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Formulating a Technology Strategy Map in the Field of Superconducting Technology

Shungo Suzuki
Research and Development Division
Industrial Science and Technology Policy and Environment Bureau
Ministry of Economy, Trade and Industry

1. Background

The Ministry of Economy, Trade and Industry (METI) introduced the R&D Program system in 2001 to prioritize investments in research and development toward attaining its policy objectives. Since then, METI has continued to clearly define the objectives of its R&D projects and strengthen collaboration between them. And then, in order for our country's national industries to create innovation ahead of other countries in a stable and autonomous manner, the New Industry Creation Strategy established in May 2004 has come to realize that strategic fields must be prioritized based on commercialization-focused R&D and deployment scenarios and integrated efforts (R&D Programs) between related measures, including regulatory reforms and standardization, and that R&D measures must be further strengthened. As specific measures, the strategy has decided to create R&D and deployment scenarios and an overview of a Technology Strategy Map for future key technologies and the commercialization of those technologies between related parties, and to prioritize strategic fields for R&D assistance.

2. Study of Technology Strategy Map

The formulation of the Technology Strategy Map was launched amid the aforementioned situation. The Technology Strategy Map and the formulation process was pushed forward with careful attention paid to the following three points:

(1) Explaining the concept, content, results, and other details about METI's R&D investments to the people of Japan and seeking their understanding about them.

(2) Grasping technological and market trends, narrowing down key technologies that should be prioritized at the national or private-sector level, and developing policy infrastructure for planning R&D projects.

(3) Promoting collaboration between different fields/industries, integration of technology, and unified implementation of related measures covering Japan's R&D, as well as mobilizing the collective strength of government, industry and academia, all in an effort to respond to specialized technology and diversifying market and social needs.

It was also decided to organize the Technology Strategy Map into the following three sections and append an outline and reference materials for the concepts and main points in creating these sections.

(1) A deployment scenario that includes related measures that must be worked out in order to provide society and the people of Japan with R&D and its results as products and services among other things.

(2) A technology map that is focused on the technological issues, fundamental technology, and desired functions, all of which are necessary for fulfilling market and social needs, and that selects key technologies from among these.

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(3) A roadmap indicating the improvement and progress of fundamental technology through R&D efforts and desired functionality as milestones on a timeline.

In this manner, METI studied the Technology Strategy Map targeting the 20 technological fields of telecommunications (1. semiconductors, 2. storage and non-volatile memory, 3. computers, 4. networks, 5. usability (displays etc.), and 6. software), life sciences (7. new drug development/diagnostics, 8. diagnostics/medical devices, and 9. regeneration medicine), environment/energy (10. CO_2 fixation/effective utilization, 11. measures for phasing out chlorofluorocarbons, 12. comprehensive management of chemical substances, and 13. 3R), and manufacturing industry (14. robots, 15. aircraft, 16. space, 17. nanotechnology, 18. components, 19. MEMS, and 20. green biotechnology). The result was the March 2005 release of the first version of the "Technology Strategy Map." Then in April 2006, the second version entitled "Technology Strategy Map 2006" was released. This update added a study of four new fields, namely 1. energy, 2. superconducting technology, 3. cancer countermeasures, and 4. technology for people's lives, and revised and added content in response to technological progress in the aforementioned 20 fields. This study was a cooperative effort by some 400 specialists and others from government, industry and academia, who were part of a taskforce established at the New Energy and Industrial Technology Development Organization (NEDO).

3. Technology Strategy Map in the Field of Superconducting Technology

The Superconducting Technology Map Formulation Committee, consisting of 27 specialists from industry and academia and chaired by Prof. Osami Tsukamoto of Yokohama National University, was established within NEDO, and repeated examination for the response of instructions to formulate a technology strategy map in the field of superconducting technology at the Industrial Structure Council's R&D Subcommittee that met in July 2005,

Superconducting technology is seed technology, and since the equipment on the output end spans a broad range, the committee decided to divide the deployment scenario into the fields of energy/electric power, diagnostics/medical, industry/transport, information/telecommunications. And they presented "Superconducting Technology Serving a Society, A Society in 2020" as a conceptual diagram which overlooked the whole fields. It also decided to define as common indispensable technology, the wire, bulk, and device, as well as the cooling and cryogenic technologies essential to keep the superconducting state. Since it would be impossible to cover everything therein, we are limiting the discussion to a look at society and the deployment scenario for energy/electric power. An intermediate version was released last October through the active efforts of the committee's members, and it was then closely examined based on external opinions, but almost no changes were made in the next version.

The formulation of the Technology Strategy Map is by no means over, rather the work so far will serve as a springboard for future work. It is crucial that we comprehensively move forward by repeating the organic activities of getting the nation and its people involved with the Technology Strategy Map as a starting point and then revise the map based on where their involvement takes it. It is believed that the extremely high-precision launch of the Technology Strategy Map in the field of superconducting technology will be highly significant in future expansion.

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4. Conclusion

I would like to take this opportunity to sincerely thanks our chairman, Prof. Osami Tsukamoto, and the committee members who spared their precious time to extremely enthusiastic discussions to study the Technology Strategy Map, and to ISTEC and think-tank staffs who gathered and organized information behind the scenes, and to NEDO and observers who made efforts for operation of meetings.

I would like to apologize for not being able to provide the official version of the Technology Strategy Map for superconducting mates, but it is currently unavailable for clerical reasons. Your patience in this matter is greatly appreciated. However, I hope you will refer to the final draft, as deliberated by the Industrial Structure Council's R&D Subcommittee, which is available from the URL listed below.

"Technology Strategy Map 2006," 15th Meeting of the R&D Subcommittee
http://www.meti.go.jp/committee/materials/downloadfiles/g60426a04-2j.pdf

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Superconductor Week Presents ISTEC's Yuh Shiohara with an Award in Superconducting

Superconductor Week announced that on April 17, 2006, it had presented ISTEC-SRL's Dr. Yuh Shiohara and Oxford Instruments Dr. S. Hong with its Superconductor Industry Person of the Year award for superconducting magnets and energy technology. The award was presented to both men at the 2006 MRS Spring Meeting held in San Francisco from April 17 to 21. Please see the press release for more information.

ISTEC Leader Yuh Shiohara Named Superconductor Industry Person of the Year
Oxford Instruments Engineering Chief Seung Hong Wins Lifetime Achievement Award

http://www.superconductorweek.com/scipoy/scipoy05PR.htm

The award for "Superconductor Industry Person of the Year," the industry's most prestigious international award in the development and commercialization of superconductors, has been bestowed upon Dr. Yuh Shiohara, Director of the Superconducting Tapes and Wires Division of the Superconductivity Research Laboratory at the International Superconductivity Technology Center (ISTEC) in Japan.

Dr. Shiohara is recognized by top peers in the industry for his broad vision and effective leadership at the head of Japan's national effort to develop high temperature superconducting (HTS) wire. HTS wire operates at the relatively warm temperature of liquid nitrogen--a common industrial refrigerant--and is expected to help solve some of the 21st century's most pressing needs, enabling a new generation of ultra-efficient motors, generators, power cables and devices, and magnetically levitated (maglev) trains.

"Much of the global effort to commercialize low-cost, high-performance HTS wire is centered on second generation (2G), YBCO coated conductor development," said Mark Bitterman, Executive Editor at *Superconductor Week.* "Dr. Shiohara's leadership in 2005 was essential to the impressive progress in 2G wire development reported by ISTEC last year, and also aided the two major industrial HTS wire manufacturers in Japan, Fujikura Ltd. and Sumitomo Electric Industries Ltd. (TSE:5802). His ability to effectively coordinate industrial, university, and governmental organizations is truly outstanding."

Shungo Suzuki, of the R&D Division of Japan's Ministry of Economy, Trade and Industry (METI), added: "Under the leadership of Dr. Shiohara, we have passed key technical milestones for the practical use of HTS wire, and we are encouraged that the industry will now advance on a sure footing. As a result, we are now stepping up our efforts to reach our next targets. This award by *Superconductor Week* brings great pleasure not only to his colleagues, but also to the many others working in superconductivity around the world."

