layer possesses insulating characteristics; therefore, the filamentarized coated conductors become electrically insulated by the scribing of the superconducting layer, allowing for the reduction of the AC losses as well as the reduction of coupling losses. In addition, by fabricating coils incorporating transposed windings of Y-system coated conductors, which have been filamentarized, we have successfully achieved AC loss reduction in a form of coils for the first time in Japan, leading to the expectation for realization of superconducting transformers.

As described above, the development of important elemental technologies is underway for power devices using Y-system coated conductors. Y-system coated conductors have great potentialities such as low cost, high critical current characteristics in magnetic fields, high mechanical strength, and low AC losses and severe development competition are taking place all around the world. As for the development of high-temperature superconducting tapes and wires, the wire-length extension had already been attained the level in the development of Bi-2223 wires, i.e., silver sheath wires, and the device development using these Bi-system wires has been promoted. In recent years, the technology development of Y-system coated conductors has greatly advanced in performance improvement and length extension. As shown in Fig. 2, the product of critical current (I_c; A@77 K, s.f.) per approx. the same cross section (1 mm^2) and the length (L; m) has reached almost the same level, i.e., 300,000 Am. In Japan, the IBAD (Ion Beam Assisted Deposition) method and Clad-type RABiTS substrates are used as the technology to equip tapes with

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in-plane grain alignments of crystals. As for intermediate layers and superconducting layers, the research and development of film deposition processes have been promoted by using vapor-phase deposition (such as PLD, MOCVD, sputtering processes), and coating/thermal decomposition of metal-organic chemical solutions.

Since the discovery of YBCO high-temperature superconducting materials in 1986, the research and development of YBCO materials has been promoted all around the world for processings of oxide high-temperature superconducting materials into wires. More recently, in Japan, conversion from YBCO to GdBCO superconducting materials, which carry potentials for increased fabrication speed (film-deposition speed), higher critical current density, and improved critical current characteristics in magnetic fields, has been applied to film deposition by the vapor-phase process.

For further improvement of critical current characteristics in magnetic fields, dispersion of Ba-Zr-O (BZO)-system non-superconducting phase crystals is considered promising as an introduction technology for artificial pinning centers, along with thickness increase of the superconducting layer, and the research and development have been promoted intensively.

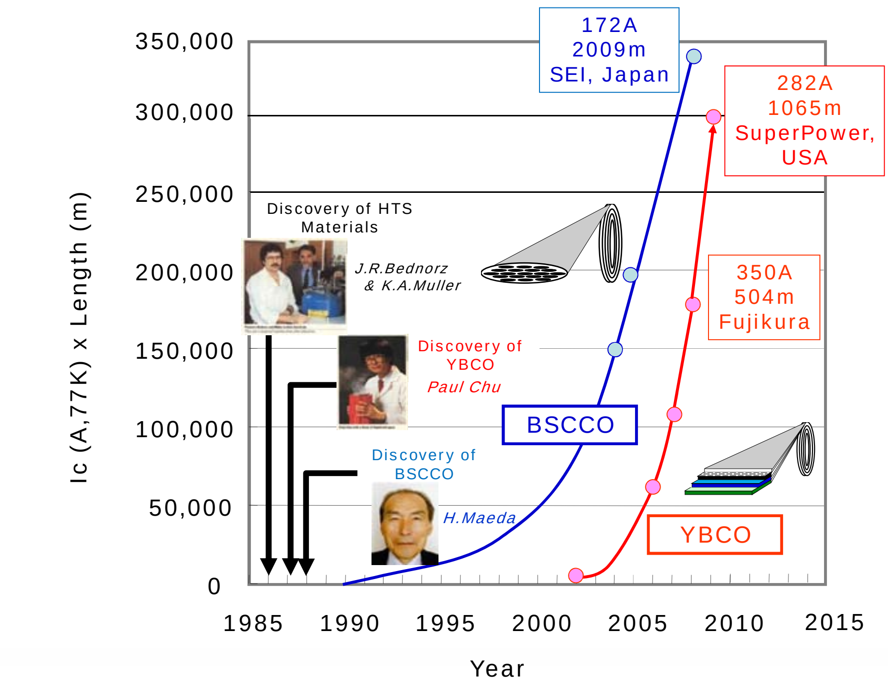

Fig. 2 Development progress of high-temperature superconducting wires

Research and development for achieving uniform characteristics of Y-system coated conductors have also advanced drastically, and Fujikura Ltd. has recently succeeded in fabricating 170-m-long coated conductors with a critical current uniformity of ±1.35 % by means of the IBAD-MgO/PLD-GdBCO process. SRL/ISTEC has also succeeded in dispersing artificial pinning centers of BZO crystalline particles for coated conductor fabrication that uses the TFA-MOD method and successfully eliminated the anisotropic critical current characteristics with applied magnetic field angles.

A severe competition has been taking place between Japan and the USA for the research and development of Y-system coated conductor fabrication processes, aiming at length extension and higher critical currents. Fig. 3 shows the international comparison of Y-system coated conductor developments as of February 2010. Length-extension technology (horizontal axis in the figure) of coated conductor piece

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length has drastically advanced in the USA, while the critical current (vertical axis in the figure) has improved in Japan. Worth noting in recent years is the advancement of coated conductor development in Korea. Until now, the level of characteristics and lengths has barely appeared in the figure; however, a result of 200 m/300 A by means of the IBAD-MgO/RCE-YBCO (RCE: reactive co-evaporation method) process has been reported, resulting in an unpredictable situation for Japan that once led the world in coated conductor fabrication technologies.

