Summer, 2008 Date of Issue: July 15, 2008

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Superconductivity

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13 Shinonome Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-7283, Fax: +81-3-3536-7318

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Patent Information
- Publication No. 2007-257872 & No. 2008-50190

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Top of Superconductivity Web21: http://www.istec.or.jp/Web21/index-E.html

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This work was subsidized by JKA using promotion funds from
KEIRIN RACE
http://ringring-keirin.jp

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Briefing Session on the "Development of Superconducting Power Network Control Technology" Conducted by Chubu Electric Power Co., Inc., Kyushu Electric Power Co., Inc., ISTEC, and NEDO

Greetings of Eisuke Masada, Chairperson of Project SMES Development Policy Conference

A briefing session for examining the results of the "Development of Superconducting Power Network Control Technology" was held on Wednesday, March 12, 2008 at Kudan Kaikan in Chiyoda Ward, Tokyo. "Development of Superconducting Power Network Control Technology" (fiscal 2004 through 2007) was commissioned to Chubu Electric Power Co., Inc., Kyushu Electric Power Co., Inc., and International Superconductivity Technology Center (ISTEC) by the New Energy and Industrial Technology Development Organization (NEDO) as part of the policy project of the Agency for Natural Resources and Energy of the Ministry of Economy, Trade and Industry. This session was held to examine the research results obtained through this technology development. More than 100 participants, including the general public and people from industry, academia, and government, had a heated discussion.

Eisuke Masada, Chairperson of the Project SMES Development Policy Meeting, made an opening speech. Then, Natsuki Takatsuka, an Assistant Director of the Electricity Infrastructure Division of the Electricity and Gas Industry Department of the Agency for Natural Resources and Energy of the Ministry of Economy, Trade and Industry made a guest speech. He indicated that superconducting technology contributes to the efficient use of electric power energy and that the current results will be useful for the future technological development of various types of power equipment, leading to the technological development of yttrium-based superconducting power equipment, which is the next R&D project.

The lecture began with a rundown of the research of Shigeo Nagaya, Project Leader, from Chubu Electric Power Co., Inc. Professor Hiroyuki Ohsaki of the University of Tokyo, General Manager of the SMES System Review Committee, outlined the system technological development results. Afterwards, Naoki Hirano, Manager of the Research Project, from Chubu Electric Power Co., Inc., lectured on a low-cost large-capacity power conversion system, a highly-reliable cryocooler, and the development of a high-magnetic-field oxide-based SMES coil. Group manager Hidemi Hayashi, from Kyushu Electric Power Co., Inc., lectured on the development of a high-withstand-voltage conduction cooling current lead system. His group achieved the system structure technological development goal and established the technology necessary to develop the SMES system. After Hayashi's lecture, Professor Tanzo Nitta of Meisei University, General Manager of the Test/Evaluation Method Exploratory Committee, outlined the actual power system interconnection test results. Then, Tatsuya Nagata, Manager of the Research Project, from Chubu Electric Power Co., Inc. and Kouichi Tone, Senior Researcher, from Kyushu Electric Power Co., Inc. lectured on the load fluctuation compensation test results and the system stabilization test results, respectively. They reported the system performance verification including the high-speed trackability to load fluctuation, the simultaneous control of active/reactive power, the power fluctuation depression effect caused by load dump, etc. through the actual power system interconnection operation test. In addition, Professor Naoyuki Uchida of Science University of Tokyo, General Manager of the Introduction Effect Exploratory Committee, outlined the application technology standardization research results. Takashi Ito of ISTEC reported on the application effect and economic efficiency evaluation of SMES and competing technologies, and the SMES test method.

Afterwards, Yuh Shiohara, Project Leader of the R&D of Fundamental Superconducting Application Technologies and Deputy Director General of ISTEC's Superconductivity Research Laboratory, reported the development trends of a next-generation wire, which is expected to be applied to SMES.

Lastly, Professor Atsushi Ishiyama of Waseda University, reported on the SMES technological development results obtained up to now and future challenges and directions for practical application.

The lecturers and participants had a lively discussion, and we received valuable input for further technological development and promoting practical application.

(Takashi Ito, Research and Planning Department, ISTEC)

Lecture, Q&A session

(Published in a Japanese version in the April 2008 issue of *Superconductivity Web 21*)

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Briefing Session on the Results of Investigation of the Search for New Superconducting Materials by ISTEC/NEDO

ISTEC has been conducting the "Investigation of the search for new superconducting materials" as a research project commissioned by NEDO for two years from fiscal 2006 to 2007. The final purpose of this research project is to provide guidelines to discover new superconducting materials with properties exceeding those of the copper oxide-based high temperature superconductors currently examined how to use practically. A committee, established by experts to play a central role for this purpose, has researched the properties of many different new superconducting materials. Upon the completion of the research project, a briefing session was held last February 29 at The Center for the Advancement of Working Women in Tamachi, Tokyo. The session was jointly organized by NEDO and ISTEC. Some 100 people attended the session and had a lively discussion.

Panel discussion

The session began with the opening remarks of the organizers. Then, Director Suzuki, from the Ministry of Economy, Trade and Industry, delivered a speech on behalf of the guests and Director General Tanaka, the Superconductivity Research Laboratory, explained the aim of this meeting, followed by the presentations of the research committee members. After the general introduction of Chairperson Fukuyama, from Tokyo University of Science, Committee Member Akimitsu from Aoyama Gakuin University lectured on the basics of superconductivity for the layperson, introducing some superconducting materials that he had discovered in his laboratory. Next, Committee Member Uchida from the University of Tokyo discussed the possibility of further raising the critical temperature within a category of copper oxide. The last presenter in the morning session was Committee Member Maeno from Kyoto University, who mainly reported that the Ru-oxide superconductor might be a spin-triplet superconductor.

In the first half of the afternoon session, Committee Members Sato (Nagoya University), Kitaoka (Osaka University), and Kanoda (The University of Tokyo) introduced Co-oxide, f electron system, and molecular crystal, respectively. These materials are characteristic superconductors. Professor Hosono from the Tokyo Institute of Technology made an unscheduled presentation on Fe-based superconductor, which has been recently made public. In this totally new superconducting material system, a critical temperature of 32 K was reported, which is being widely discussed. Professor Hosono stated in his presentation that a critical temperature of about 50 K will be probably achieved, but did not discuss the details. Chairperson Fukuyama presided at the panel discussion at the end of the program. Panelists suggested their plans of action to achieve higher critical temperatures.

Discovering superconductors with properties exceeding those of the copper oxide-based superconductor is difficult. It is significant that the present situation has been clarified through this research project and some plans of action have been presented in an easy-to-understand manner. Although the whole picture has not yet been clarified, the appearance of Fe-based superconductor, a totally new material system, is news worthy to round out this research project.

Lastly, as a person responsible for the research project, I would like to express my gratitude to NEDO, which has supported us all the time, as well as to the committee members, who have always participated enthusiastically in the committee activities.

(Koichi Nakao, Division of Material Science & Physics, SRL/ISTEC)

Lecture

(Published in a Japanese version in the April 2008 issue of *Superconductivity Web 21*)

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What's New in the World of Superconductivity (May)

Power

American Superconductor Corporation (May 8, 2008)

American Superconductor Corporation (AMSC) has announced its financial results for its fourth quarter and year ending March 31, 2008. Revenues for the fourth quarter increased to a record US $38.4 million, a 101 % increase from the $19.1 million recorded in the same quarter in the previous fiscal year. The gross margin for the fourth quarter was 33.2 %, compared with 5.7 % for the same period in the previous fiscal year. The net loss for the quarter was $1.8 million, compared with $11.6 million for the same period in the previous fiscal year.

Revenues for fiscal 2007 amounted to $112.4 million, an increase of 115 % from the $52.2 million recorded in the previous fiscal year. The gross margin for the full year was 28.5 %, compared with a negative gross margin of 0.6 % for the previous fiscal year. The net loss for the year was $25.4 million, compared with a net loss of $34.7 million for the previous fiscal year. The company's EBITDAS loss for fiscal 2007 was $9.1 million, compared with an EBITDAS loss of $28.1 million for fiscal 2006. As of March 31, 2008, AMSC had $106.2 million in cash, cash equivalents, and marketable securities and a reported backlog of approximately $199 million, compared with $76.8 million as of March 31, 2007.

David Henry, Senior Vice President and Chief Financial Officer of AMSC, commented, "AMSC entered the first quarter of fiscal 2008 with significant momentum and visibility, providing us with confidence that our strong growth rate will continue through this fiscal year. We anticipate that revenues for fiscal 2008 will increase to a range of $165 million to $175 million. We expect our bottom line to improve significantly again and anticipate a net loss of $9 million to $12 million... for fiscal 2008. For fiscal 2008, we expect EBITDAS in the range of $3 million to $7 million."

Source:
"AMSC Reports Fourth Quarter and Full Year Fiscal 2007 Financial Results"
American Superconductor Corporation press release (May 8, 2008)
http://phx.corporate-ir.net/phoenix.zhtml?c=86422&p=irol-newsArticle_Print&ID=1141990&highlight

Zenergy Power (May 19, 2008)

Zenergy Power plc has received certification for a core utility patent related to the overall design and operating process of its HTS induction heater. The patent will protect several key design specifications that are critical to the induction heater's performance. Importantly, the patent covers the key performance and cost characteristics responsible for the growing level of commercial interest in HTS solutions among the global metals producers. Michael Fitzgerald, Chairman of Zenergy Power, commented, "This latest addition to our patent portfolio from the German patent office plays a key role in safeguarding our long-term commercial exploitation of the incredible energy efficiencies of HTS technology; for the benefit of both the Group and its shareholders." The present market for Zenergy's induction heaters is estimated to be about €2 billion per annum.