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

Organization

IV SUPRA (May 31, 2006)

Eight European manufacturers of materials and components for superconducting systems meeting at the Hanover Industrial Fair recently founded the "Industrieverband Supraleitung" industrial association (IV SUPRA), with the goal of informing public and lobbying at the German Government in favor of superconductor technology and its potential for innovation. In doing so, the association hopes to create a suitable framework for the effective application and commercialization of superconductivity, particularly in the energy sector. Dr. Joachim Bock, Vice-president and CEO of Nexans SuperConductors, stated, "Superconductivity needs a lobby so that politics and economy get aware of its impact on energy technology. We need financial support for projects to implement superconducting components because they allow a considerable increase of efficiency in the generation, distribution and consumption of electrical energy". The founding members of the association are:

Adelwitz Technologiezentrum GmbH (ATZ), Adelwitz
Bruker BioSpin GmbH, Karlsruhe
ERT Refrigeration Technology GmbH, Hamburg
European High Temperature Superconductors GmbH & Co. KG, Hanau
Evico GmbH, Dresden
Nexans SuperConductors GmbH, Hürth
Theva Dünnschichttechnik GmbH, Ismaning
Trithor GmbH, Rheinbach

The association's first president will be Dr. Werner Prusseit (Theva). Industrieverband Supraleitung's website may be visited at http://www.ivsupra.de.

Source:
"Superconductivity deserves more attention as an efficiency increasing cross cutting technology"
IV SUPRA press release (May 31, 2006)
http://www.ivsupra.de/

Power

American Superconductor Corporation (May 1, 2006)

American Superconductor Corporation (AMSC) has completed the transition from the manufacturing of first-generation HTS wire to the manufacturing of second-generation HTS wire ahead of schedule. Consequently, the production of first-generation wire has been suspended, and all near-term market needs for this wire will be supplied from AMSC's inventory. As a result of the change, AMSC expects to be able to achieve its sales objectives for HTS wire with reducing the operating losses of the wire business unit by about 20% within the current fiscal year. Greg Yurek, Chief Executive of American Superconductor, commented, "Our first-generation HTS wire has been very valuable in seeding the market for superconductor products in a broad range of applications, including power cables and SuperVAR

synchronous condensers for power grid reliability, ship propulsion motors and generators, and electromagnets for multiple applications such as magnetically-levitated trains and water purification systems… Because we expect our second-generation HTS wire to have higher electrical performance and cost less to manufacture, we believe customers will rapidly adopt 2G wire as soon as we can make it available in commercial quantities." AMSC's second-generation wire will be a drop-in replacement for its first-generation wire.
Source:
"American Superconductor Completes Transition of Wire Manufacturing From First Generation to Second Generation High Temperature Superconductor Wire"
American Superconductor Corporation press release (May 1, 2006)
http://phx.corporate-ir.net/phoenix.zhtml?c=86422&p=irol-newsArticle_Print&ID=849769&highlight

Oak Ridge National Laboratory (May 3, 2006)

The Oak Ridge National Laboratory (ORNL) has included superconductivity technology in its integrated approach to meeting the goals outlined in a comprehensive "Rising Above the Gathering Storm" report commissioned by The National Academies. The report was produced in response to a request from two senators to identify the top 10 actions that federal policymakers could take to enhance science and technology and ensuring continuing prosperity. One recommendation was to respond to the need for clean, affordable, and reliable energy. ORNL suggested that the integration of basic energy research and applied research would be key to meeting this goal and cited several accomplishments in the area of superconductivity, including an ORNL-developed method to sustain high current in superconducting wires in the presence of large magnetic fields (making their use in motors, generators, and power transmission more practical) as well as the demonstration of superconducting power cables.
Source:
"ORNL poised to help nation reach goals outlined in study"
Oak Ridge National Laboratory press release (May 3, 2006)
http://www.ornl.gov/info/press_releases/get_press_release.cfm?ReleaseNumber=mr20060503-00

American Superconductor Corporation and GE Energy (May 10, 2006)

American Superconductor Corporation (AMSC) and GE Energy have received an order for two D-VAR® systems from the City of Detroit Public Lighting Department (PLD), a municipal electrical utility. The PLD will use the D-VAR systems to provide voltage support to their power grid. AMSC expects to ship the D-VAR systems in June 2006, and commissioning is expected to occur in the late summer. The Mayor of Detroit, Kwame, Kilpatrick, stated that the city expects its annual energy costs to be reduced by at least US $10 million, thanks to the D-VAR system. The D-VAR system will replace multiple local generators that were previously operated to ensure voltage stability. PLD expects significant enough savings in energy costs to completely offset the D-VAR costs in approximately 6 months.
Source:
"American Superconductor and GE Energy Receive Order for Two D-VAR(R) Systems from City of Detroit Public Lighting Department"
American Superconductor Corporation press release (May 10, 2006)
http://phx.corporate-ir.net/phoenix.zhtml?c=86422&p=irol-newsArticle_Print&ID=854637&highlight

American Superconductor Corporation (May 11, 2006)

American Superconductor Corporation (AMSC) has reported its financial results for the fourth quarter and full year ending March 31, 2006. Revenues for the fourth quarter totaled US $14.2 million, compared with $12.9 million for the same period in the previous fiscal year. Meanwhile, the net loss was $11.0 million, compared with $8.2 million for the same period in the previous fiscal year. The company ended the fourth quarter with $65.7 million in cash, cash equivalents, and short-term investments and no long-term debt. A total of $3.5 million in new orders and contracts were received during the fourth quarter, bringing their total backlog of orders and contracts to $23.8 million.

Revenues for fiscal 2006 totaled $50.9 million, compared with $58.3 million for fiscal 2005. The new loss for fiscal 2006 was $30.9 million, compared with $19.7 million for fiscal 2005. The net loss for 2006 included write-downs associated with the transition in manufacturing capability from first-generation to second-generation wire.

Source:
"American Superconductor Reports Fourth Quarter and Fiscal 2006 Financial Results"
American Superconductor Corporation press release (May 11, 2006)
http://phx.corporate-ir.net/phoenix.zhtml?c=86422&p=irol-newsArticle_Print&ID=855331&highlight

Intermagnetics General Corporation (May 24, 2006)

SuperPower, Inc. has set a new world record for the performance of second-generation HTS wires: 219 A/cm-width over 322 meters, or 70,520 amp-meters. The new record far surpasses the previous world record of 52,087 amp-meters. SuperPower has also achieved a critical current performance of 557 A/cm-width in a short sample, setting another new world record. Glenn H. Epstein, chairman and chief executive officer of Intermagnetics, commented, "We believe that this significant performance advancement by the SuperPower team is a clear indicator of the advent of commercially available 2G HTS wire. We now have demonstrated not only a significantly enhanced performance milestone, but also a production rate eight times faster than our nearest competitor - using a superconductor that is only half the thickness employed by that competitor. The high production rates follow substantial upgrades to nearly all of our pilot production equipment over the past several months."

Source:
"Intermagnetics' Superpower Subsidiary Sets New World Records For Second-Generation High-Temperature Superconducting Wire"
Intermagnetics General Corporation press release (May 24, 2006)
http://phx.corporate-ir.net/phoenix.zhtml?c=88261&p=irol-newsArticle&ID=860295&highlight

University of Albany (May 30, 2006)

The University of Albany's College of Nanoscale Science and Engineering (CNSE) has successfully demonstrated the world's first 50 kW cryogenic power inverter. Cryocooled electronics are highly desirable for the construction of integrated power systems for future Naval warships propelled by superconducting motors and generators. The cryogenic power inverter demonstration utilizes a revolutionary approach in which metal heat sinks and other bulky cooling hardware are replaced by a liquid nitrogen bath, a cooling method that is compatible with superconducting technology. The successful demonstration marks the completion of the first year of a two-year project sponsored by the Defense Advance Research Projects Agency ("DARPA").