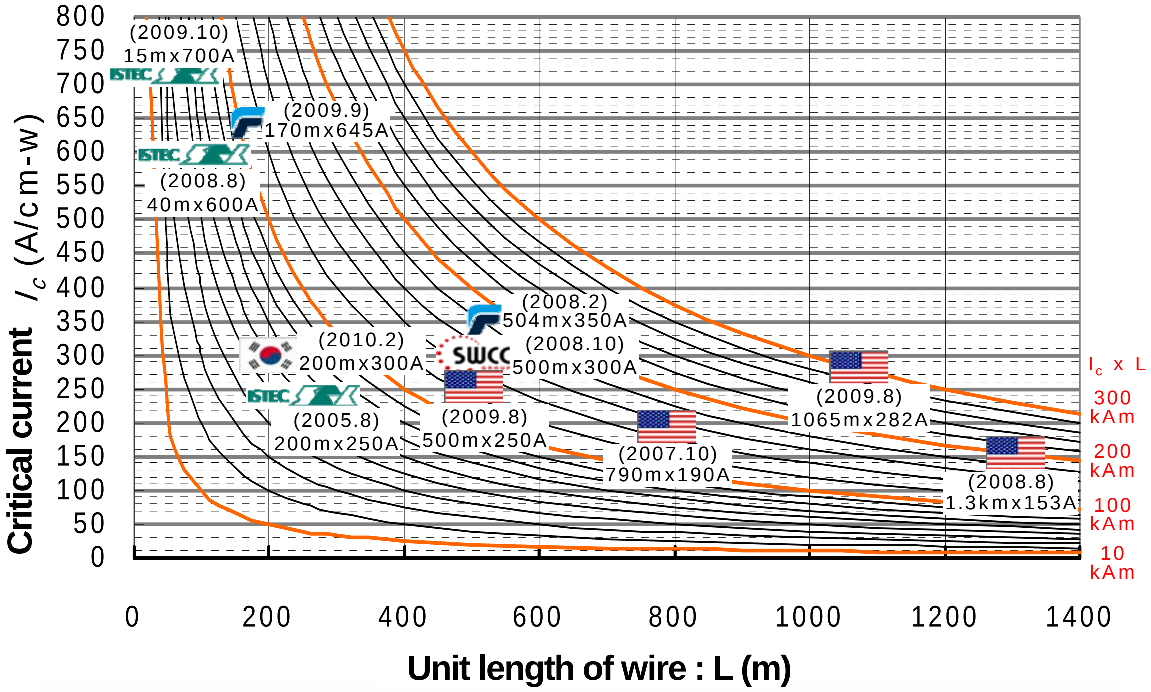

Fig. 3 International comparison of Y-based wire development

In conclusion, superconducting technologies could greatly contribute to CO_2 reduction, which is a global environment issue, by bringing about various advantages such as performance improvement and downsizing of devices. These technologies are also expected to become the economical growth strategy field that will help Japan retain the present superiority. In the future, it is important for us to construct All-Japan formation to make efforts toward practical applications and industrialization of superconducting technologies along with further advancement of technology development by about 2020.

This report partly includes the plans and the results of the Japanese national "Materials and Power Applications of Coated Conductors; M-PACC" that has been supported by the New Energy and Industrial Technology Development Organization (NEDO).

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Feature Articles: Forum on Superconductivity Technology Trends 2010 - Current Status and Future Prospects of Technology Development for Performance Improvement and Length extension of Y-based Superconducting Coated Conductors -

Teruo Izumi, Director
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Y-based superconducting coated conductors have advantages in terms of cost, in-field critical current (I_c), mechanical strength, and AC loss reduction, and a fierce development race has been taking place between Japan and the U.S. This report summarizes the trends regarding Y-based superconducting coated conductor development in Japan, which the author introduced at the Forum on Superconductivity Technology Trends.

In the development of the long coated conductors with high I_c performance in Japan, the Pulse Laser Deposition (PLD) method or the trifluoroacetate-metalorganic deposition (TFA-MOD) method have been used for fabricating a superconducting layer on the textured substrate. The substrate includes Ion Beam Assisted Deposition (IBAD) layer, which gives the texturing structure and was firstly developed by Fujikura in Japan, and CeO2 layer, which has the special effect for enhancing the texturing "self-epitaxy effect".

In the "Fundamental Technologies for Superconductivity Applications" project, which was completed at the end of fiscal 2007, Fujikura Ltd. and ISTEC jointly developed IBAD/PLD tapes and a 500-m-long tape achieved an I_c property of over 350 A/cm-width range. As for IBAD/TFA-MOD tapes, SWCC Showa Cable Systems Co., Ltd. and ISTEC undertook the development and eventually obtained a 500m-310A/cm-width. These results had accomplished the final target value of the abovementioned project and each result achieved the world's highest level of I_cxL value at the time; however, there were device-related limitations regarding the length. In response to this, the "New National Project" which started from the end of fiscal 2009 (to the end of FY2010), is engaged on the development of longer tape fabrication technology than 1km aiming at high performance motors. Regarding the tape length that had been limited by the device size, this project aims to work toward the upsizing of apparatus, while optimizing the manufacturing conditions associated with upsizing.

Meanwhile, the "Materials & Power Applications of Coated Conductors (M-PACC)" project (FY2008 to 2012) is carrying out the development of performance improvement technology that will provide necessary functions to individual power devices such as SMES, power cables, and transformers, in response to the results of the abovementioned project "M-PACC". Specifically, they are carrying out the development of extremely-low-cost technology that will realize a technical cost of 3 Yen/Am or less as a common requirement along with the development of coated conductors that have in-field performance for supporting magnetic field applications such as SMES, and the development of low-AC-loss tapes for supporting transformers and power transmission cables. In addition to the above, developments of a wide variety of function provision technologies are also underway, such as developments of high-strength tapes and high-J_e ones. As a representative result, they have succeeded in fabricating a high performance tapes of 170 m - 600 A/cm-width during the development of IBAD/PLD tapes using MgO as an IBAD material, which can realize cost reduction by speed-up. As for the improvement of in-field performance, introduction of artificial pinning centers is known to be effective, and they have obtained a tape that is isotropic against magnetic field application angles in the $BaZrO_3$ (BZO) added IBAD/PLD tapes. Conventionally, the rod-shaped BZO material in PLD film behaved anisotropically against magnetic fields. Recently, a three-dimensional observation on the internal texture of the abovementioned tape has found out a structure in which the BZO rod spreads from right above the intermediate layer, and revealed that this structure is the origin of the isotropic property. As another approach, they have also tried to improve the characteristics in magnetic fields by film thickening, and obtained a 56-A/cm-width in a 3-T magnetic field with a thick-film GdBCO tape with as thickness of 3 μm. Further, they have succeeded in introducing artificial pinning points of BZO into a TFA-MOD film. By dispersing globular BZO grains, they have realized an isotropic property in magnetic fields, which reflects this geometry. As for the development of low-AC-loss tapes, they are carrying out the development of tape thinning technology by means of cutting and scribing methods, and the development of fabrication technology to obtain tapes that are homogeneous, including the width direction.

As described above, for the development of Y-based superconducting tapes, the development of longer tapes are underway in parallel with development of performance improvement technologies. It is expected that more effective and practical tapes can be realized by integrating these technologies in the future.

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Feature Articles: Forum on Superconductivity Technology Trends 2010 - Development of Bi- and MgB_2-based Wires and their Applications -

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Superconducting Material Center
National Institute for Materials Science

Bismuth-based oxides include $Bi_2Sr_2CaCu_2O_x$ (Bi-2212) and $Bi_2Sr_2Ca_2Cu_3O_y$ (Bi-2223). Using both of these oxides, development of multi-filamentary wires are underway by means of the powder-in-tube (PIT) method, where raw powders are filled in a metallic tube for processing and heat treatment. As bismuth-based oxides have a strong anisotropy (two-dimensionality) of a system, it is relatively easy to obtain grain oriented microstructure. For Bi-2212 wires, so-called "partial-melting/slow-cooling processing" is applied where the temperature is increased to slightly above the melting point of Bi-2212 during heat treatment, then the temperature is decreased slowly. For Bi-2223 wires, grain orientation is achieved by combining machining process and heat treatment. As the melt process could not be applied to Bi-2223 wires, the filling factor of Bi-2223 superconductors had been considerably lower than that of Bi-2212 wires. Later on, the filling factor of the superconductors increased thanks to the development of pressurized heat treatment method, and now it is possible to obtain an excellent critical current property. This is referred to as DI-BSCCO (Dynamically Innovative Bi-Sr-Ca-Cu-O).