Source:
"Induction Heater Utility Patent"
Zenergy Power press release (May 19, 2008)
http://www.zenergypower.com/images/press_releases/2008-05-19-ih-utility-patent.pdf

American Superconductor Corporation (May 20, 2008)

American Superconductor Corporation (AMSC) has received orders for its D-VAR® solution for providing grid interconnections to wind farms in Australia, Canada, and the United Kingdom. These wind farms will utilize wind power systems from three different turbine manufacturers. The D-VAR systems, which together will provide voltage support for more than 200 MW of aggregate power, will be delivered to the wind farms within the next 12 months. At present, AMSC has an installed base and orders for solutions to serve approximately 7,350 MW of wind power worldwide.

Source:
"AMSC Receives Four D-VAR(R) Orders for Wind Farms on Three Continents"
American Superconductor Corporation press release (May 20, 2008)
http://phx.corporate-ir.net/phoenix.zhtml?c=86422&p=irol-newsArticle_Print&ID=1148108&highlight

Material

SCI Engineered Materials, Inc. (May 5, 2008)

SCI Engineered Materials, Inc. has announced its financial results for its first quarter ending March 31, 2008. Total revenues decreased by 30 % to US $1.7 million, compared with $2.4 million for the same period in the previous fiscal year. Gross profit declined 6 % to $429,000, compared with $458,000 for the same period in the previous year. The gross profit margin increased to 25 % of the total revenues, compared with 18.7 % for the same period in the previous fiscal year. Dan Rooney, Chairman, President and Chief Executive Officer of SCI Engineered Materials, commented, "Further progress is being achieved in our markets, as we implement the Company's growth strategy. We continued to make strategic investments in our business during the first quarter 2008. These included additional investments in equipment and marketing initiatives in the semiconductor and solar industries as well as further development of innovative products... We continue to anticipate that these initiatives will lead to substantial orders in the second half of 2008 as we pursue opportunities that offer substantial long-term growth and profitability for the Company." The company's backlog as of March 31, 2008, was $1.5 million.

Source:
"SCI Engineered Materials, Inc. Reports First Quarter 2008 Results"
SCI Engineered Materials, Inc. press release (May 5, 2008)
http://www.superconductivecomp.com/investors/ne/earnings/scci18.htm

MRI

European Advanced Superconductors (May 15, 2008)

Bruker Corporation has announced that the 2008 Frost & Sullivan Customer Value Leadership Award in the medical superconductor market has been awarded to European Advanced Superconductors (EAS) GmbH & Co. KG, a subsidiary of Bruker Corporation. The award was given in recognition of best practices and outstanding efforts in the delivery of high-end, value-added customer services. David Frigstad, Chairman of Frost & Sullivan, explained, "Existing market participants are competing for a limited pool within this concentrated market. In such market circumstances, the surest way of maintaining sustained market share is through innovative customer enhancement service strategies. EAS has achieved its success through the deployment of customer service strategies, as well as excellence in technology." EAS is a

strong player within the medical and especially the magnetic resonance imaging (MRI) superconductor market.
Source:
"Frost and Sullivan Awards its Customer Value Leadership Award in the Medical Superconductor Market to Bruker Subsidiary European Advanced Superconductors"
Bruker Corporation press release (May 15, 2008)
http://phx.corporate-ir.net/phoenix.zhtml?c=121496&p=irol-newsArticle&ID=1146141&highlight

Communication

Superconductor Technologies Inc. (May 8, 2008)

Superconductor Technologies Inc. (STI) has announced its financial results for its first quarter ending March 29, 2008. Total net revenues for the first quarter were $3.5 million, compared with $4.2 million for the same period in the previous fiscal year. Net commercial product revenues for the first quarter were $2.0 million, compared with $3.5 million for the same period in the previous fiscal year. Government and other contract revenue totaled $1.5 million, compared with $649,000 during the same period in the previous fiscal year. Net loss for the first quarter was $2.3 million, compared with $2.9 million for the same period in the previous fiscal year. Jeff Quiram, STI's president and chief executive officer, commented, "We experienced cautious spending with all of our commercial customers and although first quarter spending was disappointing, the results of the 700 MHz auction in March were encouraging for STI.... We completed our TD-SCDMA lab trial activities in China during the first week of April and are now preparing to begin field trials in May. We continue to believe that a significant commercial opportunity exists in China beginning in 2009." As of March 29, 2008, STI had $11.7 million in cash and cash equivalents and a commercial product backlog of $192,000, compared with $63,000 at the end of the same period in the previous fiscal year.
Source:
"Superconductor Technologies Inc. Reports First Quarter 2008 Results"
Superconductor Technologies Inc. press release (May 8, 2008)
http://phx.corporate-ir.net/phoenix.zhtml?c=70847&p=irol-newsArticle&ID=1142453&highlight

Superconductor Technologies Inc. (May 28, 2008)

Superconductor Technologies Inc. (STI) has announced that U.S.-based institutional investors have agreed to invest US $6 million in cash to purchase two million shares of STI's Common Stock. STI will use the approximately $5.6 million in net proceeds for general working capital purposes. The offer is scheduled to close on or around May 30, 2008.
Source:
"Superconductor Technologies Announces $6.0 Million Registered Direct Offering"
Superconductor Technologies Inc. press release (May 28, 2008)
http://phx.corporate-ir.net/phoenix.zhtml?c=70847&p=irol-newsArticle&ID=1151188&highlight

Accelerator

European Advanced Superconductors (May 20, 2008)

European Advanced Superconductors GmbH & Co. KG (EAS), a subsidiary of Bruker Corporation,

announced a new record critical current for Nb_3Sn superconductors produced using the company's proprietary powder-in-tube (PIT) technology. The PIT conductor achieved a record non-copper current of 2,634 A/mm^2 at a magnetic field of 12 T and a temperature of 4.2 K; this current is approximately 5 % higher than previous records. The PIT conductor is 1.25 in diameter and contains 288 superconducting filaments, each less than 50 µm in diameter. This unique superconductor is being developed for the Next European Dipole (NED) program at CERN. EAS acquired the PIT technology from the Dutch company SMI in December 2006 and has continued to develop very high current Nb_3Sn conductors for a range of applications, including future fusion projects.
Source:
"European Advanced Superconductors, a Division of Bruker's Advanced Supercon Business, Reports Record Current with Powder-In-Tube Superconductor"
European Advanced Superconductors press release (May 20, 2008)
http://www.advancedsupercon.com/news/pr_20080520.html

Basic

Carnegie Institution for Science (May 20, 2008)

Researchers at the Carnegie Institution for Science have reported that high pressures can induce the superconducting state in "high-temperature superconductors". One of the authors of the study, explained, "We wanted to see the effects of high pressure on one bismuth-based high-temperature cuprate ($Bi_{1.98}Sr_{2.06}Y_{0.68}Cu_2O_{8+\delta}$). Pressure has the added bonus that it can be applied gradually, like tuning a radio. We gradually tuned in to the superconductivity and could watch what happened over a broad range of pressures." Using a diamond anvil cell to squeeze the sample and specialized techniques, Raman spectroscopy and X-ray diffraction to measure changes, the subatomic effects of pressures close to 35 GPa were observed. At 21 GPa, changes similar to those seen when a material has been optimally doped were observed. Thus, critical pressure is likely related to doping. The finding that pressure can be used instead of temperature and doping has created an entirely new approach to studying the superconducting properties of high-temperature superconductors. The discovery was published in the May 30, 2008, issue of *Physical Review Letters* (First author is Tanja Cuk.).
Source:
"Superconductors get a boost from pressure"
Carnegie Institution for Science press release (May 20, 2008)
http://www.ciw.edu/news/superconductors_get_boost_pressure

Florida State University (May 28, 2008)

Researchers at the National High Magnetic Field Laboratory (NHMFL) at Florida State University, in collaboration with Oak Ridge National Laboratory (ORNL), have discovered surprising magnetic properties in the new superconductors that were recently reported in *Nature*. The superconductors, known as "doped rare earth iron oxyarsenides" appear to develop superconductivity according to a novel mechanism and have potentially powerful applications in improved MRI machines and research magnets as well as superconducting electric motors, generators and power transmission lines. David Larbalestier, Director of NHMFL's Applied Superconductivity Center, commented, "What one would like is a greater selection of superconductors, operating at higher temperatures, being cheaper, possibly being more capable of being made into round wires. Iron and arsenic, both inherently cheap materials, are key constituents of this totally new class of superconductors. We're just fascinated. It's superconductivity in places you never thought of."

Using NHMFL's Hybrid magnet, the researchers tested a sample of iron oxyarsenide obtained from ORNL and found that the material continued to exhibit superconductivity even in the presence of a 45 T magnetic field—far past the point at which other superconductors become normal conductors. A high tolerance to magnetic field is a key property that researchers hope to find in superconductors. If iron oxyarsenide materials can also be shown to support high current densities, they could be tremendously useful.