Source:
"Team led by UAlbany NanoCollege pioneers new technology to power all-electric US Navy ships"
University of Albany press release (May 30, 2006)
http://cnse.albany.edu/News/index.cfm?InstanceID=138&step=show_detail&NewsID=189

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Sensor

European Space Agency (May 19, 2006)

The European Space Agency (ESA) used a superconducting camera, the SCAM, to examine the interior of Comet 73P/Schwassmann-Wachmann 3. The SCAM is attached to the ESA Optical Ground Station in Tenerife (Canary Islands) and is an ultra-fast photon counting camera that utilizes superconducting tunnel detectors. These enabled it to detect fast and faint changes in the comet's fragments as the comet disintegrates. Using highly accurate data obtained with the SCAM, ESA scientists are charting the evolution of the dust and gas envelopes associated with each fragment. The SCAM's time resolution also enables outbursts and activity from each fragment to be tracked to changes occurring in the comet on a timescale of about one minute. The high-speed camera itself, however, operates in photon-counting mode on time-scales of microseconds. Interactions in the gas and dust flow between two fragments close to one another could also be observed. About 40 comet fragments are visible, most of which are likely to be very small with irregular and short-lived activities.
Source:
"ESA's new camera follows disintegration of a comet"
European Space Agency press release (May 19, 2006)
http://www.esa.int/esaCP/SEMN1C9ATME_index_0.html

Electronics

HYPRES, Inc. (May 8, 2006)

HYPRES, Inc., has entered into a Teaming Agreement with Argon ST, Inc., to pursue an optional ultra-high performance digital-RF receiver as part of a Ship's Signal Exploitation Equipment (SSEE) Increment F contract that was recently awarded to Argon ST. The initial task of the 30-month contact, valued at US $52.8 million, is the development and delivery of a high-performance sensor system to the U.S. Navy. The contract also includes priced options to allow the government to procure additional development systems and production units over a five-year period, beginning in 2009. Under the terms of the Teaming Agreement, HYPRES will develop and demonstrated a multi-input digital-RF channelizing receiver system. HYPRES' role in the contract could eventually represent a multi-year, multi-million dollar effort. Richard Hitt, CEO and President of HYPRES, commented, "Teaming with Argon is an exciting and tremendous opportunity for HYPRES. We plan to show that ultra-fast superconductor Digital-RF technology can improve performance, lower equipment costs, reduce power consumption, and resolve critical technology gaps facing future military SIGINT and communications systems."
Source:
"HYPRES' Digital-RF Receiver Could Serve As Risk Mitigation Option For Argon ST's Recent Ship's Signal Exploitation Equipment Increment F Contract"
HYPRES, Inc. press release (May 8, 2006)
http://www.hypres.com/pages/new/bnew_files/argon.pdf

HYPRES, Inc. (May 15, 2006)

HYPRES, Inc. has been awarded a Phase II Small Business In Research (SBIR) contract from the U.S. Army to develop digital-RF switch matrices for the programmable distribution and routing of directly

digitized radio frequency (RF) signals to programmable digital processors. Under terms of the two-year contract (valued at US $729,959), HYPRES will design, fabricate, and test a variety of asynchronous multi-rate and multi-casting switch matrices using niobium-based superconductor integrated circuit technology. Richard Hitt, President and CEO of HYPRES, commented, "Digital superconductor-based RF subsystems represent the best opportunity for programs such as JTRS, TSAT and WIN-T to reach their full potential as integrated networks. We've proven the potential of this switching technology in previous work. This is an exciting opportunity to integrate this capability into our latest prototype systems."
Source:
"HYPRES Awarded $730 Thousand By U.S. Army To Develop Ultra- Fast Switch Matrices"
HYPRES, Inc. press release (May 15, 2006)
http://www.hypres.com/pages/new/bnew_files/pr_swmrix5_15_06.pdf

Accelerator

Oak Ridge National Laboratory (May 1, 2006)

Oak Ridge National Laboratory has announced that the Department of Energy's Spallation Neutron Source (SNS) facility has generated its first neutrons. Research conducted at the SNS is expected to lay the foundation for a new generation of materials research. The SNS will greatly improve the ability of researchers to understand the structure of materials, including superconducting metals, and may potentially lead to countless new innovations. The SNS's linear accelerator contains both room-temperature and superconducting sections.
Source:
"First neutrons produced by DOE's Spallation Neutron Source"
Oak Ridge National Laboratory press release (May 1, 2006)
http://www.ornl.gov/info/press_releases/get_press_release.cfm?ReleaseNumber=mr20060501-00

Basic

Duke University (May 8, 2006)

Using a data-mining method, researchers at Duke University's Pratt School of Engineering have discovered a theoretical "metal sandwich" that is expected to act as a superconductor. The new compound, lithium monoboride (LiB), is a "binary alloy" consisting of a lithium "filling" between two layers of boron. Once synthesized (a process that will involve extremely high temperatures and pressures), the material is expected to behave like a superconductor and to have a critical temperature that is higher (greater than 39 K) than other superconductors of its class. The theoretical findings indicate a new research direction that could aid in the search for other novel superconductors. The research was reported online in the e-journal *Physical Review B, Rapid Communications* (May 5, 2006).
Source:
"New 'metal sandwich' may break superconductor record, theory suggests"
Duke University press release (May 8, 2006)
http://www.pratt.duke.edu/news/releases/index.php?story=270

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University of California – Riverside (May 16, 2006)

A team of French and German experimental scientists has verified the central prediction of a theory explaining high-temperature superconductivity developed by Chandra Varma, presently a professor of physics at the University of California – Riverside. The verification could ultimately assist in the fabrication of room-temperature superconductors and may help to settle an international debate on the fundamental physics of superconductivity. Varma's initial theory, proposed in 1989, stated that high-temperature superconductivity and related phenomena occur in certain materials because quantum-mechanical fluctuations in these materials actually increase, instead of decrease, as the temperature decreases. Varma later explained the nature of these fluctuations in a second theory proposed in 1996, noting that superconductivity is associated with the formation of a new state of matter in cuprates, in which electric current loops form spontaneously. Varma concluded that the quantum-mechanical fluctuations mentioned in his initial theory corresponded to the current loops observed in cuprates. In experiments involving the diffraction of polarized neutrons, the French-German group mentioned above directly observed the current loops predicted by Varma. Varma commented, "Further experiments of the kind by [the French-German] group should help bring a consensus in the scientific community about the fundamental physics involved in cuprates." The research of the French-German group appeared in the May 19 issue of *Physical Review Letters*.

Source:
"French-German Group Verifies High-Temperature Superconductivity Theory Proposed by UCR Physicist"
University of California – Riverside press release (May 16, 2006)
http://www.newsroom.ucr.edu/cgi-bin/display.cgi?id=1337

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

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Feature Articles: Superconducting Industrial Equipment Technology - Advances in Single-Crystal Silicon Growther Technology -

Hirohisa Takano
Keihin Product Operations
Power Systems Company, Toshiba Corporation

The manufacture of single-crystal silicon, the material used for semiconductor substrates, is a core business supporting semiconductors, and Japanese manufacturers have an extremely high share of the market. Single-crystal silicon is manufactured by placing high-purity polycrystalline silicon in a quartz crucible and then melting it with a graphite heater or similar means to form single crystals from the seed crystal. As the diameter of single crystal silicon becomes large, the convection of the silicon melt increases, and this has resulted in quality-related problems, such as the melting speed of quartz increasing and the oxygen concentration in the melt rising. In response to this, the Magnetic Field Applied Czochralski Method (MCZ Method), which applies an external magnetic field, was developed for the purpose of controlling melt convection by Lorentz force, with a focus on the silicon melt's electrical conductivity. The primary methods for applying the magnetic field are the method that applies a longitudinal magnetic field of up to about 0.5T to silicon melt and the method that applies a cusp magnetic field that is obtained by sending a reverse current through a pair of circular coils arranged one on top of the other. The development of these sorts of superconducting magnets for pulling single-crystal silicon was pursued at the research lab level starting in the second half of the 1980's, and actual application to single-crystal manufacturing lines started in the mid 1990's for 8-inch apertures (200 mm), while 12-inch apertures (300 mm) were introduced as we entered current century. The current superconducting magnets that are applied to these are comprised of coils using NbTi wire, a cryostat, and a cryocooler.

The photo shows a superconducting magnet for 8-inch single-crystal growth that uses high-temperature superconducting wire (Bi2223) that was jointly developed by Toshiba Corporation, Sumitomo Electric Industries, Ltd., and Shin-Etsu Handotai Co., Ltd., with a grant-in-aid from the former Ministry of International Trade and Industry (MITI). The characteristics of the Bi2223 tape wire at the time of the magnet's development were about half of the performance of current characteristics. Eighty kilometers of wire was used at the time. By further improvements in wire characteristics and decreased costs due to the use of next-generation wire, we can expect an energy-saving effect and magnets without the worry of quenching due to the ability to raise operating temperature to around 20 K. I look forward to the ability to apply high-temperature superconducting wire to superconducting magnets for next-generation single-crystal silicon growth. I also look forward to applications in new fields, such as steel manufacturing.

High-temperature superconducting magnets for raising single-crystal silicon

(Published in a Japanese version in the March 2006 issue of *Superconductivity Web 21*)

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Feature Articles: Superconducting Industrial Equipment Technology
- Development of Magnetic Separation Technology for Wastewater -

Tatsuo Fukunishi
Senior Managing Director
Futaba Shoji Co., Ltd.