The bismuth-based oxide wires fabricated by the abovementioned methods demonstrate excellent properties that largely surpass metal-based wires—they exhibit almost no degradation in the critical current density J_c at low temperatures of 20 K or below and up to extremely high magnetic fields of 30 T or more, reflecting their high upper critical magnetic field H_{c2} (or irreversible magnetic field H_{irr}). Thus, one of the applications of bismuth-based oxide wires is high magnetic field magnets that are used at low temperatures. Recently, as refrigerators have made a remarkable advancement, it has become easy to obtain temperatures about 20 K. The advantage of operating magnets at around 20 K is that the cooling cost can be held down lower than that of liquid helium cooling. Furthermore the magnet stability improves substantially due to the order-of-magnitude increase in the specific heat of wires. Thus, another promising application of bismuth-based wires is refrigerator-cooled magnets that do not require liquid helium. Meanwhile, bismuth-based oxide wires have a drawback that the J_c in magnetic field steeply decreases if the temperature increases further. As for Bi-2223 wires, however, a substantially large superconducting current can flow even at liquid nitrogen temperature (77 K) if the magnetic field is sufficiently low; therefore, the application to power transmission cables, which generates only low magnetic fields, is seriously considered and the fabrication of a prototype is currently underway.

MgB_2, on the other hand, is believed to be free from weak coupling among crystal grains, which causes a problem for high-temperature oxide superconductors. This means that orientation processing is not required, and in this regard, this material is considered to have a practical advantage. Currently, wire developments are promoted by mainly using the PIT method, and long multi-filamentary wires that far exceed 1 km are being developed.

As for SiC-added wires, the H_{c2}, extrapolated to 4.2 K, reaches up to 25 T. This value is equivalent to the H_{c2} of practical Nb_3Sn wires. Further, the H_{c2} of the wires at 20 K is around 11 T, and this value is comparable to the H_{c2} of practical Nb-Ti wires at 4.2 K, which are most widely used at present. These results indicate a possibility that the Nb-Ti wires, which are currently in practical use at 4.2 K, could be replaced by MgB_2 wires and operated at 20 K. As just described, MgB_2 wires can provide a substantially high H_{c2} even at a temperature of 20 K; therefore, one of the possible applications of MgB_2 wires is superconducting devices cooled by liquid-helium-free refrigerators. The most promising application is an open-type MRI, and the prototype fabrication is already underway. For wires fabricated by the PIT method, J_c values over 100 kA/cm^2, which is considered as a rough standard for practical level, have been obtained at 20 K in a magnetic field of 2 T, and it is believed that applications in relatively low magnetic fields are also possible with the present J_c level; however, J_c decreases sharply with an increase in the magnetic field to ~10 kA/cm^2 at 5 T. With the PIT method, as the filling factor of the MgB_2 core is low (approx. 50 %) and a high J_c is very difficult to obtain, filling factor should be increased. As solutions to this problem, methods such as hot press, cold press, and Mg diffusion method have been attempted and improvement of J_c has been achieved.

The abovementioned information is a brief description about the current status of bismuth-based oxide wires and MgB_2 wires. Neither of the two wires has reached to a practical level yet and, for the future, the J_c must be improved to an even higher level by means of advanced microstructure control. The author believes that the reduction in impurities and improvement of the degree of c-axis orientation are important for bismuth-based oxide wires, and the improvement of filling factor for MgB_2 wires.

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Feature Articles: Forum on Superconductivity Technology Trends 2010
- Current Status of Development for Power Devices using Y-based Wires -

Noboru Fujiwara, Director
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SRL/ISTEC

The "Materials & Power Applications of Coated Conductors (M-PACC)" project (fiscal 2008 to 2012) is carrying out the development of power devices (SMES, power cables, and transformers). This project has completed the second year of its five-year program and is about to undergo the interim assessment in the current fiscal year. At this Forum on Superconductivity Technology Trends, the author reported about the developments of individual devices along with the results achieved in fiscal 2009.

SMES

We are conducting the development of 2 GJ-class SMES as a measure to improve the stability of power systems.

On the basis of the design results of 2 GJ-class SMES obtained in the previous project, we are carrying out an experiment to confirm the maximum hoop stress of 600 MPa applied to a coil. We fabricated a coil with a diameter of 250 mm and performed a current conduction test in an 11 T magnet. With this coil, we confirmed the tolerance up to a conduction current of 214 A and an electromagnetic stress of 560 MPa. We will continue the experiment to achieve the interim target of 600 MPa. Further, we fabricated a class coil with a diameter of 600 mm using a conductor made by bundled four Y-based wires to which coil insulation was applied (see Fig. 1), and confirmed a conduction property of over 2 kA.

Other than the above, in the development for coil conduction cooling, we advanced the design of refrigerant flow for the cooling system, and confirmed that we achieved 3 W/m^2, which was the target value for the technology that dissipates the coil-generated heat by conduction cooling. Further, in the system consideration for SMES, we are verifying the methods that analyze current distribution in parallel strands as measures for the analytical estimation of quench phenomenon in Y-based bundled conductor coils.

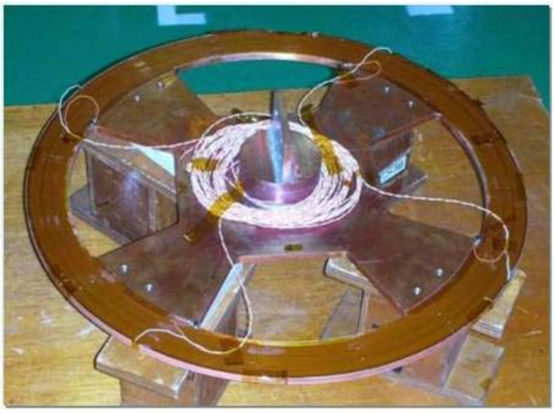

Fig. 1 ϕ600 mm-class coil using four-wire bundled conductors

Power Cable

We are carrying out the development for 66 kV/5 kA large-current cables and 275 kV/3 kA high-voltage cables, which are compact and capable of large power transmission.