Source:
"Powerful superconductor is in a class all its own"
Florida State University press release (May 28, 2008)
http://www.magnet.fsu.edu/mediacenter/news/pressreleases/2008/2008may28.html

National Institute of Standards and Technology (May 28, 2008)

Researchers at the National Institute of Standards and Technology (NIST) have revealed that the new iron-based superconductors recently reported in *Nature* share similar unusual magnetic properties with previously known superconducting copper-oxide materials. Using the NIST Center for Neutron Research (NCNR), a facility that uses intense beams of neutrons to probe the atomic and magnetic structures of materials, researchers revealed that an iron-based sample (provided by materials scientists in Beijing) contained a form of magnetism similar to that found in copper-oxide superconductors: layers of magnetic moments interspersed with layers of nonmagnetic material. The layered atomic structure of the iron-based superconductors suggests that this similarity with copper-oxide materials is not accidental. The group's research appeared in the May 28 Advanced Online Publication of *Nature*.

Source:
"New iron-based and copper-oxide high-temperature superconductors"
National Institute of Standards and Technology press release (May 28, 2008)
http://www.nist.gov/public_affairs/releases/iron_oxide.html

University of Tennessee at Knoxville (May 28, 2008)

Researchers at the University of Tennessee at Knoxville, in collaboration with Oak Ridge National Laboratory (ORNL) and the National Institute of Standards and Technology (NIST), have reported major new findings regarding the new iron-based superconductors that were recently discovered. Utilizing a sample from researchers in China and facilities at NIST and ORNL, the researchers found that when the new iron-based superconductors are doped to become superconducting, they lose their static magnetism—similar to the phenomenon seen in cuprate superconductors. This finding suggests a broader significance to the tie between magnetism and superconductivity. The group's work has been published in the online edition of *Nature*.

Source:
"Getting warmer: UT Knoxville researchers uncover information on new superconductors"
University of Tennessee at Knoxville press release (May 28, 2008)
http://www.utk.edu/news/article.php?id=4635

(Published in a Japanese version in the July 2008 issue of *Superconductivity Web 21*)

(Akihiko Tsutai, Director, International Affairs Department, ISTEC)

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Feature Article: Advancement in Superconducting Industrial Equipment Technology

- Trends in Technology of Superconducting Industrial Equipment and Transport Machinery -

Hiroyuki Ohsaki, Professor
Department of Advanced Energy
Graduate School of Frontier Sciences, The University of Tokyo

The Central Japan Railway Company announced on December 25, 2007 that the company would bear the cost for the construction project of the Linear Chuo Express, which will connect the Tokyo metropolitan and Nagoya areas, toward the launch of commercial operations in 2025. The project has a strong impact and is attracting a high level of interest as a one of the future high-speed key railroad plan beyond the superconductivity application system. Before this announcement, the company had announced in September 2006 that it would replace the facilities of the Yamanashi Experimental Line, extending the line to 42.8 km. In April 2007, the company then set the target year for commercial operations of the express at 2025. The total construction cost of this railroad line is estimated at 5.1 trillion yen. The company aims to open the line in 2025, but this schedule is somewhat tight given the long-term Shinkansen construction plan. The company has already begun the study of the system, as well as a review of the route in full consideration of economic efficiency and a geological survey by drilling. Superconducting magnets using Nb-Ti wires have shown a good track record on the Yamanashi Test Line so they can be used for the actual line without any problems. Meanwhile, expectations are placed on high temperature superconducting technology. A shakedown with high temperature superconducting magnets using Bi2223 wires mounted on board was carried out on the Yamanashi Test Line in 2005. A conceptual design and a trial manufacture of model coils have been being carried out at the Railway Technical Research Institute to study the applicability of yttrium-based wires. Introducing high temperature superconducting technology should enhance the stability, reliability, and economics of the entire system.

I would like to discuss high-gradient magnetic separation concerning the practical use of superconducting technology in the field of industrial and transport machinery. The research and development of superconducting magnetic separation has been carried out for a long time. A business-academia collaboration team headed by Professor Shigehiro Nishijima of Osaka University has researched and developed a wastewater treatment system with a capacity of 500 to 2000 tons per day. MS-Engineering Ltd., which is using the research and development results, has delivered a superconducting magnetic separator to a papermaking company and the separator is in practical use. Given the growing environmental awareness in Japan, the need for wastewater treatment has been increasing. Since various groups have been researching and developing superconducting magnetic separation, the introduction of practical systems will probably further spread through the world market.

Recently, the research and development of superconducting rotating machines has been being promoted in Japan. The market is potentially large. The development of motors for electric propulsion ships, stimulated by development in the U.S.A. and Germany, is under way in collaboration with industries and universities. The industry-university group led by IHI Corporation has developed a 365-kW superconducting motor for a ship and has reported the test results. The group is planning to develop a megawatt class motor by upsizing a current 400-kW class motor for an inland vessel, which is being looked forward to. Also, Sumitomo Electric Industries carried out a demonstration shakedown of a high temperature superconducting vehicle with an onboard superconducting motor using Bi2223 wires. Application potentialities of superconducting technology to the transport sector started being investigated immediately after the discovery of a high temperature superconductor, and the car motor has been counted as a field of application. Although there are many challenges for the practical use of superconducting technology, the demonstration shakedown indicates that wire, equipment, and cooling technology have advanced greatly. Increases in the range of uses for larger industrial motors from the application of such motors to the transport sector will greatly impact the industry. Putting superconducting motors in practical use will be a challenge because conventional motors are tough competitor. Developing more practical technologies in conjunction with the development of generators such as wind power generators will be necessary.

Material process is a noteworthy field as an application of superconducting technology. Typically, the process uses a direct electromagnetic action or drive based on a strong applied magnetic field. This includes a magnetic field applied to silicon single crystal growth. Various possibilities are considered to develop high-quality, high-performance materials. Engineers are working on the research and development of non-contact spin processors using superconducting magnetic levitation and magnetic bearing technologies. They are trying to manufacture high-quality products by achieving clean space with very few impurities.

The application of superconducting technology has many possibilities in the industrial and transport sectors. The application may be widened if the requirements are satisfied. If high temperature superconducting wires become higher in performance and lower in cost, cryocooler and cooling technology advances, and superconducting coiling technology is enhanced, the research and development to put superconducting technology to practical use is desirable to be further promoted as a cutting edge technology to achieve high magnetic fields, large electromagnetic force, and high performance.

(Published in a Japanese version in the March 2008 issue of *Superconductivity Web 21*)

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Feature Article: Advance in Superconducting Industrial Equipment Technology
- Prospects for Technology of High Temperature Superconducting Induction/Synchronous Machine -

Taketsune Nakamura, Associate Professor
Department of Electrical Engineering
Graduate School of Engineering, Kyoto University

The author's laboratory conducts theoretical and basic experimental research on HTS-ISM (High T_c Superconducting Induction/Synchronous Machine) with a high temperature superconducting squirrel cage rotor applied.[1,2] With the cooperation of ISTEC-SRL and company research centers, basic data are being collected and analysis methods that are worth designing are being established.[3-5] Although simple in structure, the HTS-ISM is a very interesting research subject for both applied research and pure science because the sole alternative is to infer its machine characteristics from primary side information alone. Manufacturing know-how is now being accumulated. The author's laboratory goal is actual application under joint researchers' guidance.

We have so far clarified the mechanism of exhibiting the rotational characteristics of an HTS-ISM from the relationship between the current-transport characteristics of an HTS rotor bar and leakage reactance.[2] We studied an HTS-ISM with yttrium-based wires applied jointly with ISTEC-SRL, as part of NEDO's project, Research and Development on Basic Technologies Required for Superconductivity Applications, to clarify the relationship between the steepness of electric field-electric current density characteristics and torque characteristics.[3] In addition, we studied an HTS-ISM with DI-BSCCO® wires applied jointly with Sumitomo Electric Industries and verified the relationship between the critical current value of the rotor bar and maximum synchronous torque.[4] We also studied the application of an HTS-ISM to a generator jointly with Chubu Electric Power Co., Inc.[5] and jointly studied an MgB_2 HTS-ISM with Kyushu University for a liquid hydrogen-circulating pump.[6] For the application of an HTS-ISM to a generator, we are planning to make the generator fully superconductive specialized in low-speed synchronous rotation mode from the examination of cooling and equipment properties. We are going to conduct a verification test soon. Furthermore, we are developing variable-speed control technology with superconducting non-linear current transport characteristics applied.

In this report, we have reviewed the current research and development of the HTS-ISM. We are trying to enhance the efficiency of the HTS-ISM and increase its power density based on existing rotary machines, considering the optimum introduction of high temperature superconducting technology into the HTS-ISM based on simple machine structure and controllability. We expect that competition with conventional machines will facilitate the application of the HTS-ISM to the industry. The development of the rotary machine has a long history of approximately 180 years. As technologies have been established, there are major obstacles to introducing new technologies. Innovations appear to always be required to make the rotary machine more sophisticated because the rotary machine has a long history. In this light, the recent development of high temperature superconducting materials has made remarkable progress. The optimum introduction of superconducting technology paying attention to the interface with existing technologies will bring about a technological revolution. To achieve this technological revolution, confirming the advantage of superconducting technology in the application of middle-capacity rotary machines that come to many users' notice, as well as in the application of large machines, is necessary. The author's group has targeted middle-capacity rotary machines and is working to develop the world's first technology in this area. We are devoting ourselves to achieving our goal so that we can soon report new developments.

Picture of the external view of the HTS-ISM test system developed by the author's laboratory

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(Published in a Japanese version in the March 2008 issue of *Superconductivity Web 21*)

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Feature Article: Advancement in Superconducting Industrial Equipment Technology

- Advancement in Non-contact Spin Processing Technology—Reducing Dust through the Application of Superconducting Magnetic Levitation -

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Faculty of Information Science and Engineering
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Shinsuke Miyazaki
MTC Co., Ltd.