Superconducting magnets use superconducting wire to create a magnetic field space with a large volume without consuming much power. In recent years, cryocoolers that can cool to about 4 K without using a liquid He cryogen have been created, and material that becomes superconducting even at around 10 K has been developed. These technologies have made it possible to manufacture superconducting magnets that can continuously operate for long periods of time without human intervention. We are developing a waste treatment system as an application of magnetic separation technology that uses a strong magnetic field. In this wastewater treatment by superconducting magnetic separation, we continuously purify wastewater at a high rate of speed by magnetizing non-magnetic material (magnetic seeding), such as suspended substances (SS) and COD/BOD causative agents that are found in wastewater, and then using a strong magnetic field from a superconducting magnet and a high gradient magnetic field induced by a magnetic filter to magnetically separate and recover the magnetic-seeded substances.

Wastewater that includes contaminants is first introduced into the reaction tank, where a coagulant and magnetic particles are added to form a magnetic flock that contains sludge substances. The magnetic flock is sent to the settling tank where the heavy flock rapidly precipitates. The smaller and relatively light flock is sent along with overflow from the settling tank to the magnetic separator, which consists primarily of a superconducting magnet. There, the light flock is captured by a magnetic filter in the magnetic separator. The treated water is used as recycled water. In addition, the magnetic flock precipitated in the bottom portion of the settling tank and separated by the magnetic filter in the magnetic separator is collected as magnetic sludge, and the magnetic particles in it are reused.

A superconducting magnet with a 400-mm bore (magnetic field space) was used for magnetic separation. It was placed horizontally so that the magnetic filters could be continuously replaced and cleaned and was designed with a maximum magnetic flux density of 3 Teslas. A cylinder of non-magnetic material was positioned so that it passed through the electromagnet bore section, and circular magnetic filters were placed within there. The magnetic filter that attracted the magnetic flock was automatically taken outside the magnetic field, cleaned, and then returned to the magnetic separation section by a newly developed filter system without lowering the magnetic field.

This system is capable of treating 2,000 tons of wastewater a day despite a small installation area of only 6 m x 6 m. This water treatment technology by magnetic separation constantly reduces COD (Cr) and turbidity (NTU) of industrial wastewater from the region of 200 - 600 to 110 - 230 and from the region of 100 - 300 to 2-10, respectively. It also enables advanced wastewater treatment by combining the use of substance absorption and magnetic separation using a magnetically porous material (for example, magnetic activated carbon) to further eliminate soluble components.

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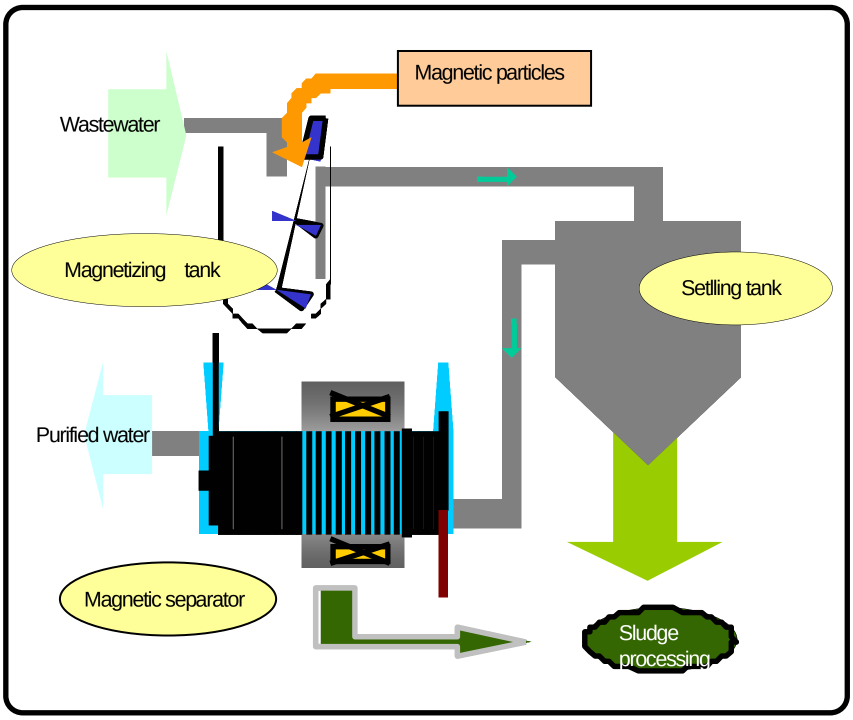

Fig.: Wastewater magnetic separation system

Photo: Superconducting magnet

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Feature Articles: Superconducting Industrial Equipment Technology - Advances in Strong Magnetic Field Magnetron Sputtering Using a Bulk Superconductor -

Ryohei Yabuno
President
IMRA MATERIAL R&D CO., LTD.

Since RE123 bulk superconductors such as Sm123 and Gd123 can compactly produce a strong magnetic field exceeding 5T through cooling by a small cryocooler, it is possible to create innovative industrial equipment by using the bulk superconductor as an extremely strong magnet. Our group, IMRA MATERIAL and Nagoya University, has been developing a magnetron sputtering system that uses such a strong magnetic field, and succeeded in the preparation of films with distinctive characteristics.

The strong-magnetic field sputtering system we developed produces a magnetic field of 1.0T above the target, which is about 20 times larger than that of ordinary systems. The strong magnetic field concentrates the plasma near the target, and enables the formation of films even at a low gas pressure of 10^{-3} to10^{-2} Pa, which is one to two orders of magnitude lower than what was possible with a conventional system. At low gas pressure, the mean free path of sputtered particles increases, and it becomes possible to form films with a distance of several tens of centimeters between the target and the substrate compared with a distance of 10 cm or less in ordinary systems. This lower-pressure, long-distance film formation improves the linearity of sputtered particles, thereby enabling film formation on the inside of holes with a high aspect ratio.[1), 2)] For Cu film formation on a Si substrate, which is envisioned for next generation LSI wiring, we have achieved more than 30% bottom coverage for a 200-nm diameter, 1.1-µm deep via and more than 60% bottom coverage for a 65-nm wide, 250-nm deep trench.

In addition, increasing the distance between the substrate and the target reduces plasma damage on the film, thereby enabling the preparation of a high-quality film. For ZnO, which is expected as a next-generation transparent conductive film, the position dependence of resistivity, which had been a serious problem for films prepared with conventional sputtering systems, was significantly suppressed when the film was prepared with our sputtering device.[3)] Since we can expect that a very sharp boundary will be formed between layers of a multilayered film deposited by the strong-field sputtering technique, our group launched a joint research with Nikon Corporation on film formation technology aimed at increasing the reflectivity of multilayer mirrors for extreme ultraviolet (EUV) light which is used in next-generation semiconductor lithography systems. The research was launched this year as a project at the Innovation Plaza Tokai, Japan Science and Technology Agency. We are currently building and evaluating a new sputtering system equipped with two strong-field magnetron cathodes.[4)]

Fig.: Strong magnetic field sputtering system
(actual test model)

In addition to the aforementioned characteristics, other productivity related advantages of the strong-field sputtering technique had also become clear: for instance, we can use a more than two times thicker target of ferromagnetic material such as Fe, in comparison to an ordinary machine.

Based on these results, our company built an actual test model of a strong magnetic field sputtering system (see Figure) capable of forming various kinds of films. This system has two strong magnetic field cathodes (one for DC and the other for RF sputtering) and one ordinary permanent magnet cathode for RF sputtering, enabling studies of film formation of insulating materials using the strong-field sputtering technique that was not possible so far.

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Feature Articles: Superconducting Industrial Equipment Technology - Development of Inspection System for Foreign Matter in Food/Pharmaceuticals -

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Toyohashi University of Technology

This year marks the 20th anniversary since the discovery of high-temperature superconducting, and we finally developed a practical inspection system that uses high-temperature SQUIDs to detect metallic foreign matter in food/pharmaceuticals. The system was jointly developed by Toyohashi University of Technology, Advance Food Technology Co. Ltd., and Sumitomo Electric Hightechs Co., Ltd. This is the first practical model in the world. Figure 1 is a photo of the overall system.

Food processing plants produce food with great care, but foreign matter still gets mixed into foods on rare occasions. Losses, including product recovery costs and lost profits (expected profits had there been no accident), run to several billions to several tens of billions of yen for large food processing manufacturers, and the prevention of such accidents is, therefore, a major concern for them. At present, inclusion of foreign matter is detected by eddy-current, x-ray, and other test methods, but these methods are not sensitive enough. For example, they cannot even detect stainless steel mesh wires (0.3 to 0.5 mm in diameter) of the strainers (filters) used in the manufacturing process. Our super high-sensitivity SQUID sensor system, on the other hand, can detect such small bits of foreign matter. Our system magnetizes test samples using a magnet and measures residual magnetization by a high-sensitivity magnetic sensor. It is immune to the effects of moisture and temperature, and it is attracting the attention of natural and organic food manufacturers because there is no ionization from the use of x-rays. As was announced in newspapers, Hokkaido's Yotsuba Milk Products Co., Ltd., introduced a large model of our system in 2005 to emphasize its commitment to offering safe food products. Since the SQUID detection system we developed is the sole high-sensitivity inspection system in existence, it is expected to be come an industry standard and thereby contribute to improving the quality of life of people around the world.