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For the development of large-current cables, we verified the thermal characteristics in the case of overcurrent conduction. The temperature rise in superconducting wires is suppressed by transporting an overcurrent through the Cu former and the Cu shield layer in parallel with the superconducting wires. We carried out the designing on the basis of the results of previous simulations and prototyped and evaluated the cables. When the superconducting cable was subjected to a overcurrent of 31.5 kA/2 sec., the temperature rise in the superconducting wires was 163 K, which was a result nearly identical to the simulations. In addition, we carried out a mechanical prototyping of a 10 m three-core in one cryostat cable core, which partially used Y-based wires in the manufacturing line, in order to verify the mechanical characteristics of superconducting wires by using the spiral pitch of an actual cable as the parameter. (See Fig. 2)

Fig. 2 three-core in one cryostat 10-m-long model cable core

As for the development of high-voltage cables, we carried out developments such as the evaluation of insulation materials, development of terminal connection parts, reduction of AC losses, and withstanding overcurrent of 63 kA/0.6 sec. (See Fig. 3) Especially for AC losses, we fabricated and evaluated superconductors using wires that were fabricated by the Metal Organic Deposition (MOD) method. We achieved *Ic* = 9,200 A and an AC loss of 0.235 W/m@3 kArms under a supercooled condition of 68.7 K. (See Table 1)

Fig. 3 Conductor using IBAD-MOD wires

Table 1 Conductor specification

Conductor specification	**Cu former ϕ 25.5 mm**
	2-layer,46 tapes
	TFA-MOD YBCO 3 mm
Conductor *I*c	**4700 A (77.3 K)**
	9200 A (68.7 K)
AC loss @3 kA	**0.235 W/m(It/*I*c=0.46)**

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Transformer

We are carrying out the development for 66/6 kV, 20MVA-class power transformers, which feature compactness, high efficiency, and incombustibility. As for the transformer winding technology, we prototyped and tested a model coil using triple-layer Y-based wires. In the windings of this model coil, the wires were transposed in the middle of coil to homogenize the current flowing through each wire, and we verified the soundness of the windings against overcurrent. We also prototyped and evaluated a current-limiting model transformer in relation to the provision of current-limiting function, which is a feature of this transformer development. (See Fig. 4) To confirm the current behavior flowing through the windings at the time of superconducting quench, we verified the inhibition of short-circuit current with the secondary side short-circuited, by configuring a current-limiting model transformer of four-winding structure where the auxiliary winding for measurement, the primary winding and the secondary winding were added to the main winding. We confirmed that it is possible to limit the short-circuit current to 43 A (approx. 1/30) against a current value of 1,200 A, which is a calculated result for the primary side.

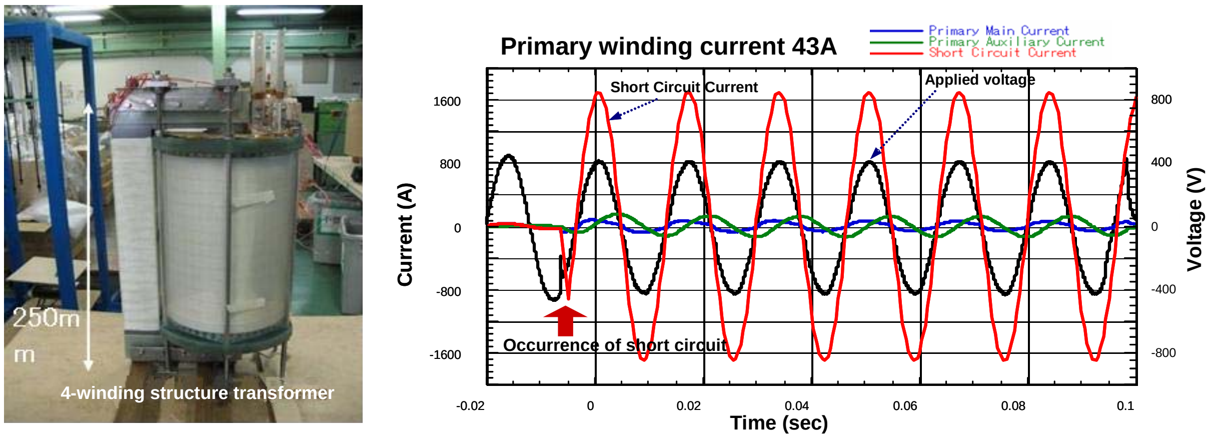

Fig. 4 Current-limiting model transformer (left) and the test result (right)

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Feature Articles: Forum on Superconductivity Technology Trends 2010 - Demonstration of Bi-based Superconducting Cables and Expectations for the Future -

Tomoo Mimura, Researcher
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Tokyo Electric Power Co., Inc.

Dr. Hara, General Manager, R&D Center, reports about the overview, progress, and prospects for the future of the Bi-based Superconducting Cable Demonstration Project, which Tokyo Electric Power Company (TEPCO) has been promoting.

The contents of the report consisted of four points: the abstract of cable development, contents of the research and development at Tokyo Electric Power, the contents of the Bi-based Superconducting Cable Demonstration Project, and the practical use of superconducting cables.

As for the meaning of developing superconducting cables, there is a possibility of construction-cost reduction due to the advantages of three-in one cables such as compactness, bulk power transmission, and diversion of existing conduit lines, as well as an expected CO_2 reduction effect. An estimation result shows that the possibility for a substantial reduction in construction cost when specifically compared with the power transmission by conventional XLPE(CV) cables, and the cable tunnel construction cost required for the CV cables is substituted by the conduit line construction cost for superconducting cables.

TEPCO has been promoting the research and development for cables in collaboration with Sumitomo Electric Industries, Ltd., and we have an experience of the conducting a confirmation test for one year to confirm the stability of cables by using a 100-m cable system at the Yokosuka Research Laboratory of the Central Research Institute of Electric Power Industry; however, the further improvement in wire performance is required when considering the practical use for power systems.

In response to the test results, Sumitomo Electric Industries developed the performance improvement of Bi-based superconducting wires and improved the critical current about 200 A (4-mm width). Along with the improvement in wire performance, it was decided that the Bi-based Superconducting Cable Demonstration Project should be promoted with the cooperation of the New Energy and Industrial Technology Development Organization (NEDO) and Japanese Ministry of Economy, Trade and Industry (METI).

The development targets of the Bi-based Superconducting Cable Demonstration Project are: realization of 66-kV, 200-MVA-class three-in one superconducting cables, establishment of loss reduction technology that allows for compactness and limits the AC loss to 1 W/m, and verification of the stability of cables against fault currents. This project is a six-year program starting from 2007, and the Asahi Substation of Tokyo Electric Power has been selected as the test site. After undergoing the verification of cooling system in this fiscal year, the project plans to carry out a long term test for one year from the autumn of 2011.

The project strives to demonstrate the cable performance by developing a practical-level superconducting cable system, which uses Bi-based wires that have a good performance in cable developments, at an early date and by conducting a long operation of an actual system; while, in parallel with this, Yttrium-based wires, which have a high potential for improved wire performance, are under development with the aim of achieving higher-performance lower-cost cables.

Regarding the future expectations from Tokyo Electric Power, these cables have prospects for the use in transmission systems from bay-area power stations to Metropolitan areas, which aims to reduce cable tunnel construction cost, as well as for the measures against the aging of existing power cables, e.g., replacement of POF (Pipe-type Oil Filled) cables and so on. For the early practical use of the superconducting cables, the advancement of technology development for the cost reduction of superconducting wires and cooling systems is essential, and it is important for the future to make efforts toward the matter in tie-up with the Yttrium-based Device Development Project.

