Summer, 2011 Date of Issue: July 15, 2011

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

Akihiko Tsutai, Director
International Affairs Division, ISTEC

Award

Superconductor Technologies Inc. (May 12, 2011)

Superconductor Technologies Inc. (STI) has received the MICO award in recognition of its potentially disruptive and market-changing intellectual property (IP). The MICO award was presented by MDB Capital Group at the second annual Bright Lights Conference in New York City. The Bright Lights conference focuses on publicly traded companies with disruptive and market-changing IP, providing institutional investors with the opportunity to discover companies with embedded IP values that have been largely unrecognized. Jeff Quiram, STI's president and chief executive officer, commented, "We are leveraging our extensive IP portfolio and manufacturing expertise to develop second generation (2G) HTS wire for large emerging power generation device and electricity distribution markets. We are honored to receive the MICO award, which recognizes our significant IP portfolio and the progress we have made applying our industry leading expertise in HTS materials and manufacturing for existing applications that include high power transmission cables, superconducting fault current limiters, and superconducting motors and generators."
Source:
"STI Received MICO Award at MDB Capitals Bright Lights Conference 2011"
Superconductor Technologies Inc. press release (May 12, 2011)
http://phx.corporate-ir.net/phoenix.zhtml?c=70847&p=irol-newsArticle&ID=1562955&highlight

Power

Converteam (April 4, 2011)

Converteam presented a wide range of products and services at the Hanover Fair in Germany. Included in this presentation was the Hydrogenie project. With financing from the European Union, Converteam is developing and building the first HTS generator to operate with practically no losses in a hydroelectric plant. The generator is scheduled to begin operation in Germany later this year. The HTS generator promises a quantum leap in efficiency as well as space and weight savings of up to 70 %, compared with conventional solutions. The new technology for hydroelectric power plants represents an increasingly profitable, environmentally friendly source of power generation.
Source:
"Converteam at the Hanover Fair – with environmentally-friendly drive solutions"
Converteam press release (April 4, 2011)
http://www.converteam.com/majic/pageServer/100400019a0000/en/20110404-2-HanoverFair-eco-friendly-sol.html

American Superconductor Corporation (April 5, 2011)

American Superconductor Corporation (AMSC) has issued an update regarding its anticipated financial results for its fourth quarter and fiscal year ending March 31, 2011. The update was issued in response to the refusal of Sinovel Wind Group Co., Ltd. to accept contracted shipments of 1.5-MW and 3-MW wind turbine core electrical components that AMSC was prepared to deliver. These delayed shipments are the primary cause for the lower-than-anticipated financial results for AMSC's fourth quarter and full-year fiscal 2010. AMSC now expects that its total revenues for the fourth quarter will be less than US $42 million and that it will generate a net loss for the fourth quarter on both a GAAP and non-GAAP basis. Consequently, AMSC's full-year fiscal 2010 revenues are now expected to be less than $355 million, compared with the previous forecast of $430 million – 440 million. AMSC's cash balance was also negatively impacted by its increased inventory level relate to the refusal of shipments by SInovel and Sinovel's failure to pay AMSC for some contracted shipments made in fiscal year 2010. Such events have also caused AMSC to review the appropriateness of the timing of its revenue recognition on approximately $56 million in unpaid shipments made during the second, third, and fourth quarters of fiscal 2010. AMSC is continuing to have active discussions with Sinovel regarding when Sinovel will accept further shipments and when it will be able to pay for past shipments.

Source:
"AMSC Issues Update Regarding its Anticipated Fourth Quarter and Fiscal Year 2010 Financial Results"
American Superconductor Corporation press release (April 5, 2010)
http://phx.corporate-ir.net/phoenix.zhtml?c=86422&p=irol-newsArticle_Print&ID=1547039&highlight

Zenergy Power plc (April 5, 2011)

Zenergy Power plc has received an order from Applied Superconductor Ltd. for an engineering study to create a detailed design and to model the network impact of a saturated-core superconducting fault current limiter (SFCL) for the 33-kV distribution grid in the United Kingdom. Applied Superconductor, in turn, received an order for a 33-kV FCL from CE Electric UK under the Low Carbon Network Fund Tier 1 arrangement. Herbert Piereder, CEO of Applied Superconductor, commented, "We believe that strategically placed SFCLs will facilitate the connection of both renewable and non renewable distributed generation. They help the electricity network to withstand the consequential increase in fault level without the need for major network reinforcements. We are currently looking at larger scale applications which will lead to improved security and quality of electrical supply at affordable price levels."