The system we developed uses a conveyor belt, but there have been many requests for systems that can handle food that has a high viscosity and is difficult to filter with a strainer, such as fruit juice and ground meat. We are currently busy developing such a system to satisfy this demand.

Fig. 1 External view of foreign matter inspection system

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System specifications are as follows:

• Measurement magnetic damping ratio: 0.14% (1/732) (DC, vertical direction)

• System dimensions: 1,500 x 477 x 1,445 mm (L x W x H)

• Dimensions of effective aperture: 200 x 80 mm (W x H)

• Conveyor speed: 1 to 25 m/min

• Shell: All stainless steel (HACCP compatible)

• Includes an automatic nitrogen feeder

• Sensors: Three high-temperature superconducting SQUIDs

• Sensor drive circuit: Modulated FLL system

• Detection performance (reference values): Detection of stainless steel or steel balls 0.3 mm in diameter at a distance of 30 to 50 mm

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Feature Articles: Superconducting Industrial Equipment Technology - Current State of Voltage Standard Technology and a Remote Calibrating Network System -

Akira Shoji
Group Leader
Nanoelectronics Research Institute
National Institute of Advanced Industrial Science and Technology

The Josephson voltage standard is spreading worldwide as a universal standard that uses the quantum effect. Its use extends to a primary standard at standards research labs in various countries and to the secondary standards of certified calibration providers. However, the use of standards that employ Zener diodes is common with secondary standards, while the use of the Josephson voltage standard is limited. This is due to the fact that Josephson voltage standard systems are expensive and maintenance costs are high, including the need for liquid helium as a cryogen. Hypres in the U.S. is already marketing a Josephson voltage standard system that uses a cryocooler, while in Japan, a prototype using a small GM cryocooler has been built, with a commercial model planned for release soon from IQUANTUM Corporation, a company founded in November 2004 (http://www.iquantum.jp/).

Since the future use of Josephson voltage standard systems that operate with a cryocooler will eliminate the need for liquid helium, it will be possible to dramatically lower the cost of system maintenance. However, the system price itself does not differ much from systems that do use liquid helium. Consequently, reducing the system price is essential in greatly expanding the use of the Josephson voltage standard in secondary standards.

Fig. 1 shows a picture of prototype liquid helium-free Josephson voltage standard system built by AIST. In the Josephson voltage standard, the voltage value is determined by the frequency of the microwaves to which the Josephson element is subjected. Using this characteristic makes it possible to calibrate a secondary standard in a remote location by means of a primary standard. Specifically, by using the microwave frequency emitted by a GPS satellite, a method has already been established for calibrating the secondary standard of a frequency by a primary standard in a remote location. Consequently, the use of the Josephson voltage standard in a secondary standard enables calibration by a primary standard in a remote location. Such remote calibration technology holds great significance for companies that manufacture such products as electric and electronic components in foreign countries, and that is one more reason why expanded use of the Josephson voltage standard as a secondary standard looks promising.

Fig. 1 Prototype liquid helium-free Josephson voltage standard system built by AIST

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Feature Articles: Superconducting Wire and Magnet Technology - Prospects for Technologies for Improving High-Magnetic-Field Characteristics of Y Wire -

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Kyoto University

The development of YBCO coated conductors (CC) that uses $YBa_2Cu_3O_{7-x}$ film, which has excellent J_c characteristics, for tape wires has recently reached a fevered pitch. However, J_c in magnetic fields at 77K, which is necessary for the broad application of CC, is inadequate from a commercial standpoint. This is due not only to the affects of grain boundaries, but also to the fact that effective fluxoid pinning centers within YBCO film are lacking. Commercializing CC as an attractive material requires the improvement of J_c in magnetic fields at 77K from the conventional level of several times to about 10 times.

Toward that end, a technique employing nanotechnology is being developed in Japan and overseas for introducing high-density, low-cost artificial crystal defects that will serve as pinning centers within YBCO film. Defects introduced in this manner are known as artificial pins. At present, it is becoming clear that J_c in magnetic fields at 77K is dramatically improved by solidly pinning fluxoids using artificial pins.

The crystal defects that can be used as artificial pins include transposition (one-dimensional artificial pins), grain boundaries (two-dimensional artificial pins), and micro-precipitates (three-dimensional artificial pins). Recently, the doping of $BaZrO_3$ nanoparticles in YBCO film has been studied, and interestingly enough, it has been revealed that $BaZrO_3$ gathers in a nanorod shape in the c axial direction. That means they too can be used as high-density one-dimensional artificial pins.

Furthermore, tape wire with artificial pins on $REBa_2Cu_3O_y$ film (film wherein the Y site of $YBa_2Cu_3O_{7-x}$ is replaced with RE = Sm or Gd etc.), with its high critical temperature and irreversible magnetic field, is expected to further increase J_c within magnetic fields. Fig. 1 shows J_c characteristics (77K, B//c) within a magnetic field for $REBa_2Cu_3O_y$ film that have been reported thus far. The values obtained exceed the J_c values of NbTi wire at 4.2K and 5T, and this proves the hidden potential of high-temperature superconducting.

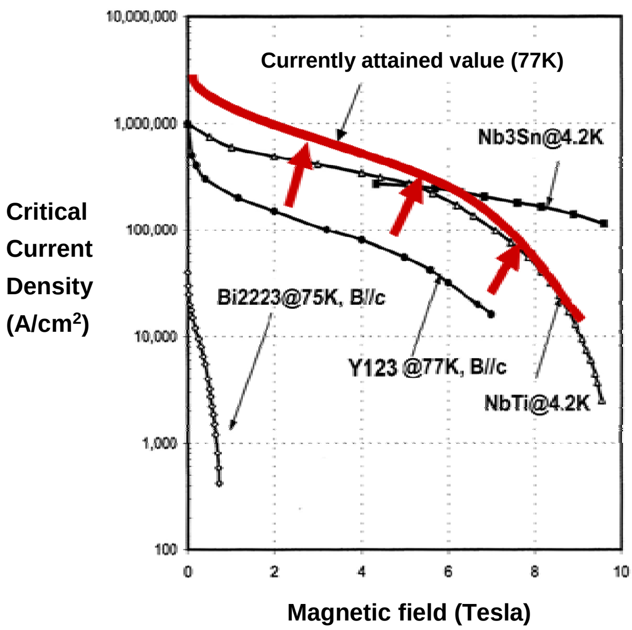

Fig. 1 Comparison of J_c characteristics between conventional YBCO CC (Y123) and various other types of wire (77K, B//c)

Understandably, the J_c characteristic within a magnetic field of YBCO or REBCO CC on which artificial pins have been introduced improve several times when the temperature it is used at lowers from 77K to 65K. Further cooling to 20K results in a one-figure increase in J_c characteristics and the disappearance of

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anisotropy, and even when a 20 to 30T magnetic field is applied, J_c maintains a high value. Such superior J_c characteristics greatly exceed the characteristics of other types of superconducting wire.

If low-cost, easy-to-use YBCO or REBCO CC were created, it could be used in a broad range of applications, from various types of electrical and industrial equipment to high magnetic field applications such a nuclear fusion and NMR. Efforts toward creating commercialized YBCO or REBCO CC coupled with improvements in the excellent features of these wires and the technology for introducing pinning centers are expected to produce wire that has never-seen-before advanced characteristics in the near future.

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Feature Articles: Superconducting Wire and Magnet Technology - Prospects for High-Performance Bismuth 2223 High-Temperature Superconducting Wire and Coil Technologies -

Kazuhiko Hayashi
Electric Power & Energy Research Laboratories
Sumitomo Electric Industries, LTD.

1. Improvement of Bismuth 2223 Wire

At present the only long high-temperature superconducting wire that can be commercially produced is Bi2223 wire. Since Bi2223 superconductors were first discovered in 1988, their critical current density has been improved and the length of their wires has increased thanks to silver-sheathed power-in-tube (PIT). However, the recent use of overpressure sintering in the heat treatment process, which is the final crucial process among wire manufacturing processes that determines superconducting characteristics, improves the density of bismuth superconducting filaments from 85% to 100%, and increases the production yield for long wire from 20% to 90%, thereby enabling the mass production of 1,500m unit length wire with no defects. Sumitomo Electric Industries, LTD. has begun marketing such wire on the name DI-BSCCO®.