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Feature Articles: Forum on Superconductivity Technology Trends 2010
- Application of Superconducting Devices to Mixed Signal Circuits -

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Signals that occur in nature are analog signals of continuous quantity. As opposed to this, data inside information processing devices, such as computers, are represented as digital signals of discrete values. Mixed signal circuits handle both the analog and the digital signals; specifically, they include an analog-to-digital converter (ADC), which converts analog signals to digital signals, and a digital-to-analog converter (DAC), which converts digital signals to analog signals.

The primary advantage of mixed signal circuits comprised of superconducting devices is that high performance can be realized without parallelization by utilizing the high-speed performance of superconducting circuits. In semiconductor mixed signal circuits, parallelization is heavily used to improve the performance. An example of parallelization is the method to increase the sampling frequency of ADCs where the measuring is carried out by using multiple ADCs with phase-shifted measuring frequencies and the measurement results are overlapped to increase the effective sampling frequency. The problem with this method is that the characteristics of the ADCs used must be identical with a high degree of precision and the accuracy of phase control must be high enough; if these conditions are not fulfilled, then the converted result turns out to be unreliable. Normally, it becomes harder and harder to fulfill these conditions as the speeds of devices and the degree of parallelization increase.

Another advantage of superconducting devices is that circuit configurations can be simplified by utilizing the quantum effect that is specific to superconductivity. A flash-type ADC, which is a high-speed ADC, comprises comparators that distinguish between "1" and "0" in the signal, and a resistance ladder circuit that distributes the signal to each comparator. As a superconducting ADC can measure the periodic change of binary bits by using the periodicity of Superconducting Quantum Interference Device (SQUID), a minimum of n comparators are required to realize an n-bit ADC. As opposed to this, with semiconductor comparators, which do not have periodicity, at least 2^n-1 comparators are required to perform an n-bit ADC. To process six bits, for example, 63 comparators are required when using semiconductors, while only a minimum of six comparators are required when using superconducting circuits.

On a consignment from NEDO, ISTEC is developing flash-type ADCs for a real-time oscilloscope that observes high-speed optical waveforms and has achieved a sampling speed of 34 GS/s without parallelization, which far exceeds that of semiconductor ADCs. The superiority of superconducting devices is also outstanding in high-precision ADCs, and Hypres, Inc. of the U.S. is developing one-rack devices by implementing ADCs, which exceed 14 bits with a bandwidth of 10 MHz, on refrigerators. Further, superconducting DACs have a high precision that is to be used as a national voltage standard, and ISTEC is developing pulse-driven AC voltage standard devices using superconducting DACs in collaboration with the National Institute of Advanced Industrial Science and Technology.

As explained above, superconducting devices allow the configuring of far simpler mixed signal circuits when compared with semiconductor devices; therefore, extremely reliable ADCs and DACs are expected to be realized, which will support Japanese science and technology.

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Feature Articles: Forum on Superconductivity Technology Trends 2010 - Development of Advanced Biotech/Nondestructive Sensing Technology using High-temperature Superconducting SQUID -

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A project under the theme of "Creation of Advanced Energy/Electronics Industry by Superconducting Systems" has started in the "Strategic Promotion of Innovative Research and Development" project of Japan Science and Technology Agency. One of the objectives of the theme is the "Development of Advanced Biotech/Nondestructive Sensing Technology using High-temperature Superconducting SQUID," and we are planning to undertake the research challenges faced by the joint research of six institutes: Kyushu University, Hitachi, Ltd., Hitachi High Technologies Corporation, International Superconductivity Technology Center, Okayama University, and Toyohashi University of Technology.

SQUID is known as a super-sensitive magnetic sensor, and expectations are rising for the development of advanced sensing systems that provide unprecedented high performance and new features by utilizing the high sensitivity. Development of HTS-SQUID systems is indispensable for enabling the expansion into industrial applications; however, the reality is that the potential performance has not yet been tapped sufficiently due to the immaturity of fabrication processes, etc. Therefore, this project aims to develop HTS-SQUID systems with high sensitivity and high reliability that are comparable to low-temperature SQUIDs in order to enable the expansion into industrial applications.

The figure shows the overview of this project. One of the objectives is the development of high-performance, high-reliability HTS-SQUID systems for industrial applications. To this end, we will develop HTS-SQUID systems with high sensitivity and superior immunity against magnetic disturbance by upgrading the integrated SQUIDs that had been developed until now. Further, we will develop sensor systems that can operate in magnetic fields by upgrading the noise elimination method, magnetic field compensation method, etc.

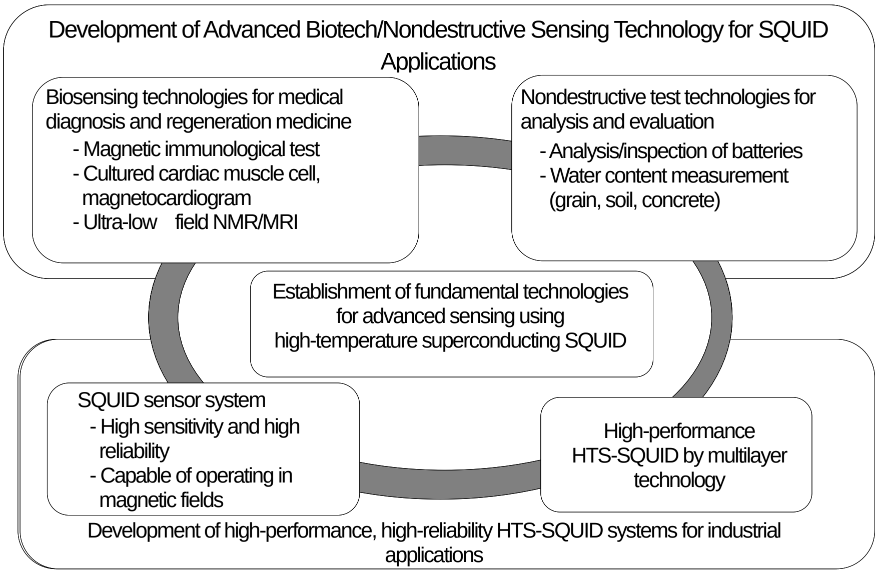

Fig. Overview of research challenges

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Another objective is the development of an advanced biotech/nondestructive sensing technology using SQUIDs. That is to say, we will develop biosensing technologies for medical diagnosis and regeneration medicine, and expand the applications into immunological test, detection of cultured cardiac muscle cell, magnetocardiogram, and ultra-low field NMR/MRI. In addition, we will develop nondestructive test systems for analysis and evaluation of batteries, which will become important in the energy field, and for analysis and evaluation of water content, which will become important in the agriculture field.