Source:
"Order for Design and Engineering of 33-kV FCL"
Zenergy Power plc press release (April 5, 2011)
http://www.zenergypower.com/images/press_releases/2011/2011-04-05-order-for-design%20and-engineering-of-33-kV-fcl.pdf

Superconductor Technologies Inc. (April 6, 2011)

Superconductor Technologies Inc. (STI) has announced that Southwire Company has completed the testing of STI's second-generation HTS wire samples, confirming that the samples met the company's initial requirements for HTS AC power cable applications. The Los Alamos National Lab also performed the same measurements on the same wire samples and obtained matching results. Jeff Quiram, STI's president and chief executive officer, commented, "STI's pioneering work using RCE-CDR to make HTS wire is promising an effective low-cost alternative to current manufacturing processes for HTS wire. Southwire's validation demonstrates that our world-class 2G HTS wire technology is on track to enable innovative AC power applications. We are eager to continue our work with Southwire in these exciting

programs and we look forward to developing a business relationship for that purpose."
Source: "Superconductor Technologies Inc. Meets 2G HTS Wire Customer Requirements for HTS AC Power Cable Applications"
Superconductor Technologies Inc. press release (April 6, 2011)
http://phx.corporate-ir.net/phoenix.zhtml?c=70847&p=irol-newsArticle&ID=1547158&highlight

Zenergy Power plc (April 13, April 14, and May 24, 2011)

On February 11, 2011, the Board of Zenergy Power announced the completion of a review of the Group's business and strategic options and an assessment of the long-term viability of the Group's overall strategy. At that time, the Group concluded that Zenergy's business could best be developed as part of a larger group possessing access to funding and the necessary commercial relationships. Accordingly, the Board began the process of seeking a purchaser for the group. Subsequently, the Board was advised by representatives of certain shareholders that these shareholders do not believe that selling the company would be in their best interests and that if the Board were to continue pursuing the sale of the company, the representatives would put forward a resolution to remove the non-executive Directors (NEDs) from the Board. After consideration, the NEDs concluded that in view of the level of support, it would not be in the best interests of the Company and shareholders to enter into a public debate regarding the Company's strategy. Consequently, the Board has resolved to terminate the sale process. The NEDs have also resigned from the board, and a new Executive Chairman, Simon Cleaver, and two new non-executive Directors, David Whelan and Georg Oehm, have joined the Board.

Regarding Zenergy's new business strategy, the new Executive Chairman Simon Cleaver commented, "The changed Board firmly believes that to have sold the Company in its entirety at the current time would not have maximized the potential value of Zenergy. High Temperature Superconductivity (HTS) has the ability to provide a step change in efficiency levels for electronic power distribution networks (grids), electrical metal heating and renewable power generation and Zenergy is almost certainly the global leader in the field. Whilst we need to get our sleeves rolled up and conduct an immediate review of the Company before we issue any detailed plans, our initial strategy is based on using the Company's specialist IP and knowledge to form joint ventures and strategic alliances to help commercialize Zenergy's products. We are pleased to have concluded these Board changes. The Board will now be focused on giving the business a new and very clear strategic direction with the aim of restoring shareholder value and working with industry partners to continue developing what the Board believes is a suite of market leading products."

In a subsequent statement made at the company's Annual General Meeting on May 24, 2011, Mr. Cleaver elaborated, "The previous board's decision to put the Company into an 'Offer Period', which has now ended, and announce that the Company was for sale, both surprised and disappointed me. I have always believed that the intellectual property and technologies developed by Zenergy are both significant and valuable and, was therefore concerned that this approach was unlikely to maximize the value of the Company. Both David Whelan and Dr Georg Oehm who recently joined the Board and who represent parties with significant interests in Zenergy, together with a substantial number of other shareholders, agreed with this assessment. We did not take this action lightly. We were aware of the limited time horizon in which to enact a turnaround. We simply believed, and still do, that Zenergy Power is one of the leading exponents of High Temperature Superconductivity in the world and that this valuable intellectual property was at risk of being sold as a distressed asset."

After a review of the business, the new Board has found that the cash and burn rates are as previously stated and with the exception of a few well-documented and previously announced delays, no fundamental problems or technical issues exist. Technology development is progressing, although further time is needed to fully develop and commercialize these products. A cost base review to identify areas where savings may be possible is presently ongoing. Regarding the company's commercialization strategy, Mr. Cleaver commented, "To achieve full commercialization we need both commercial and strategic partners. This is not a new observation, as the Company has always needed partners. Our products in development are products for the global marketplace. Zenergy lacks the infrastructure and reach to sell and maintain these products on a global scale. We are encouraged by the strong level of interest we have received from numerous significant industrial companies in developing a relationship with Zenergy. Whilst the process is at an early stage, we are engaging with these parties to determine levels and areas of interest."