In addition, the critical current (77K, 0T) at the outset of our development of overpressure sintering was around 130A at a standard width of 4.3 mm, but thereafter, improvements such as homogenization and zero defects across the entire manufacturing process, i.e. the powder process, fabrication process, and heat treatment process, resulted in the critical current (77K, 0T) reaching 201A. At present, it is possible to commercially produce 150A-class long wire, and a manufacturing system for 200A-class long wire is in the process of being established. Fig. 1 shows the improvement in critical current and the advance in length for Bi2223 wire thus far.

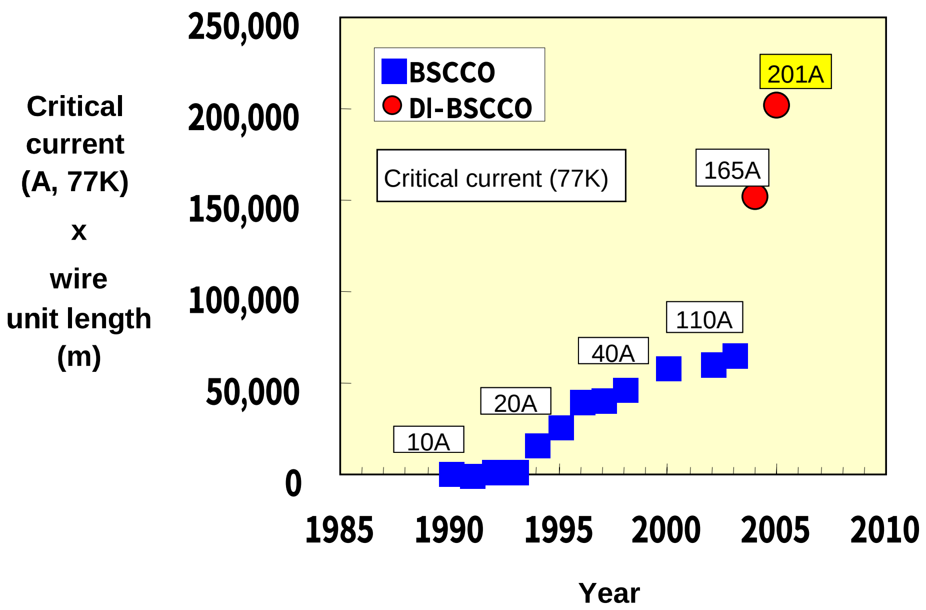

Fig. 1 Performance improvements in bismuth 2223 high-temperature superconducting wire

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2. Prospects for Coil Technology

Sumitomo Electric Industries, LTD. , along with Toshiba and Shin-Etsu Handotai Co. Ltd., are producing magnets for eight-inch silicon single crystal growth by means of 20K conduction cooling that uses Bi2223 wire. However, the critical current of wire in this case is 40 to 50A, and magnet size is about two times that of an NbTi magnet. The 201A critical current achieved this time cleared Je = 40,000A/cm^2 at 20K, several-T magnetic field, which is the primary operating conditions for magnet usage, which is a big application product field for bismuth 2223 high-temperature superconducting wire. It is able to achieve a coil operating current density that is higher than with an NbTi magnet operating at 4.2K. For example, at 20K operation, it is even possible to design a coil that produced 10T in a room temperature bore with a 200-mm diameter. The expansion of the superconducting market by magnet usage is expected in a variety of fields, including magnetic resonance imaging (MRI), nuclear magnetic resonance (NMR) used for protein analysis among other applications, and Maglev trains..

In addition, the effects of dramatically increased critical current values and high production yields due to the adoption of overpressure sintering will result in a dramatic reduction in the merit factor, i.e. wire cost to current per meter (cost/current per m). Since this will enable a reduction in the total cost of the superconducting wire required in application products, price competitiveness will improve for superconducting magnets as well as other products such as superconducting cable and liquid nitrogen-cooled motors. The expansion of application products other than magnet usage is also expected.

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Feature Articles: Superconducting Wire and Magnet Technology - Current State of Characteristic Improvement and Coil Technology for MgB_2 Wire -

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Magnesium diboride (MgB_2) has an excellent superconducting transition temperature of 39 K, the highest for a metal superconductor. It is a simple compound consisting of magnesium (Mg) and boron (B), and research on commercializing wires made of it is actively underway around the world because of the ease of synthesizing it and the ready availability of its constituents. A number of methods have been proposed for making MgB_2 wires, but recently, the so-called powder-in-tube (PIT) method, which fabricates wires by packing powder in metal tubes and by machining the tubes to wire, has predominated. For MgB_2 wire fabrication by the PIT method, there is the in-situ method in which a mixture of Mg and B power is packed into a metal tube and then MgB_2 is synthesized by a heat treatment, and the ex-situ method in which MgB_2 powder is packed into a metal tube and processed directly.

In the PIT method, raising the density of the powder mixture that is filled into the tube is effective in raising J_c, and in that respect, using a metal tube with a high degree of hardness is advantageous. At present, wire is being manufactured using mainly Fe and Ni tubes. Cu tubes, which offer good machinablity and thermal conductivity, are also used, but Cu poses the difficulty of not standing up to high heat treatment temperatures due to its reaction with MgB_2. However, a method that prevents the reaction between Mg and Cu by lining the inside of Cu tubes with Nb or another material is currently being tested.

A variety of attempts are underway with the recent in-situ method to improve J_c characteristics by adding nano-sized impurities to a mixture of Mg and B powder. The addition of nano-sized SiC particles is attracting the most attention lately[1], but the addition of other materials such as B_4C, various hydrocarbon compounds, and nanocarbon is being attempted, and fairly major improvements in J_c are being obtained, particularly in high magnetic fields. The improvement of J_c by adding such carbon compounds is thought to be the result of the upper critical magnetic field B_{c2} improving, which is introduced through a shorter coherence length by carbon substitution for boron.

With the ex-situ method, it had not been possible to obtain a high J_c, but recently a rather high J_c was obtained with tape created by extracting an MgB_2 core from a tape manufactured using the in-situ method and then crushing it into powder and packing it into an iron tube.[2] In particular, tape that was annealed for 1 hour at 600℃ after fabrication is attracting attention for its high J_c that exceeds the original in-situ processed tape in high-magnetic fields. This is thought to be due to the strong bonds between grains because the surface of grains of MgB_2 powder obtained by crushing cores are clean and do not oxidize. The improvement of B_{c2} introduced during the machining process is another reason for high J_c.

The B_{c2} of MgB_2 wire is greatly affected by manufacturing conditions, but with in-situ processed tape to which SiC has been added, B_{c2} will be 11T at 20K, and this value rivals B_{c2} at 4.2K of commercial Nb-Ti wire, which is currently the most widely used. This points to the potential to replace the current commercialized Nb-Ti wire at 4.2K with MgB_2 wire at 20K. One of the conceivable applications for MgB_2 wire is in superconducting equipment that does not require liquid helium. Recent advances in cryocoolers have been striking, and it is possible to easily obtain temperatures as low as 20K. In addition, a method for using liquid hydrogen, which has a boiling point of 20K, as a cryogen is also being proposed. The advantages of

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operating magnets at 20K are the ability to suppress cooling costs compared with cooling with liquid helium and the ability to greatly improve magnet stability because the wire's specific heat is a full figure higher.

Such advances in MgB_2 wire have led to the recent manufacture of long wires exceeding 1 km. In addition, test production of small coils is underway. For example, a 50-mm diameter, 60-mm height small solenoid coil succeeded in generating a 1.3 T magnetic field at a temperature of 20K and a bias magnetic field of 1T, and MgB_2 is considered promising for superconducting magnets using cryocoolers and liquid hydrogen cooling.[3] And quite recently, there has even been success in operating in persistent current mode with MgB_2 coils,[4] and although the temperature was 4.2K, operation continued for 12 hours with no attenuation of the 1.5T magnetic field. This is expected to lead to applications to MRI magnets among other things.

As has been discussed herein, there have been steady advances in the development of MgB_2 wire, but it has not yet reached the commercial level, whether one is talking about the in-situ method or ex-situ method. It is essential that the characteristics of MgB_2 wire be improved through future research.

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Feature Articles: Superconducting Wire and Magnet Technology - Advances in High-Performance Nb_3Sn Wire Technology and Magnet Technology for Physical and Chemical Research -

Yukinobu Murakami
Yasuhiko Otani
Japan Superconductor Technology Inc.

Among superconducting magnets for physical and chemical research, NMR magnets are the one type for which a stable market is forming. Since resolution and the S/N ratio improves along with the increase of the magnetic field in NMR analysis, the development of magnets that can produce even higher magnetic fields looks promising. Raising the performance of Nb_3Sn wire is indispensable to increasing the magnetic field of magnets. Specifically, increased Jc and strength are required.