Through the development and evaluation of these prototypes, we aim to establish the fundamental technologies for HTS-SQUID sensing devices. To realize superconducting systems, a joint research in industry-academia collaboration where they complement each other while exploiting their own characteristics is important. We would like to carry out a fruitful joint research through this project.

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Feature Articles: Forum on Superconductivity Technology Trends 2010 - Progress in Y-based Wire Processing/Evaluation Technologies for Devices -

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A Y-based wire is normally fabricated as a tape wire on a 5 or 10-mm-wide metal substrate. The surface is coated with a silver layer of several tens-of-micrometer thickness for stabilization. This configuration is considered as a completed Y-based wire; however, further processing is required depending on the device requirements before applying the wire to actual devices. The processing include a wide variety of steps, such as processing to add a stabilization layer, insulation, connection, mending, etc. From among these, this manuscript especially reports the wire-thinning processing for AC loss reduction and the progress of evaluation technology for the processing.

Superconductors generate the so-called "AC loss" due to alternate currents and AC magnetic fields. As this phenomenon degrades the superiority of superconducting wires, it must be reduced as much as possible. Types of AC losses include hysteresis loss, coupling loss, and eddy-current loss at a normal conducting portion. The size of AC loss is dependent on the environment in which the wires are placed inside the device; therefore, accurate evaluation cannot be performed or the judgment cannot be made whether the AC loss is within an acceptable range unless the design of the actual device is determined. Hysteresis loss is a problem for almost all devices, and wire thinning is required for the reduction of this loss. Ideally, by thinning the wire in the longitudinal direction, it should be possible to reduce hysteresis loss while maintaining the total critical current value. One method for wire thinning is to cut the original tape wire into a large number of filaments; though, another promising method is to scribe "streaks" only on the superconducting layer (and the silver layer on it) and leaving the metal substrate as it is to virtually achieve the wire thinning by exploiting the structures of Y-based wires. This method is referred to as "scribing."

Although thinning technologies for Y-based wires are indispensable for the full-fledged applications to AC devices, the actual situation is that little progress has been made so far worldwide. Under such circumstances, Superconductivity Research Laboratory already started the technology development in a predecessor project, which formed the foundation for the present NEDO project "Materials & Power Application of Coated Conductor." Several wire-thinning methods are under consideration, and the method, which is believed to be the closest to practical applications at the present stage, combines laser beam radiation and chemical etching. Using this method, the project aims to ultimately reduce the hysteresis loss to 1/10 by dividing a 5-mm-wide, 100-m-long wire into 10 filaments. (Currently, we have succeeded in dividing a 5-mm-wide, 50-m-long wire into 5 filaments, which is the interim target.)

For the effective development of thinning technologies, concurrent developments of homogeneous-wire fabrication technology and long-wire evaluation technology are required before and after the processing stage. Superconductivity Research Laboratory has been developing the Hall sensor array method, SQUID method, magneto-optics method, etc. Recently, to provide further support for the development of thinning technologies, we are developing the laser-scanning shape detection method and long-wire AC susceptibility measuring method with an aim of improving the efficiency of the wire-thinning technology development.

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Feature Articles: Forum on Superconductivity Technology Trends 2010 - Exploration of New Superconductors and Related Active Functions, and Applications to Wires -

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Background of this project

Iron is a representative example of a magnetic element, and it has been believed that iron is worst suited for the manifestation of superconductivity. Excluding cuprate, the highest T_c has been obtained for an iron compound, and the strongest property against magnetic fields has been observed. I wonder if any researchers, including the author, could have predicted such a result three years ago. The author cannot get over the wonder that the diversity and possibility of materials are far beyond our imagination.

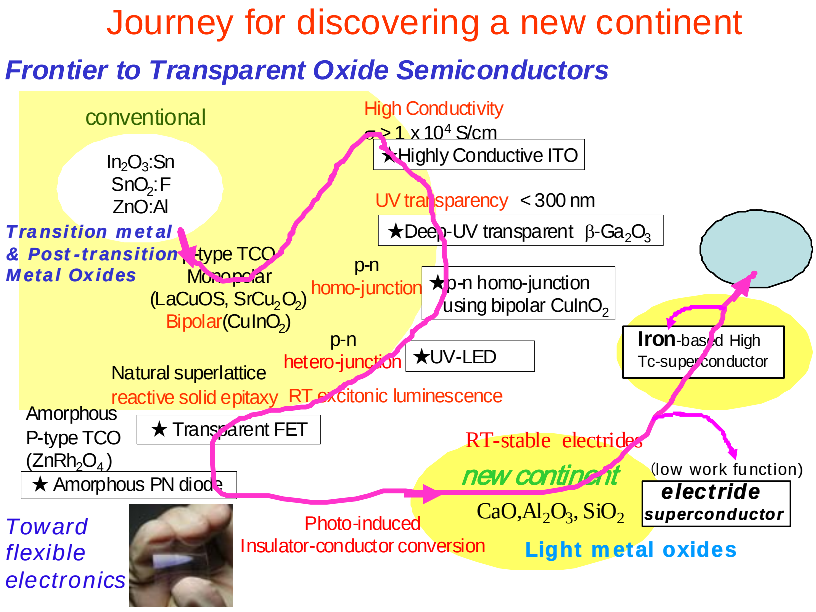

Fig. 1 Function cultivation of transparent oxides in last decade

Superconductivity is the most dramatic and lucid phenomenon among the many electronic properties of condensed matter and the impact on industrial applications will be enormous if the performance is improved. This is why superconductivity keeps attracting many researchers. Researches on superconductivity, which have been leveled off for a while, are gaining impetus all together around the world seeing the discovery of iron-based superconductors as an opportunity. Especially, China's rush is tremendous and expensive measuring devices for superconducting physical property have already been ordered, far exceeding the number of units in the Japanese market. "It will be Japan or China, if a new, epoch-making superconductor is to be discovered," is a famous prediction made by Dr. M. L. Cohen, superconductivity theorist.

The iron-pnictide-based superconductor, which our group reported in February 2008, has appeared in as many as 2,000 reports in journals, and special projects have started one after another around the world and fierce competitions are taking place. The highest value of T_c is 56 K, which surpasses T_c of metal-based materials and follows that of copper-oxide-based materials. Discoveries of superconductors with superior properties can make great contributions in solving the energy and environment issues such as CO_2 reduction, and this discovery has removed the taboos on candidate materials and significantly broadened the horizons for material exploration. Researchers filled with ambitions are taking part in the development of frontiers as if they are trying to "strike while the iron is hot."

This iron-based superconductor was discovered in the course of function exploration of transparent oxides on which the author has concentrated over the last 10 years with the support of JST (Fig. 1). As for the main challenge, a material named "Transparent Amorphous Oxide Semiconductor (TAOS)" is created,

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and it can be easily fabricated by sputtering at room temperature and has a mobility that is 10-20 times higher than that of amorphous silicon. TFTs using TAOS are coming close to practical applications as backplanes for driving FPDs, including 3D-LCDs and OLEDs, which are about to be launched by corporate groups at home and abroad. The author believes that in addition to setting a specific target, making good use of serendipity and inspiration, which appear during the course of drastic exploration, is the key to material research.