1. Introduction

As shown in the International Technology Roadmap for Semiconductor (ITRS), the miniaturization of semiconductor devices has been significantly progressing. Recently, the research and development for 32-nm architecture construction has been increasing. In order to handle this miniaturization of semiconductor devices, higher accuracy is required for the fabrication of semiconductor devices and tighter pattern tolerance for the photo masks used in the photolithography process in which circuit patterns are transcribed onto wafers. Various types of spin processors are used in the fabricating process of these photo masks and semiconductor device products. Particulate dust is discharged from the rotating bearings of spin processors, decreasing the cleanliness around objects to be processed such as photo masks. As a result, particulate dust enters the space between patterns and remains there, becoming one of the main causes of low-quality final products and decreasing product yield. This problem needs to be solved and demands the development of a non-contact spin processor that can completely isolate the turntable of the spin processor in the clean bench.

Focusing on magnetic levitation using high temperature superconductor bulk, MTC Co., Ltd. and Niigata University have been conducting joint R&D to apply magnetic levitation to a spin processor, to solve the above problem.[1)] We conducted an element test with a goal of operation at 30 K in direct cooling by a refrigerator that is in the process of production. In this report, we present the test results with the element testing equipment and measures to improve the levitation height.

2. Test results with the element testing equipment

Table 1. Required specifications of non-contact spin processor and test results with element testing equipment

	Actual machine specifications	Element testing equipment
Number of revolutions	2000 rpm	2500 rpm
Acceleration/deceleration range	200-500 rpm/s	50 rpm/s
Turntable diameter	400 mm or more	210 mm
Levitation height	10 mm or more	5 mm
Additional load	1-2 kg	None
Allowable vibration	+/-0.2 mm or less on the circumference	—
Operating temperature	No restriction	30 K

The required specifications for non-contact spin processors for semiconductor fabricating process are summarized in Table 1 and the conceptual diagram of suggested equipment is shown in Fig. 1. The required specifications shown in Table 1 conform to those of a spin processor used to clean photo masks and wafers. It is a low-rotation type spin processor used for semiconductor fabricating process. This type of spin processor is the first target for this research.

Fig. 2 shows the schematic diagram and external view of the element testing equipment fabricated on an experimental basis. First, we placed a copper cooling plate in a hollow concentric cylindrical stainless chamber and embedded eight HTS bulks (Gd-based, 30 mm in diameter x 10 mm thick) in the cooling plate. We connected a single-stage GM refrigerator to one end of the cooling plate and cooled it down to approximately 30 K. We embedded a ring-type neodymium permanent magnet 200 mm in diameter in an aluminum turntable 210 mm in diameter and configured a magnetic levitation system opposite to the HTS bulk. We fixed a DC servomotor to the cryostat stand. We coupled one rotating flange to the DC servomotors. We provided the center of the turntable and the rotating flanges with 12 neodymium permanent magnets 10 mm in diameter each and transmit rotation by magnetic coupling. A test using this equipment revealed that stable levitation and steady rotation were achieved at a levitation height of 5 mm and a rotation speed of 2500 rpm.

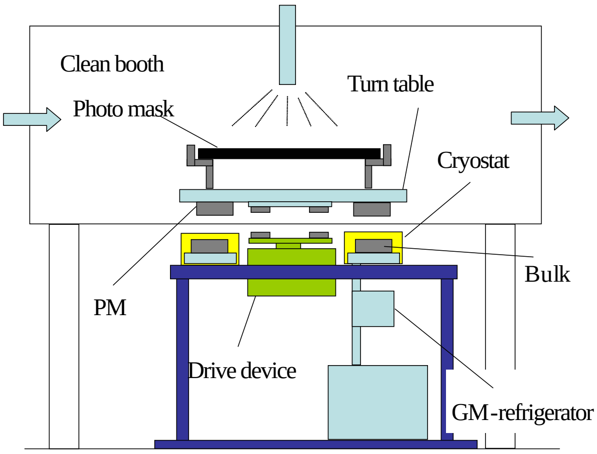

Fig. 1 Conceptual diagram of non-contact spin processor with superconducting magnetic levitation applied

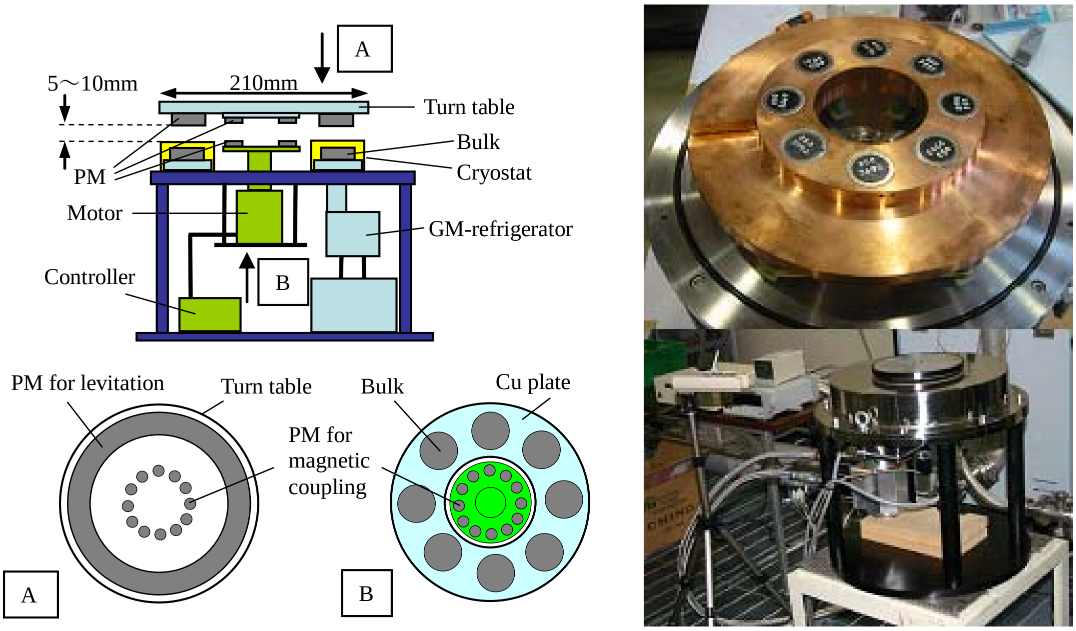

Fig.2 Element testing equipment

Although stable levitation and steady rotation were achieved with element testing equipment, neither levitation height nor acceleration/deceleration have satisfied the required specifications. Since acceleration/deceleration greatly depends on the turntable mass, we cannot design the spin processor unless the weight of the permanent magnet for magnetic levitation is determined. We decided to make improvements to increase the levitation height, fabricating the magnetic circuit shown in Fig. 3 to do so. We replaced the turntable of the element testing equipment shown in Fig. 2 with the magnetic circuit and conducted a levitation test, which revealed a levitation height of 14 mm.

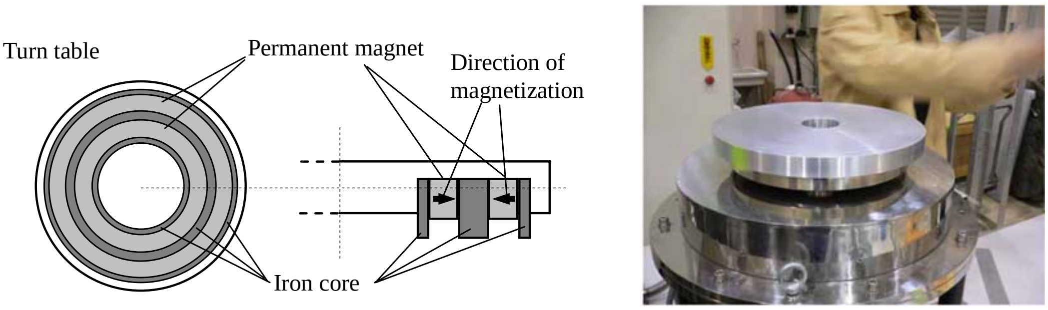

Fig.3 Permanent magnet for levitation aiming to improve the levitation height

3. Summary

The superconducting magnetic levitated non-contact spin equipment proposed in this research is highly likely to provide breakthrough technology for reducing dust in semiconductor fabricating equipment. We are planning to fabricate the verification testing equipment with a turntable 400 mm in diameter, at an additional load of 1 or 2 kg, a rotation speed of 3000 rpm, a levitation height of 10 mm (at normal temperature), and an operation temperature of 20 to 30 K required for a low-rotation practical spin processor. We are going to evaluate the field-trapping characteristics of a high temperature superconductor, the loss characteristics of a high temperature superconductor in a ripple magnetic field, the levitation/rotation stability, and the starting/braking control characteristics, using the verification equipment. We are also going to study lightening the turntable and structural design to reduce the moment of inertia.

This research is designated as a subject for fiscal 2007, Original Seeds Development Business, a commissioned development project by the Japan Science and Technology Agency (JST).

(Published in a Japanese version in the March 2008 issue of *Superconductivity Web 21*)

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Summer, 2008 Date of Issue: July 15, 2008

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Feature Article: Advancement in Superconducting Industrial Equipment Technology

- Study on the Application of High Temperature Superconducting Material to the Railway Field -

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Railway Technical Research Institute

With respect to the application of high temperature superconducting material to the railway field, the Railway Technical Research Institute (RTRI) is carrying out a research to apply the superconducting technology nurtured through the development of the maglev train to the conventional railway. Some examples under development will be introduced below.