There are primarily two manufacturing methods for Nb_3Sn wire: the bronze process and the internal tin process. Stable mass production process for the bronze-processed Nb_3Sn wire with low-Sn content bronze was established early on, and it has been applied to a great number of NMR magnets.

To improve the layer Jc by reducing the grain size of Nb_3Sn and to increase the ratio of the Nb_3Sn reaction layer in the wire cross section are effective to progress in Jc for Nb_3Sn wires. One method that has been applied to achieving this with the bronze process is the raising of Sn content in bronze matrix. However, as the concentration of Sn increases, the workability of bronze decreases, and since the solid solubility limit of Sn within bronze is 15.8wt%, it used to be thought that around 15wt% was the actual process limit. At present, the dispersion of precipitate within bronze and the improvement of the wire manufacturing process have enabled the manufacture of Nb_3Sn wire that raises the Sn content in bronze matrix to 16wt%. Fig. 1 shows typical Jc for Nb_3Sn wire with different Sn content in bronze matrix. You can see how Jc improves along with the increase of Sn concentration.

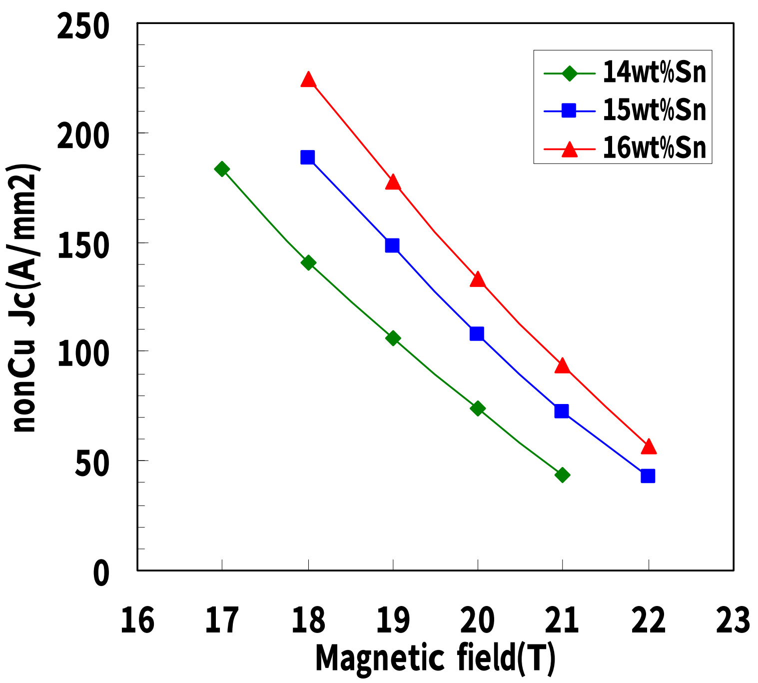

Fig. 1 Improvement of non-Cu Jc by increasing Sn concentration

On the other hand, the increased magnetic fields has made magnets larger, and since the hoop stress that acts on wires is also increasing, the Nb_3Sn wire used on the outer part of Nb_3Sn coils for high-field magnets must have high mechanical strength. JASTEC has achieved a high 0.2% proof strength of 300 MPa by employing Ta as a reinforcing material.[1)]

Ta reinforced high-strength Nb_3Sn wire and 16wt% Sn bronze Nb_3Sn wire were applied to the joint development of an NMR magnet by National Institute for Materials Science (NIMS) and Kobe Steel, Ltd., resulting in a 930 MHz NMR magnet, the best at the time.[2)] Fig. 2 shows external view of the 930 MHz magnet currently in operation at NIMS. This development project is one example of improved Nb_3Sn wire performance directly linking to improved magnet performance. As you can see, wire performance is a strong determinant of final magnet performance, and there is every expectation that wire performance and magnet performance will continue to mutually improve.

Fig. 2 External view of 930 MHz NMR magnet

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Feature Articles: Superconducting Wire and Magnet Technology - Contributions to Mass Production Technology and Large Projects for Metal Wires -

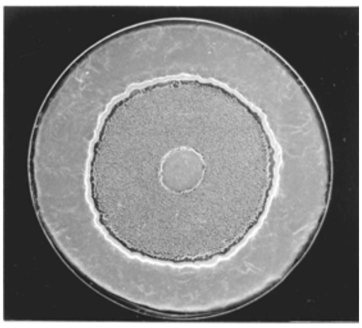
Akio Kimura
Superconducting Products Dept., Nikko Copper Works
Metals Company
The Furukawa Electric Co., Ltd.

The ITER project requires several hundred tons of superconducting wire (Nb_3Sn wire and NbTi wire). Whether all this can be manufactured within the specified timeframe is a major issue facing wire manufacturers.

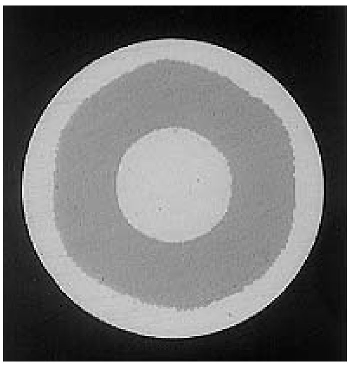
The Large Hadron Collider (LHC) being built in Europe uses 1,200 tons of NbTi superconducting strands. Furukawa Electric received an order for one-eighth of the outer cable (92 tons) for the acceleration ring, which we successfully filled while maintaining extremely stable characteristics for all specifications. In recognition of our achievement, we were presented with the Golden Hadron award by CERN. (Fig. 1)

Fig. 1 2003 Golden Hadron award

Hot extrusion of billet is possible for the Nb_3Sn wire manufacturing method that Furukawa Electric applied to mass production, and we are using the bronze process, which is capable of increased size. Meanwhile, to manufacture NbTi wire, we extrude and draw complex multi-core billet and then perform aging heat treatment midway through to improve flux pinning strength, but almost all portions of the manufacturing process are the same as with Nb_3Sn wire, which makes it possible to easily expand specific technologies and control technologies established by manufacturing various types of wires to the manufacture of other wires. Fig. 2 is a photo of a cross section of Nb_3Sn wire for ITER and NbTi wire for LHC.



a) Nb_3Sn strand (for ITER CS model coil)



b) NbTi strand (for LHC outer cable)

Fig. 2 Cross section photo

Two points considered to be crucial in mass production are the procurement of uniform raw materials and technology for preventing wire breaks.

The most difficult raw material to procure in terms of uniformity is the bronze (Cu-Sn alloy) used in Nb_3Sn wires. The next most difficult to procure is NbTi alloy. LHC screened manufactures and ended up certifying only one.

Both Nb_3Sn and NbTi wire have several thousands of filaments with diameters of several µm. That is why they are both extremely susceptible to breakage due to contaminants. Even an impurity measuring a mere 20 µm can cause a wire break. Wire breaks occur during the wire drawing process, the last phase of wire manufacturing, and when they occur frequently, they dramatically lower yields, increase man-hours, and wreak havoc on manufacturing plans. Consequently, preventing wire breaks is the most crucial point in the mass production of wire.

Furukawa Electric has achieved good results, averaging 0.09 breaks/km, by establishing technological countermeasures in the middle-manufacturing phase for Nb_3Sn wire used in the ITER-CS model coil. We were also able to later reduce the average number of wire breaks for NbTi wire for LHC to the same level.

Large projects such as LHC and ITER may be short term, but it is necessary to keep manufacturing large quantities of superconducting wire for several years. From the standpoint of such projects, wire manufacturers are like leadoff hitters because they kick off production, and their success or failure will dramatically impact the schedule from that point on. Furukawa Electric would like to contribute to and fulfill its responsibilities for ITER based on its mass production technology for highly uniform superconducting wire that has been proven in the LHC project.

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Patent Information

Introduction of Published Unexamined Patents in the 4th Quarter of Fiscal 2005

The following are ISTEC's patents published from January through March 2006. For more information, access the homepage of the Patent Office of Japan and visit the Industrial Property Digital Library (IPDL).