Objectives of this project and their features

We have set the following objectives:

[Exploration of substances and functions**]**

a. Realization of new superconductors of $T_c > 77$ K.

b. Discovery of completely new, materially expandable high-temperature superconductors.

c. Discovery of outstanding functions.

d. Fostering of young ace researchers capable of exploring innovative substances.

[Wire applications**]**

a. Realization of meter-long class of wires made of iron-based materials and new superconductors that demonstrate a critical current density (J_c) of 10^5 A/cm^2 or higher at low temperatures.

b. Realization of Josephson junctions and devices using iron-based materials and superconducting thin films.

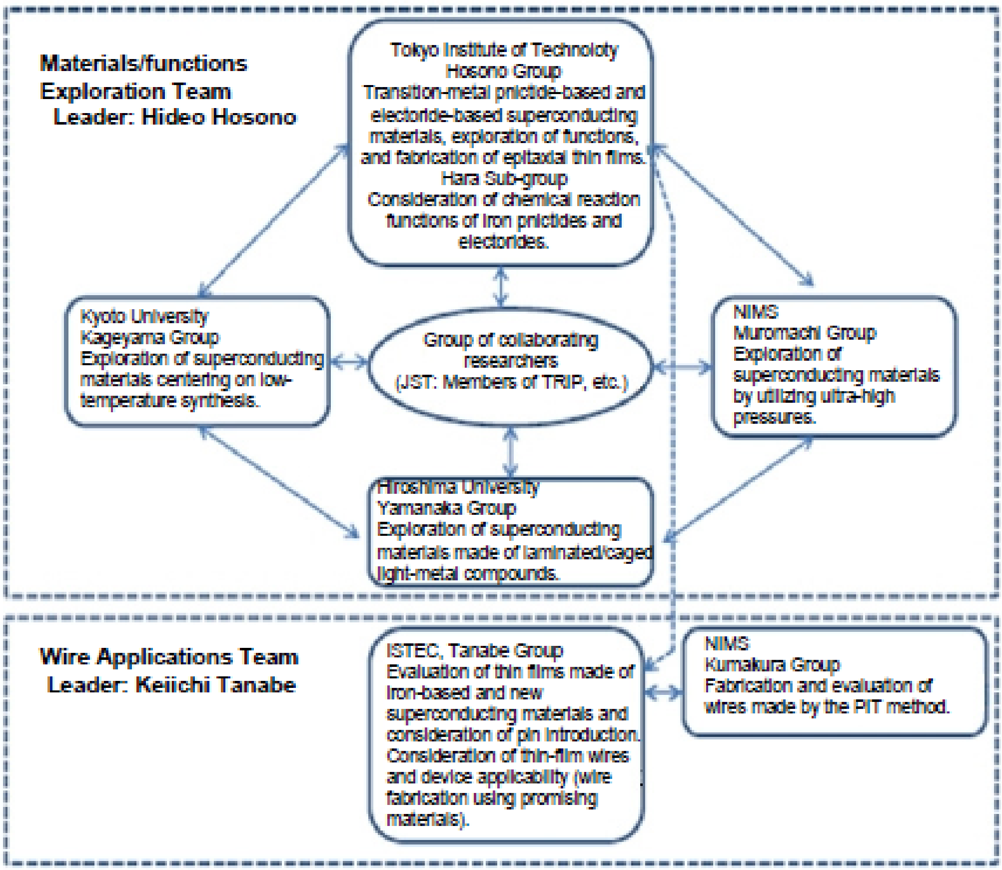

Fig. 2 Research Team

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The actual situation in the exploration of high-temperature superconductors is that we have no other choice than to rely on the intuition, amount of activities, and tenaciousness of researchers, let alone the empirical rule regarding the exploration of superconducting materials "The harder we explore, the lower the T_c decreases," which was set by Prof. Akimitsu. Thus, we have organized the exploration team by appointing experts of solid-state chemistry as the group leaders (Shoji Yamanaka -Hiroshima University, Eiji Muromachi -NIMS, Hiroshi Kageyama -Kyoto University, and Hosono -Tokyo Institute of Technology) who have a good record of accomplishments in the exploration of new materials. Physicality measurement/theory and material exploration are the two wheels of one cart. For the former, we would like to keep the balance in collaboration with JST's special project "Transformative Research-project on Iron Pnictides (TRIP)" (project leader: Prof. Hidetoshi Fukuyama).

As for wire applications, ISTEC (Keiichi Tanabe, Deputy Director General of SRL) is in charge of thin-film wires and devices, and NIMS (Hiroaki Kumakura, Managing Director of Superconducting Materials Center) is in charge of wires fabricated by the PIT method.

One of the real thrills of material exploration is the possibility to find a new function different from the original intent; in addition, the impact may be greater than initially expected. As we carry out research on many unknown material systems and materials with unknown physicality, we would like to advance the project with flexible policies.

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Feature Articles: Forum on Superconductivity Technology Trends 2010 - Global Environment Issues and Superconducting Power Device-related International Standardization -

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School of Computer Science and Systems Engineering, Graduate School
Kyushu Institute of Technology

Currently, there is a crying need for the reduction of CO_2 emissions around the world as an indispensable measure for solving the global environment issues. One of such measures is the utilization of nuclear energy and natural energy that are free from CO_2 emissions, and another measure is the expansion and diffusion of efficiency improvement technologies that can greatly reduce the emissions. Superconducting technologies belong to the latter as they exploit the property of eliminating electric resistance; they also feature a property of making great contributions to the former—promotion of natural energy utilization. Thus, we can say that superconductivity is an indispensable technology for smart grids, which aim at efficient energy utilization by realizing voltage conversion, transmission, storage, etc., with low losses for the electric power generated by solar and wind energies.

The superconducting power devices currently under development at home and abroad include superconducting cables, superconducting transformers, superconducting magnetic energy storage devices, current limiters, rotating equipment, etc. It is believed that we need to wait until the 2020s for a large number of such power devices to be produced and used; however, foreseeing such a situation, the international standardization of superconducting power devices may not allow any delay. The purpose of standardization is to conduct commercial transactions on the basis of the internationally common concept of values and principles, which will provide various advantages for manufacturers such as improvement in productivity and promotion of new entries, and advantages for users such as reduction in prices and enhancement of convenience. We must recognize, however, that it will take nearly 10 years before standardization produces any effects on the market. The reason why we need to hasten standardization is that we can now expect that the diffusion of superconducting power devices will have been promoted 10 years from now or later.