The development of a superconducting traction transformer for rolling stock aims at reducing the weight of onboard transformers. Assuming its application to Shinkansen trains, RTRI has already fabricated a 4-MVA class prototype, using bismuth-based high temperature superconducting wires. (http://www.jstage.jst.go.jp/article/rtriqr/47/1/24/_pdf, http://www.rtri.or.jp/rd/openpublic/rd42/02/hennatuki.htm)

The development of a large-capacity, high-efficiency pulse tube cryocooler essential to a superconducting transformer is now under way, concurrently with the technological development to reduce the AC loss of coils. (http://www.rtri.or.jp/rd/openpublic/rd77/CS/cs_1.5.html)

RTRI is also developing a superconducting flywheel power storage system effective for the absorption of regenerative power of the railway and usable as the measure for peak cut and others. Although small in size, a superconducting magnetic bearing consisting of a high temperature bulk superconductor and a superconducting coil has an advantage of being able to support heavy weights stably. RTRI is now verifying its effect through load and rotation tests. (http://www.jstage.jst.go.jp/article/rtriqr/49/2/127/_pdf, http://www.rtri.or.jp/rd/openpublic/rd77/CS/cs_1.6.html)

In addition, non-destructive rail diagnosis using a high temperature superconducting SQUID is an application example of a superconducting device. The purpose of this research is to detect a white etching layer on the surface of a rail, which is a sign of rail destruction, with a SQUID.
(http://www.rtri.or.jp/rd/openpublic/rd77/CS/cs_1.7.html)

As for the development of the maglev train, RTRI believes that a small, light, and highly reliable superconducting magnet can be obtained by applying next-generation wires. RTRI has just begun a basic research with a subsidy granted by the Ministry of Land, Infrastructure and Transport. For example, if the cooling temperature of coils can be increased to about 50 K, the following advantages can be obtained:

- Since the heat capacity increases, the coil stability dramatically improves.
- The onboard cryocooler can be simplified, resulting in a reduction in weight and power consumption.
- Since the thermal insulation structure can be simplified, a reduction in the weight of the magnet itself and fabrication costs is expected.

As the results, we expect that a simplified magnetic structure and improved reliability can be achieved by applying next-generation wires. (http://www.rtri.or.jp/rd/openpublic/rd77/CS/cs_1.4.html)

(Published in a Japanese version in the March 2008 issue of *Superconductivity Web 21*)

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Summer, 2008 Date of Issue: July 15, 2008

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Feature Article: Advancement in Superconducting Industrial Equipment Technology

- Advancement in High Gradient Magnetic Separation System Technology -

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National Institute of Advanced Industrial Science and Technology

Hiroshi Ueda
Waseda University

Kazuhiro Kajikawa
Kyushu University

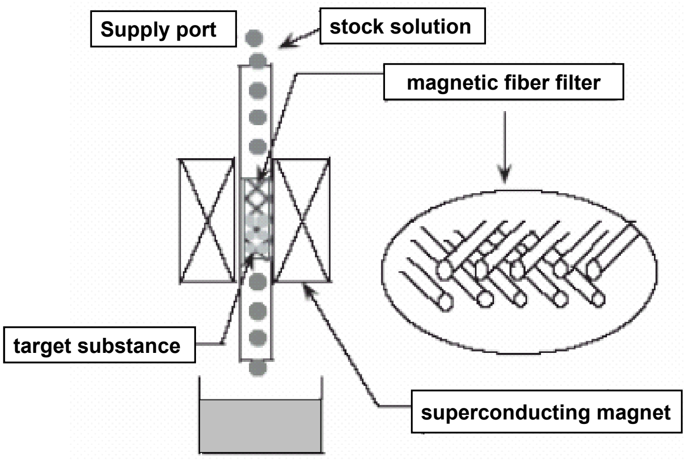
Recently, cellular and molecular separation (screening and sorting) technology using micro/nano-beads in the biochemical and drug discovery fields has greatly progressed in Japan, Europe, and the United States. In the medical field, a technology to enable separating cellular and molecular proteins using affinity magnetic micro-beads is being established. Marketing of analyzers with two to four types of robotized screening system has already begun in the United States. These bead technologies enable the separation and purification of target cells and molecules from solution by attaching an affinity substance that combines specifically with target protein to the surface of the beads. A surface-active agent that combines specifically with various types of proteins on the surface of iron oxide has been developed and marketed in the United States. The surface-active agent is available in Japan, too.

It is important for separation and screening technology using affinity beads to improve reaction efficiency. An increase in the reaction surface area leads to improving separation efficiency and reducing work hours. To achieve this, size reduction is a challenge. If the bead size can be reduced to one tenth, the number of beads increases by 10^3 and the total surface area of beads increases by 10 if they have the same mass. The probability of combining with a target substance contained in minute amounts can be increased exponentially and the trapping time reduced dramatically by about 1/10 according to increasing of the total surface area of them.

The affinity beads under development are roughly divided into magnetic and non-magnetic beads. The non-magnetic beads, which are divided into organic such as polymer beads and inorganic such as porous silica beads, can be reduced in size relatively easily. These nano-size affinity non-magnetic beads have already been developed. These non-magnetic beads require separation and purification by affinity chromatography with the target in diluted solution and placed in a column. They are appropriate for batch treatment for inspection and analysis, but not for enrichment or high-speed, large-quantity, continuous separation or purification necessary for industrial application. Magnetic beads, which are separated and purified by magnetic force, are easy to enrich and suitable for high-speed, large-quantity, continuous separation and purification. Therefore, the development of separation and purification technologies by magnetic nano-beads is expected for industrial use. However, the separation and detection system by high-gradient magnetic separation using permanent magnets under development has limited magnetic force. In order to increase magnetic force to attract magnetic beads against viscosity resistance in a solution and recover them, it is necessary to compensate for a specific quantity of magnetism with volume. For this reason, nano-sized magnetic beads are not in use. The minimum size limit is about 1.0 to 1.5 microns in diameter.

In addition to the application to magnetic separation, Resovist (SPIO: Super Paramagnetic Iron Oxide) of magnetic beads several tens of nanometers in diameter is used for clinical use as a contrast medium for MRI. Magnetic beads are an essential tool for the development of medical care and medical engineering.

We have especially studied the application of a high-gradient magnetic separation system using superconducting magnets for the high-speed, continual separation and purification of antibodies (immunoglobulin) that are present in minute amounts in serum, among other proteins for medical use. Immunoglobulin is a polypeptide containing 2 % sugar and is a 10- to 15-nm Y-shaped molecule. It has a region at the end of the L-chain (light chain) of the Y end that combines specifically with an antibody. By attaching an affinity substance that combines specifically with this region of the globulin to the surface of magnetic nano-particles, it is possible to combine specifically the antibody with the surface of magnetic nano-particles. These affinity magnetic nano-particles can be trapped through magnetic separation technology. As a result, the continual high-speed separation and purification of the antibody can be made. We proved through a basic experiment that it is possible to separate and purify proteins for medical use by employing magnetic nano-beads with a high-gradient magnetic separation system using superconducting magnets. We generated a maximum 5 Tesla magnetic field with a small desktop conduction cooled superconducting magnet using a small cryocooler. We provided the center of an electromagnet with a room-temperature cylindrical space approximately 26 mm in diameter, passed a glass tube with an inner diameter of 20 mm and an outer diameter of 24 mm through this space, and inserted a filter consisting of thin-fiber stainless wool about several microns in diameter (8, 10, and 20 μm in diameter) in this tube. We generated a high-gradient magnetic field around this filter (stainless fiber) and succeeded in trapping and separating magnetic nano-beads of 80 nm in diameter with this high-gradient magnetic force. We presented the results in The 2007 Fall Meeting on Cryogenic and Superconductivity.[1) 2)]



Schematic diagram of HGMS for Immunogloblin

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(Published in a Japanese version in the March 2008 issue of *Superconductivity Web 21*)

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Feature Article: Advancement in Superconducting Material Technology - Reducing the AC Coil Loss by Using Scribing Y-based Wires -

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Research Laboratory, Kyushu Electric Power Co., Inc.

The application of superconducting wires to a transformer helps to reduce the cross section of the coil and iron core because of its high-current density and low-loss characteristics, resulting in considerable reduction in size and weight. Coolant is not combustible because liquid nitrogen is used. Superconducting power transformers will find wide application because of these features. They will be used to address an increase in the number of transformers owing to increasing demand for power as they enable downsizing with high efficiency. When new substations are built, superconducting transformers enable increasing substation capacity while substations are downsized. Superconducting transformers can coexist with superconducting cables, enabling an increase in the capacity of substations, fault current limiting functions, and more. Superconducting transformers will be put to practical use as soon as possible in substations and buildings in midtown areas. For this reason, The group including Kyushu Electric Power Co., Inc. and Kyushu University have proceeded with the development of superconducting power transformer (Bi-based wire).Since recent Y-based wires have a large critical current in a high magnetic field, it is possible to decrease AC loss and reduce costs in the future by making wires thinner. Kyushu Electric Power Co., Inc. has also worked together with the abovementioned group on developing element technologies such as low-loss and large-current technologies in a national project since fiscal 2006.