1) Publication No. 2006-036574 "Method for manufacturing RE-Ba-Cu-O based oxide superconductors"

For the crystal growth caused by the thermal decomposition of the RE123 phase, a high-temperature, extended-period melting process had been required in the manufacture of conventional RE123 superconductor bulks that use the RE123 phase plus the RE211 phase or 422 phase compounds as the starting material. This invention provides a manufacturing method for entirely new superconductor bulks that use RE-Ba-O oxide and Ba-Cu-O oxide as their starting materials. Since Ba-Cu-O oxide melts at a far lower temperature than RE-Ba-O oxide and easily reacts with RE-Ba-O oxide to form the RE123 and RE211 phases, it is possible to shorten the melting process. It is also extremely effective in manufacturing large superconducting bulks because it allows the RE123 crystallization process followed by penetrating of the liquid phase Ba-Cu-O into the whole voids of the RE-Ba-O skeleton body.

2) Publication No. 2006-044963 "Oxide superconductors and method for manufacturing the same"

This invention provides a MOD method using fluorocarbon acid that can manufacture La, Nd, and Sm superconductors. With this invention, fluorocarbon acid with a carbon number of 3 or more is made to react with a metal acetate that includes metal M selected from a group consisting of lanthanum, neodymium, and samarium, fluorocarbon acid with a carbon number of 2 is made to react with barium acetate, and fluorocarbon acid with a carbon number of 2 or more is made to react with copper acetate. They are respectively refined and then these reacted products are melted in methanol so that the molar ratio of the aforementioned metal M, barium, and copper, will be 1:2:3. The resultant coating fluid is coated onto a substrate to form a gel film, which is then applied a pre-baking and a heat treatment for crystallization to produce an oxide superconductor.

3) Publication No. 2006-062896 "Oxide superconducting material and method for manufacturing the same"

This invention provides oxide bulk superconductors with a high critical current density by the introduction of effective pinning centers. Specifically, it distributes the particles of the $BaCeO_3$ or $Ba(Ce_{1-a}M_a)O_{3-b}$ ($0 < a < 0.5$, $0 \le b \le 0.5$, M is a metal element such as Zr, Hf, or Sn) phase as pinning centers within RE-Ba-Cu-O (RE is an element selected from the Y, La, Nd, Sm, Eu, Gd, Dy, Ho, Er, Tm, Yb group) 123 phase matrix. Furthermore, this oxide superconducting material is characterized by the addition of Pt and/or Rh.

4) Publication No. 2006-062897 "Oxide superconducting material and method for manufacturing the same"

This invention provides a manufacturing method for oxide bulk superconductors that have a high critical density and little disparity in superconducting characteristics by refining the microscopic structure of the material. Specifically, this oxide superconducting material is characterized by the intermingling of area (A)

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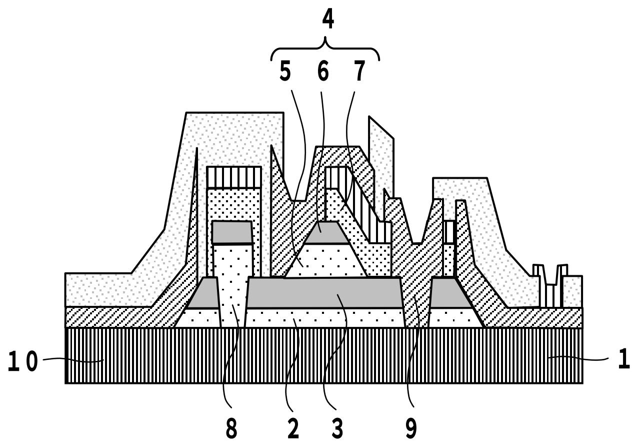
containing relatively large RE_2BaCuO_5 phase or $RE_{4-2z}Ba_{2+2z}Cu_{2-z}O_{10-d}$ ($0 \le z \le 0.1$, $-0.5 \le d \le 0.5$) phase particles and area (B) containing extremely fine RE_2BaCuO_5 phase or $RE_{4-2z}Ba_{2+2z}Cu_{2-z}O_{10-d}$ phase particles in a $RE_{1+x}Ba_{2-x}Cu_3O_y$ (RE is at least one element selected from the Y, La, Nd, Sm, Eu, Gd, Dy, Ho, Er, Tm, Yb group) superconducting matrix.

5) Publication No. 2006-066783 "Superconducting circuit device and method for manufacturing the same"

In the conventional method for manufacturing superconducting circuits, a succeeding layer is formed on the previous layer with its layer patterns. But it is recognized that the existence of a ground plane affects the surface roughness of the succeeding layer, that is an insulating layer or a superconducting base electrode layer, it causes large spreading in the critical current of Josephson junctions. This invention is characterized that the pattern formation for the superconducting ground plane is finally carried out after successive formations of the ground plane, 2nd insulating layer, and Josephson junctions on the aforementioned insulating layer.

Diagram of fundamental structure



1: Substrate 2: Ground plane 3: 1st insulating layer 4: Josephson junction element 5: Base electrode 6: Base insulation layer 7: Counter electrode 8: Ground plane contact hole 9: Moat 10: 2nd insulating layer

6) Publication No. 2006-083022 "Oxide superconductors and method for manufacturing the same"

This invention relates to oxide superconductors that are manufactured by the TFA-MOD method and exhibit high superconducting characteristics. The primary component of the oxide superconductors from this invention are represented by the general expression $LnBa_2Cu_3O_{7-x}$ (here, Ln is at least two types selected from the group consisting Gd, Tb, Dy, Ho, Er, and Tm and the molar content of each element is 10 to 90%) and characterized by the small inclusion of 10^{-2} to10^{-6} fluorine of copper at molar ratio. As a result, the precursor film obtained by mixing the raw material solutions of Ln superconductors can adjust its lattice constant with the substrate, and the obtained superconducting film contains a high percentage of c axis-oriented particles even though a thick film is formed on the substrate, thereby dramatically improving superconducting characteristics.

(Katsuo Nakazato, Director, Research and Development Promotion Division, SRL/ISTEC)

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Standardization Activities

Topics in March

- JIS H 7308 (Copper to non-copper volume ratio of Nb_3Sn composite superconducting wires) and JIS H 7309 (Critical temperature of Nb-Ti, Nb_3Sn, and Bi-system oxide composite superconductors by a resistance method) issued -

The Japanese Standards Association issued the following two Japanese Industrial Standards (JIS) related to superconductivity on January 20.

Title: Superconductivity - Part 12: Matrix to superconductor volume ratio measurement - Copper to non-copper volume ratio of Nb_3Sn composite superconducting wires
Standard no.: JIS H 7308
Date established: January 20, 2006
Issued by: Japanese Standards Association
Organization of standard: Introduction, scope, normative reference, terms and definitions, principles, apparatus, measurement procedure, calculation of results, precision and accuracy of test method, test report, Annex A, Annex B, Annex C, Annex D, Annex E, Annex F, Annex G, and explanations.
Overview of test method: Test methods that adopt the principle of the paper mass method are specified for separating and weighing each site from the cross section photo of a Nb_3Sn composite superconductor with a cross section from 0.1 mm^2 to 3 mm^2 and a copper ratio of 0.1 or more.
Draft standard compiled by: This draft was compiled by installing the JIS Draft Compilation WG6 (Supervisor: Prof. Takakazu Shintomi, Nihon University) under the JIS Draft Compilation Committee (Chairman: Prof. Kozo Osamura, Kyoto University).
Corresponding international standard: IEC 61788-12:2002 Superconductivity - Part 12: Matrix to superconductor volume ratio measurement - Copper to non-copper volume ratio of Nb_3Sn composite superconducting wires

Title: Superconductivity - Part 10: Critical temperature measurement - Critical temperature of Nb-Ti, Nb_3Sn, and Bi-system oxide composite superconductors by a resistance method
Standard No.: JIS H 7309
Date Established: January 20, 2006
Issued by: Japanese Standards Association
Organization of standard: Introduction, scope, normative reference, terms and definitions, determinating of critical temperature, requirements, apparatus, measurement procedure, Tc determination, accuracy precision, test report, Annex A, and explanations.
Overview of test method: Critical temperature test methods by the resistance method and targeting Nb-Ti, Nb_3Sn, and Bi-system oxide composite superconductors used for industrial applications are specified.
Draft standard compiled by: This draft was compiled by installing the JIS Draft Compilation WG11 (Supervisor: Prof. Satoru Murase, Okayama University) under the JIS Draft Compilation Committee (Chairman: Prof. Kozo Osamura, Kyoto University).
Corresponding international standard: IEC 61788-10:2002 Superconductivity - Part 10: Critical temperature measurement - Critical temperature of Nb-Ti, Nb_3Sn and Bi-system oxide composite

superconductors by a resistance method

Order copies of JIS standards directly from:
Japanese Standards Association
4-1-24 Akasaka, Minato-ku, Tokyo 107-8440 Japan
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Web store (http://www.jsa.or.jp)

(Yasuzo Tanaka, Director, Standardization Department, ISTEC)

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