The 90th Technical Committee (TC90) of IEC (International Electrotechnical Commission) in which 11 countries were involved directly and 15 countries participated as observers had dealt with the standardization of superconductivity-related technologies. In the committee, Japan had made a great contribution to the promotion of international standardization as a secretariat country. The international standards that have been established until now include terminology standards and 13 test standards, and the standard for current lead is scheduled to be released as the first product standard in the near future. At present, superconducting cables draw most attention and are under consideration at CIGRE (International Council on Large Electric Systems). Two years from now, standardization is expected to start upon receiving the report from the council. As superconducting wires will be used for various superconducting power devices including superconducting power cables, the standardization of wires also needs to be hastened. Differences in international opinions, however, have arisen on whether or not to unify the standards for metal-based superconducting wires, which have already acquired the market, and high-temperature superconducting wires, which are expected to grow in the future. This illustrates the difficulty of internationalization.

From now on, we need to carry out investigations and research with the aim of standardization of promising superconducting power devices, while tenaciously appealing the meaningfulness of standardization to other countries and submitting proposals for standardization whenever the opportunity comes along.

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Feature Articles: Forum on Superconductivity Technology Trends 2010 - Low-Carbon Society realized by Superconductivity -

Koichi Kitazawa, President
Japan Science and Technology Agency

A long-term national plan needs target settings in accordance with the technological levels. Low-carbon society (LCS) needs 30- or 50-years to avoid usage of fossil fuels and to increase domestic energy supply. Utilization of superconductivity will add an attractive tint to our LCS plan in the future, making the goal even more attractive.

In Japan, industries paid extensive efforts to save energy in the manufacturing processes during the 1970s and 1980s. As a result, Japan still maintains the world's lowest level in CO_2 emissions per GDP. With this technology, Japan can make a great contribution to the reduction of CO_2 emissions in the world. Europe is more advanced than Japan in recycling and home-energy-saving efforts. Further, acceptance of renewable energies is also advanced.

Meanwhile, the U.S. and China both of which emit the world's largest amount of carbon dioxide gases (each amounts to 20 %), have belatedly started to take the road toward green innovations. As for the target, they are planning to make big investments so that to outstrip Europe and Japan in a stroke, in the development of energy-saving and new-energy technologies, and they even have development plans (power company of three gorges dam) in units of 20 million kW in the wind-power energy field.

Japan used to be wavering between Europe, which is ahead of the rest of the world, and the U.S./China, which aim to change their images from old-guard cronies to a leading group; however, we expect that the plans of individual ministries will be adjusted to the latest global dynamics as new growth strategies are revealed.

Under such circumstances, superconductivity is in the situation where its adaptations are under consideration, such as efficiency improvement of large-scale wind-power generators and shipboard power units, and ground burial of cables for trunk power lines in urban areas. To this end, we need to establish fundamental technologies such as AC loss reduction and improve the reliability including cooling.

After all, however, the most predominant feature of superconductivity is that the resistance is completely zero. This feature becomes increasingly prominent as the length exceeds a super long distance of 1,000 km. The biggest problem with natural energies, such as wind and solar power, is that they are dependent on environmental conditions—whether the wind is blowing or not, or it is sunny or shaded. The fundamental solution can be worked out when sharing of electric power is enabled on a global scale. In that sense, we expect the progress of superconducting technologies as green innovations, while aiming at the goals such as Global Energy Network Equipped with Solar cells and International Superconductor grids (GENESIS) Project and Sahara Solar Breeder Project.

Meanwhile, the loss of earth's geo-magnetism has become a topic of scientific concern. If the geo-magnetism is lost, electrically charged cosmic rays will reach the earth's surface, and then humans cannot survive. A superconducting permanent current loop that circles around the equator can save humans from this risk. Technically, it is very difficult to achieve, but it is on a feasible scale that may be accomplished by making efforts from one generation to the next. For the future, we need to invest in Japan's cutting-edge technologies.

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Patent Information

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Planning & Management Division
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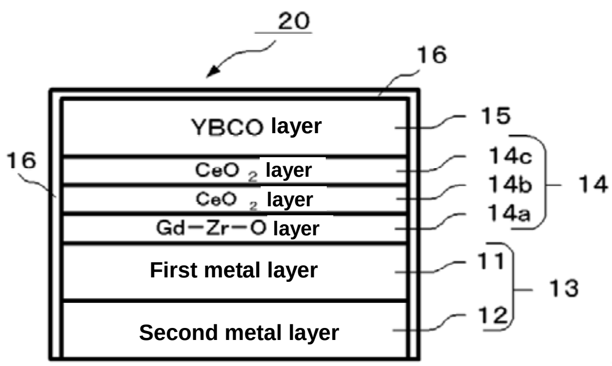
Published patents in the latter half of FY 2009

The following is ISTEC's patent published from October 2009 through March 2010. For more information, access the homepage of the Japan Patent Office or visit the Industrial Property Digital Library (IPDL).

1) Publication No. 2010-44969: "Tape-shaped Oxide Superconductors and Substrates used for them"

This invention concerns oxide superconductors and the substrates used for them, which are suitable for use in power devices such as transmission cables and energy storage systems, and in power machinery such as motors. It particularly relates to tape-shaped oxide superconductors and the substrates used for them, which are suitable for oxide superconductors fabricated by the film-forming method in which a thin layer of ceramics is formed on the substrate by heating and firing a precursor film after it has been applied.



13 Substrate
14 Intermediate layers
15 Yttrium Barium Copper Oxide (YBCO) superconducting layer
16 Ag stabilization layer
17 Tape-shaped oxide superconductor

Fig. Cross section of tape-shaped oxide superconductor (vertical to the axial direction)

The tape-shaped oxide superconductor in accordance with the present invention consists of the following: the substrate (the core material) made by connecting the first metal layer and the second metal layer, the single or multiple intermediate layer(s) comprised of a bi-axially-oriented inorganic material which is placed on the first metal layer of the substrate, and the oxide superconducting layer comprised of a laminated body (oxide superconductor). Materials that have a higher mechanical strength than the second metal layer, do not have orientation or magnetism, and have a higher thermal conductivity and lower electrical resistance are used for the first and the second metal layer, respectively. In addition, the superconducting layer and the second metal layer are electrically connected by depositing stabilizing layers on the upper and lateral sides of oxide superconducting layers of this laminated body. Further, the first metal layer and the second metal layer that become the core material are connected, and materials each of which has a higher mechanical strength than the second metal layer, do not have orientation or magnetism, and have higher thermal conductivity and lower electrical resistance are used for the first and second metal layers.

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This tape-shaped oxide superconductor has a superior heat dissipating performance because the second metal layer with high thermal conductivity and low electrical resistance is connected to the intermediate layer side and the opposite side of the first metal layer, which becomes the core material with higher mechanical strength, and allows for easier scribing of the superconducting layer by laser processing. Further, for the fabrication of superconducting coils, the design of electrodes connection of a superconducting coil can be simplified as the current may be applied to the superconducting layer via this second metal layer when winding with the Ag stabilization layer facing inward.

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