To verify low AC loss technology, which is a key technology for coils for superconducting power transformers using Y-based wires, we divided superconducting layers of 5-mm wide Y-based wires into five 1-mm wide filaments and fabricated a model coil shown in Fig. 1, using filament wires insulated with polyimide tape. We also fabricated a model coil with 5-mm wide non-divided Y-based wires to compare the AC loss reduction. The specifications of the non-divided Y-based wire and 70-m long model coil are shown in Table 1. Figure 2 compares the current-carrying loss characteristic of the 70-m long model coil with non-divided and 5-filament Y-based wires. We measured AC loss with an electric method (4-probe method) and our proprietary thermal method (boil-off method). The results obtained by both measurement methods are almost identical. The measurement verified that the division into 5 filaments reduces the current-carrying loss to approximately one

Fig. 1 Model coil of Y-based wires (5-filament 70-m long wire)

Table 1 Specifications of the non-divided Y-based wire and model coil

YBCO tape type	IBAD/PLD
Tape width	5 mm
Tape thickness	0.12 mm
Critical current at 77K and self field	~65 A
Inner diameter of coil	100 mm
Height of coil	57 mm
Number of coil turns	10
Number of coil layers	19

fifth. The result was the same as that of the manufacturer's measurements.

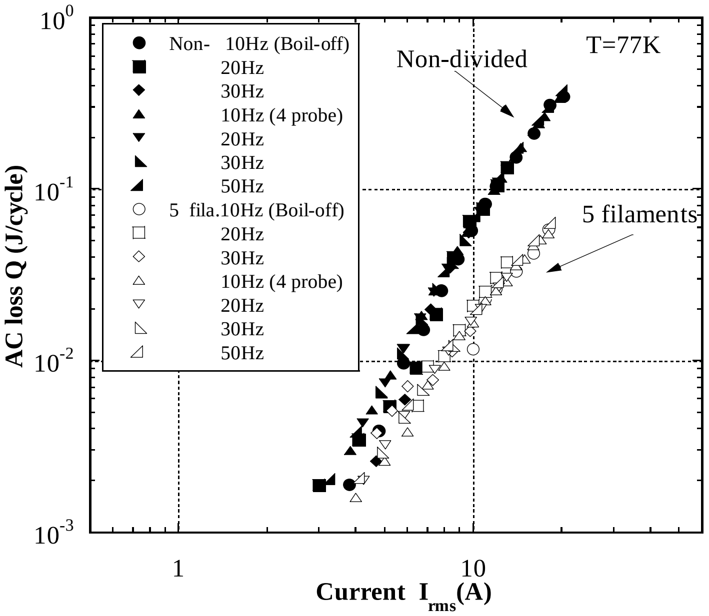

Fig. 2 Measurements of the AC loss of the model coil (Comparison between the 5-filament model coil and the non-divided model coil)

We have successfully established the important basic technology of superconducting power transformers from these results and made a good start to practically use superconducting power transformers. We will continue to develop current homogenization technology and transposition technology with the multilayer parallel conductor of Y-based wires. These technologies are element technologies for transformers to increase transformer current.

The results were achieved by Kyushu Electric Power Co., Inc. in cooperation with the International Superconductivity Technology Center, Fujikura Ltd., Fuji Electric Systems Co., Ltd., and Kyushu University in the project on R&D of Fundamental Superconducting Application Technologies, which was commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

(Published in a Japanese version in the April 2008 issue of *Superconductivity Web 21*)

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Feature Article: Advancement in Superconducting Material Technology - Current Status of the High-Magnetic Field Characteristic Technology of REBCO Wire -

Kaname Matsumoto, Professor
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Development work aimed at dramatically increasing J_c of a high temperature superconducting thin film in a high magnetic field near 77 K by introducing a crystal defect in a YBCO high temperature superconductor and by strongly pinning fluxoid with nanostructure control is proceeding. Crystal defects thus introduced are called artificial pinning centers (APCs). The distribution and density of crystal defects are theoretically designed in the APC method so that maximum J_c is obtained, enabling the introduction of APCs in thin films. Crystal defects that can be used as APCs are classified into several categories according to dimensionality: 1-dimensional APCs (linear defects) such as dislocations and columnar defects, 2-dimensional APCs (planer defects) such as dislocation arrays of small angle grain boundaries and large precipitate surfaces, and 3-dimensional APCs (particle-like defects) such as fine precipitates on a scale equivalent to or greater than coherence length and heterophase precipitates.

The authors proved the principle by the PLD method and the substrate surface modification method using Y_2O_3 nanoislands. The latter is a method of introducing 1-dimensional APCs such as dislocations in YBCO thin films at high densities with the Y_2O_3 nanoislands on the substrate being a start point. It was confirmed that as the density of a nanoisland increases, J_c in a 77-K magnetic field (B//c) improves several-fold or more. Around the same time, an American group introduced fine particles in YBCO thin films with the switching target and mixed target methods. J_c that is several times greater than that from using the pure YBCO thin film was obtained with both methods.

Subsequent to these research efforts in the germinal stage, many research projects on APCs have begun. A $BaZrO_3$ mixed target is frequently used to introduce a large number of nanorods 5 to 10 nm in diameter in YBCO thin films. Nanorods are parallel to the c axis and act as 1-dimensional pins. J_c has reached 0.7 MA/cm^2 (77K, 1T, B//c) and 0.1 MA/cm^2 (77K, 5T, B//c) with $BaZrO_3$ nanorods. The nanorod formation mechanism, which has not yet been clarified completely, is of great interest in terms of material science.

Although 2-dimensional APCs of crystal grain boundaries consisting of anti-phase boundaries (APB) and small angle boundaries are available, there are actually few application examples. Meanwhile, 3-dimensional APCs have a few patterns. One is to simultaneously deposit both YBCO and a substance that does not form nanorods such as Y_2O_3, using PLD to introduce nanoparticles in YBCO thin films. Nanoparticles 10 to 20 nm in diameter can be introduced in the films at high densities as APCs by this method. The PLD target method with the composition displaced is also available. It has been reported that a concentration fluctuation is formed in the films with Sm substituted for Ba, by forming an Sm rich film with an $Sm_{1+x}Ba_{2-x}Cu_3O_{6+\delta}$ target, and APCs with a strong low-T_c portion are obtained. The YBCO thin film has an irreversible magnetic field of 10 T or more at a temperature of 77 K by using APCs. Recently, values exceeding J_c of a practical Nb-Ti wire works at 4.2 K have been reported. It can be expected that wires with performance as high as that of Nb-Ti wire can be achieved at 77 K by introducing APCs in REBCO wires using YBCO or GdBCO.

(Published in a Japanese version in the April 2008 issue of *Superconductivity Web 21*)

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Summer, 2008 Date of Issue: July 15, 2008

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Feature Article: Advancement in Superconducting Material Technology
- Technology for High Magnetic Field Characteristic of Bi-2223 Tape Wire -

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Kobe Steel Ltd.

Seyong Choi, Tsukasa Kiyoshi
National Institute of Materials Science

The critical current at a practical level is expected to be maintained, even in a magnetic field of 23.5 T (corresponding to a resonant frequency of 1 GHz of a hydrogen nucleus) or more, by cooling down Bi-2223 tape wire fabricated by the Controlled Over Pressure (CT-OP) method to a temperature of 4.2 K or less. A project to develop a Nuclear Magnetic Resonance (NMR) magnet of a resonance frequency of beyond 1 GHz by using this wire is under way at the System Development Program for Advanced Measurement and Analysis of the Japan Science and Technology Agency (JST).

We applied external magnetic fields up to 30 T, using a hybrid magnet developed by the National Institute of Materials Science, and measured the critical current of a 4.2-mm wide, 0.22-mm thick, and 30-mm long short sample at 4.2 K. In the preliminary measurement, the sample was damaged irreversibly owing to electromagnetic force caused by current carrying in a high magnetic field, resulting in deteriorated characteristics. We soldered the tape wire and a copper plate into one piece, using this sample to measure its characteristic in a state where the sample is not damaged irreversibly. In these measurements, after measuring I_c of each sample $B\parallel$ and $B\perp$ in a specific magnetic field, we moved them to another magnetic field and then measured I_c in reverse sample order to the measurement in the previous magnetic field. We used 100 μV/m as a electric field criterion.

We changed the external magnetic field from 0 T to 30 T to 0 T to measure I_c. The results in a magnetic field of 10 T or more are shown in Fig. 1. In an external magnetic field of 30 T, when the external magnetic field is parallel and perpendicular to the tape face, critical currents I_c were 293 A and 226 A, respectively. When these critical currents were divided by the cross section of the Bi-2223 tape wire, critical current densities J_e's of 317 A/mm^2 and 245 A/mm^2 were obtained. The goal of 200 A/mm^2 or more was achieved.

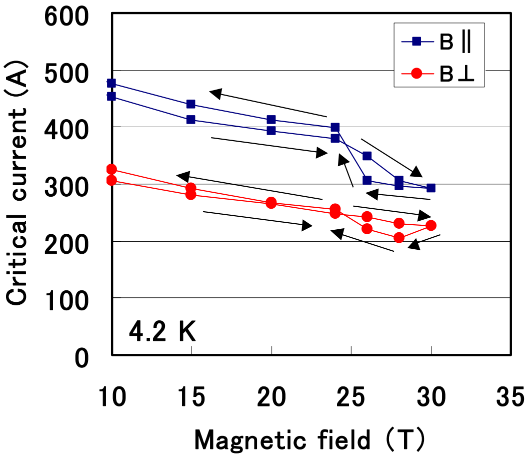

Fig.1 External magnetic field dependence of the critical current of the Bi-2223 tape wire

A hysteresis where the critical currents at the discharging process are lower than that at the charging process is seen in a magnetic fields higher than 24 T as shown in Fig. 1, and the magnitude relation is reversed in a magnetic field of 24 T or lower. To confirm the repeatability of this hysteresis, we obtained a 30-mm long Bi-2223 tape wire with the same cross section from another lot. We set it in the holder in the same manner as the sample in Fig. 1 to measure the critical current, repeating increase and decrease in a magnetic field ranging from between 24 T to 30 T. The results are shown in Fig. 2. Firstly, we measured it while the magnetic field was decreased down from 30 T to 25 T. Secondly, we measured it while changing the magnetic field from 25 T to 30 T to 25 T. Thirdly, we measured it while changing the magnetic field again from 25 T to 30 T to 24 T. The first, second, and third values in Fig. 2 indicate these experimental results. Fig. 2 shows that a hysteresis loop where I_c at discharging is lower than that at charging reproducibly appears in a high-magnetic field of 25.6 T or more, as likely seen in Fig. 1. In the third run, unlike in the first and second, we measured I_c several times at intervals of 0.2 T from 26 T. These values of I_c are different from those in the first and second runs, suggesting that this hysteresis loop depends on the history of changes in the external magnetic field. The Bi-2223 tape wire may exhibit this hysteresis because an Ag sheath composing the tape wire yields to greatly stress the Bi-2223 core, but this has not yet been confirmed at the present stage.

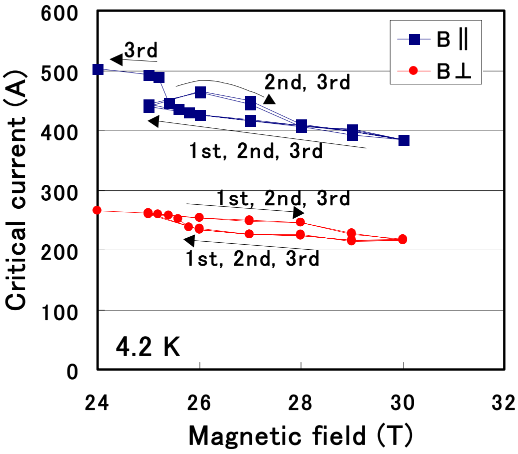

Fig. 2 Hysteresis in the I_c-B characteristic of the Bi-2223 tape wire

We integrated the tape wire and reinforcement copper plate into one piece to obtain a sample. We evaluated the characteristics of this sample, instead of that of Bi-2223 tape wire itself. However, the evaluation shows that the Bi-2223 tape wire fabricated by the CT-OP method has high potential in high magnetic fields at 4.2 K. It will be possible to develop a conductor that can withstand electromagnetic force in a high magnetic field alone and has J_e higher than 200 A/mm^2, by using reinforcing materials such as stainless steel tape and brass tape stronger than copper and improving the critical current density of the Bi-2223 tape wire. For a hysteresis loop observed in a magnetic field of 26 T or more, the evaluation of the I_c-B characteristic of the above-mentioned reinforcing conductor may help clarify its mechanism.

This research was commissioned by the Japan Science and Technology Agency (JST) as part of the System Development Program for Advanced Measurement and Analysis, Development beyond 1 GHz-NMR.

(Published in a Japanese version in the April 2008 issue of *Superconductivity Web 21*)

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Summer, 2008 Date of Issue: July 15, 2008

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-5703, Fax: +81-3-3536-5714

Feature Article: Advancement in Superconducting Material Technology

- Advancements in Low AC Loss Technology of Bi-2223 Wire -

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The mass-production technology of km-class Bi-2223 wire with good superconducting characteristics at 77 K is close to being realized, but low AC loss technology for the wire is essential for practical use of AC equipment such as cables and transformers. This article presents a current research project in our laboratory (http://www.super.eee.tut.ac.jp) for reducing AC loss.

Downsizing a superconductor by multifilamentary structure is effective to reduce loss (hysteresis loss) generated in a superconductor in an AC magnetic field. However, no loss reduction effect is obtained by only a simple multifilamentary structure because all filaments are electromagnetically coupled each other and behave as a bulk superconductor. We are proceeding with developing a wire with twisted filaments (Fig. 1) to suppress coupling between filaments and obtain the effect of multifilamentarization.$^{1)}$

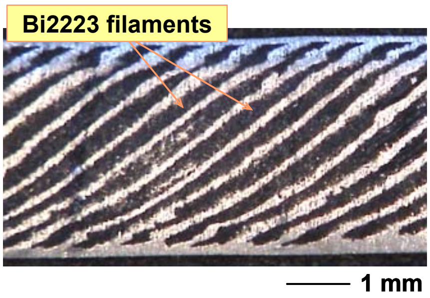

Fig.1 Twisted wire (Wide face of the wire after polishing)

Fig. 2 shows the field amplitude dependence of AC losses under the parallel magnetic fields of 37-filament twisted wires. The twisted filaments help to reduce loss within a magnetic field range of 10 mT or more. The loss values in a sample (T1) having a twist length of 9 mm decreased by up to half of the value of the non-twisted filament sample (NT). A more remarkable effect on loss reduction was obtained in a sample where filaments are prevented from directly contacting each other by increasing their silver content (T2). In either case, however, the value of loss is far greater than where a multifilamentary effect was completely obtained because the pure-silver matrix has low resistivity and coupling current running between filaments is not sufficiently suppressed.

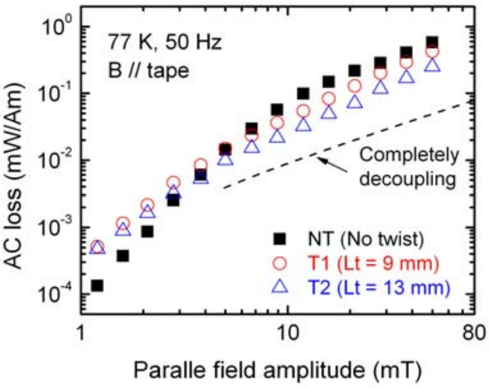

Fig. 2 Reduction in AC loss under parallel transverse field by filament twisting

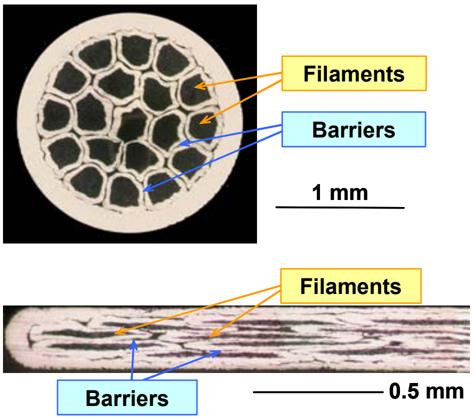

Fig. 3 Barrier wire fabricated by the dip-coated method (Top) after processing thin round wire, (Bottom) fully-reacted sample

In order to increase transverse resistance between filaments and reduce the effect of the coupling current, we inserted a high-resistive barrier layers among the filaments. $^{2)}$ We have been fabricating barrier wires by dip-coating method. In this method, the oxide powders are directly coated on the surface of monocore rod before stacking into multifilamentary structure. The cross sectional view of a barrier wire is shown in Fig. 3. Considering the reactivity with the Bi-2223 filaments, we used Ca_2CuO_3 or $SrZrO_3$ as barrier material and improve their workability by mixing a small amount of Bi2212 powder. A barrier was generally positioned between the filaments. The deterioration of the current transport characteristics (J_c) caused by introducing the barrier has decreased to approximately 10 %. The comparison of AC losses (50 Hz, 50 mT, under parallel magnetic fields) between a non-barrier wire and a barrier wire is shown in Fig. 4. Although the barrier wire has less filaments and longer twists, AC losses have been greatly reduced. Further advancement in research should improve the continuity of the barrier layer, and optimization of the number of filaments (filament size) and twist length should help to further reduce AC losses.

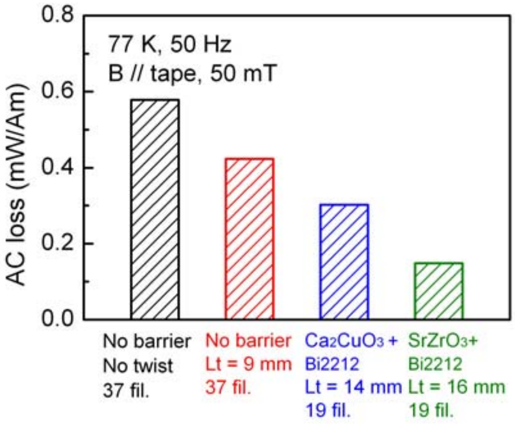

Fig. 4 Comparison of AC loss under parallel transverse field between wires with or without barriers

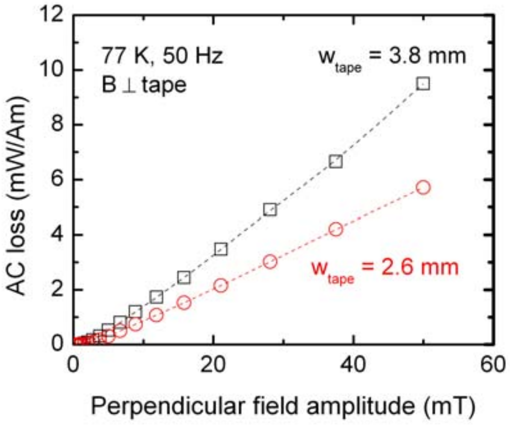

Fig. 5 Reduction of AC loss under perpendicular transverse field by reducing wire width.

Securing the homogeneity of the barrier layer over the entire wire when the wire is lengthened is a major challenge to dip-coating method. We are proceeding with the development of barrier wires by introducing a metal barrier layer such as Cu or Ni that offers excellent ductility, oxidizing the metal layer after molding to obtain a highly resistive layer (in-situ oxidation method).3), 4)

The loss value under AC perpendicular magnetic fields to the wide face of a wire is greater than that under parallel fields by one digit or more because of the shape anisotropy and demagnetizing field effect of the wire. Reducing the loss value is essential in order to apply wires to windings used for transformers. Severer conditions (both shorter twist length and higher transverse resistivity) are required to decoupling the filaments under perpendicular fields than under parallel magnetic fields. In order to reduce AC losses by the shape effect (Fig. 5) and achieve the short twist length of several millimeters, development of slim wire is essential. With the combination of introducing the high-resistive barrier in mind, we are proceeding with our research to improve the AC performance of slim wires.5)

Part of the research project introduced in this article was supported with Grants-in-Aid for Scientific Research (No. 17206026, No. 17760233) and TEPCO Research Foundation's research grant.

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(Published in a Japanese version in the April 2008 issue of *Superconductivity Web 21*)

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Summer, 2008 Date of Issue: July 15, 2008

Superconductivity

Superconductivity Web21

Published by International Superconductivity Technology Center
1-10-13, Shinonome, Koto-ku, Tokyo 135-0062, Japan Tel: +81-3-3536-5703, Fax: +81-3-3536-5714

Feature Article: Advancement in Superconducting Material Technology

- Large Current Capacity Nb_3Sn Conductor Technology for ITER -

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Seven nations and areas, Japan, European Union (EU), Russia, the U.S.A., China, South Korea, and India, ratified the ITER Agreement signed in October 2006, which became effective in October 2007. The ITER International Fusion Energy Organization (ITER Organization) that implements the ITER project was officially established. Concurrently, the Ministry of Education, Culture, Sports, Science and Technology designated the Japan Atomic Energy Agency (JAEA) as a domestic agency that conducts activities based on the ITER Agreement and started a practical operation to construct ITER.1)

Approximately 500 billion yen is earmarked for ITER construction with superconducting coils accounting for one fourth the construction cost. A superconducting coil consists of toroidal field (TF) coils, poloidal field (PF) coils, and a central solenoid coil (CS). An Nb_3Sn conductor is used for a TF coil and CS. The ITER Organization and JAEA concluded the TF Conductor Procurement Arrangement in November 2007 and started work to procure Nb_3Sn conductors for TF coils. Japan is responsible for procuring 25 % of the TF coil conductors. Europe and Russia have concluded a similar arrangement.

A TF coil conductor is a cable-in-conduit conductor with a cable obtained by twisting 900 Nb_3Sn strands and 522 copper wires in five stages inserted into a metal tube made of SUS316LN. A TF coil conductor is operated under a maximum magnetic field in the conductor of 11.8 T and at a rated current of 68 kA. Table 1 and Fig. 1 show the major parameters of a TF coil conductor and strand and the schematic view of a TF coil conductor, respectively.

Table 1 Major parameters of conductor for ITER TF coils

Superconducting material	Nb_3Sn
Strand diameter	0.82 mm
Cu/no-Cu in Nb3Sn strand	1
Thickness of Cr plating	2 μm
Cabling pattern	((2SC+1Cu)x3x5x5+core)x6 Cu core: 3x4
Number of Nb3Sn strands	900
Number of Cu strands	522
Local void fraction	29-33 %
Inner diameter of jacket	40.5 mm
Thickness of jacket	1.6 mm
Central spiral tube	7 mm(outer diameter), 9 mm (inner diameter)
jacket material	316 LN

JAEA fabricated a 3.5-meter long conductor sample using a newly developed superconducting strand, simulating the actual TF conductor fabrication process. The conductor sample combines two conductors in parallel. The sample is designed so one end is electrically connected and electric current is supplied from the other end. We measured the current sharing temperature (Tcs) of the TF coil conductor at a rated magnetic field and current, using the SULTAN test facility of Swiss Federal Institute of Technology. The test revealed that the conductor sample has a Tcs of 6 K or more in the TF coil operation condition and performance satisfies design criteria.[2)]

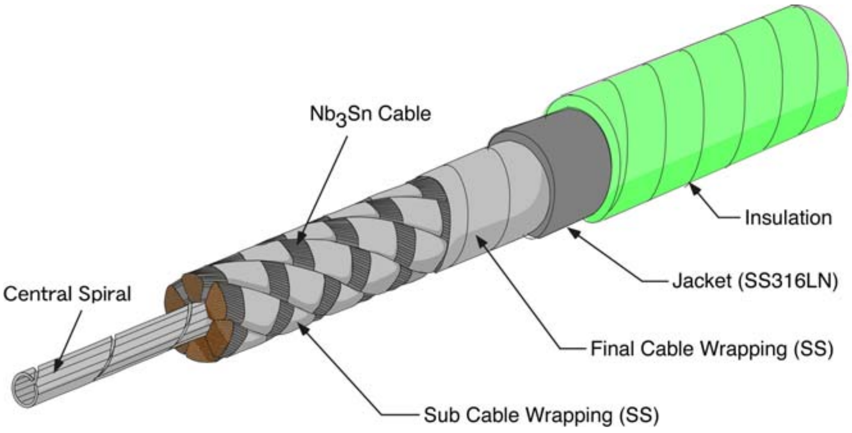

Fig.1 Nb_3Sn cable-in-conduit type conductor with spiral for ITER TF coils

We measured in detail the changes in the superconducting performance of the newly developed Nb_3Sn strand for strain under different magnetic fields (10 to 13 T) and at different temperatures (4.2 K to Tcs), using the measurements for a detailed analysis of the sample performance evaluation.[3)]

The conductor of the actual TF coil is about 760 meters long. We developed fabrication technology for long conductors. A butt welding technique to lengthen an approximately 10-meter long jacket, a technique to pull stranded wire into a metal tube, and a technique to compact a metal tube into a designed conductor diameter after pulling will all be important. JAEA has fabricated a compactor, test-fabricated a jacket, and developed a welding technology preventing beads from protruding into the inner face so stranded wire can be retracted smoothly. JAEA established all the technologies necessary to fabricate long lengths of conductors.[4)]

As has been discussed, JAEA has almost completed the technological development of Nb_3Sn conductors for ITER TF coils and started fabricating the conductor in March 2008, which will be put to actual use.

(Published in a Japanese version in the April 2008 issue of *Superconductivity Web 21*)

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Summer, 2008 Date of Issue: July 15, 2008

Superconductivity Web21

Published by International Superconductivity Technology Center
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Patent information

Published Unexamined Patents in the 3rd & 4th Quarter of Fiscal 2007

The following are ISTEC patents published from October 2007 through March 2008. For more information, visit the Japan Patent Office Web site and the Industrial Property Digital Library (IPDL) or other patent databases.

1) Publication No. 2007-257872 "Fabrication Method of YBCO-based High Temperature Superconductor Film-forming Composite Substrate and YBCO-based High Temperature Superconductor Film"

This invention provides composite base materials that can form YBCO-based high temperature superconductor films, with excellent orientation, that do not depend on changes of film formation conditions. The invention also offers a method to fabricate c-axis oriented films having aligned crystal orientation reproducibly.

In the process of researching the fabrication of the c-axis oriented films of a YBCO-based high temperature superconductor by physical means, the inventor discovered the reproductivity of c-axis oriented films drastically improves by using composite base materials that Zr or a Zr-oxide is present on the surface and which have aligned crystal orientation. This patent explains why the reproductivity improves as shown below.

(1) When the temperature rises in a state where a YBCO-based high temperature superconductor comes in contact with Zr or a Zr-oxide, a decomposition reaction occurs at temperatures lower than the melting point of the superconductor, forming CuO, $Y_2Cu_2O_5$, $BaZrO_3$, or other compounds. This reaction does not complete with only a simple solid-state reaction, but proceeds while producing a Ba-Cu-O-based liquid phase as an intermediate product.

(2) Generally, mass transfer through the liquid phase proceeds very quickly. Using this in an early stage of the growth of a superconducting film will help the migration of particles that accumulate one after another, promoting the growth of c-axis oriented particles in the lateral direction.

(3) As a result, c-axis oriented particles will grow on the surface of the base material. Even if there are some defects on the surface of the base material, the migration accelerating effect will enable the formation of highly grown superconducting films.

2) Publication No. 2008-50190 "Manufacturing Method of Tape-shaped RE-based (123) superconductor"

This invention is based on findings that J_c decreases as the film thickens and an unexpectedly low I_c value are caused by generation of cracks and deterioration of the electrical connectivity of grain boundaries. Thick-film tape-shaped superconductors having the performance of J_c = 3.20 MA/cm^2 and I_c = 525 A/cm (X=1.5) can be obtained by using a solution with the molar ratio of RE, Ba, and Cu being RE : Ba : Cu = 1 : X : 3 and X being smaller than 2.

Ba, among metal atoms that compose the RE-based (123) superconductor, easily causes segregation without uniformly dispersing during pre-sintering, depending on the pre-sintering conditions. Ba impurities such as $BaCeO_3$ other than the RE-based (123) superconductor will be formed because an excessive amount of Ba is locally found in this segregation area. Ba impurities frequently deposit at grain boundaries. The presence of a dielectric such as impurities at grain boundaries deteriorates electrical characteristics between crystal grains and induces the generation of cracks, resulting in a decrease in J_c and I_c. Based on this concept, the segregation of Ba was prevented by making the molar ratio of Ba lower than its standard molar ratio to improve current transport characteristics.

(Ichiro Nagano, Acting Director, Research and Development Promotion Division, SRL/ISTEC)

(Published in a Japanese version in the May 2008 issue of *Superconductivity Web 21*)

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