Source:
"Change of Directorate, End of offer period"
Zenergy Power plc press release (April 13, 2011)
http://www.zenergypower.com/images/press_releases/2011/2011-04-13-directorate-change-and-end-of-offer-period.pdf
"New Directors & Strategy Update"
Zenergy Power plc press release (April 14, 2011)
http://www.zenergypower.com/images/press_releases/2011/2011-04-14-new-directors-and-strategy-update.pdf
"AGM Statement"
Zenergy Power plc press release (May 24, 2011)
http://www.zenergypower.com/images/press_releases/2011/2011-05-24-agm-statement.pdf

Nexans (April 15, 2011)

Nexans and 13 European partners have reached a significant milestone in the progression of the EC-funded ECCOFLOW project to develop an innovative and multi-purpose superconducting fault current limiter (SFCL) suitable for a variety of utility applications. The group announced that the design and development phase of the four-year project has now been completed and that the manufacturing of the SFCL will soon begin. The ECCOFLOW SFCL will be assembled at Nexans' facility in Germany and will be installed at an Endesa substation in Palma de Mallorca, Spain, for testing. The device will use second-generation HTS tapes for the current limiting components and represents the first multi-purpose unit suitable for applications at different locations in the European grid. Once testing in Mallorca has been completed, a long-term test in the Vychodoslovenska Energetika a.s. power network in Košice (Slovakia) will begin. The ECCOFLOW project is being coordinated by Nexans and involves partners from throughout the European Union, including several electric utilities.

Source:
"Nexans coordinates the ECCOFLOW project for superconducting fault current limiter (SFCL) with new generation tapes"
Nexans press release (April 15, 2011)
http://www.nexans.com/eservice/Corporate-en/navigatepub_142482_-30414/Nexans_coordinates_the_ECCOFLOW_project_for_superc.html

American Superconductor Corporation (April 21, 2011)

American Superconductor Corporation (AMSC) has announced that its HTS wire is being used in an electrical substation built by the Institute of Electrical Engineering, China Academy of Science (IEE CAS) in Baiyin, China. The IEE CAS is a scientific research base focused on the high-tech research and development of new electrical engineering and energy technologies. Dr. Xiao Liye, head of the IEE CAS, commented, "The Baiyin superconductor substation is one of the most ambitious superconductor projects

undertaken to date anywhere in the world. This is a holistic project that demonstrates how superconductors will be applied in substations throughout China in the years ahead. As China's electricity needs continue to increase, these solutions will be essential to maintain a high level of efficiency and reliability for our homes and businesses." The substation began operation in February 2011 and includes all of the following systems utilizing AMSC's HTS wire: a superconductor fault current limiter, a superconductor power cable system, a superconductor magnetic energy storage (SMES) system, and a superconductor transformer. Greg Yurek, American Superconductor founder and Chief Executive Officer, commented, "China is moving forward on multiple fronts to become a first large-scale, commercial adopter of superconductor power grid solutions. We applaud IEE CAS for developing superconductor products and implementing them in the Baiyin substation, and we look forward to supporting many more such implementations in China in the years ahead."
Source:
"American Superconductor Wire Serves in Superconductor Electrical Substation in China"
American Superconductor Corporation press release (April 21, 2010)
http://phx.corporate-ir.net/phoenix.zhtml?c=86422&p=irol-newsArticle_Print&ID=1553151&highlight

Superconductor Technologies Inc. (May 4, 2011)

Superconductor Technologies Inc. (STI) reported its financial results for its first fiscal quarter, ending April 2, 2011. The company's total net revenues amounted to US $1.6 million, compared with $3.4 million for the same quarter in the previous fiscal year. The net loss for the quarter was $3.7 million, compared with $2.5 million for the same quarter in the previous year. Jeff Quiram, president and chief executive officer of STI, reported that significant progress had been made in the company's second-generation HTS wire initiative during the first quarter: "In early February, we produced and delivered wire samples for all three of our target applications: HTS wind turbines, HTS power cables and superconducting fault current limiters (SFCL). Our wire samples have now been tested and validated by three entities: Southwire Company, one of North America's largest wire and cable providers; Los Alamos National Laboratory; and an industry leading manufacturer of large turbines and motors. Having demonstrated that our proprietary HTS manufacturing process is capable of producing wire that meets customer specifications, our next objective is to establish commercial relationships with customers that will incorporate STI wire into new HTS devices. We are also on track with our plans to adapt our manufacturing process to produce 2G HTS wire in the longer lengths required by our customers." As of April 2, 2011, STI had $16.1 million in cash and cash equivalents. During the quarter, the company received $12.4 million in net proceeds from a registered direct offering of common stock. At the end of the quarter, STI had a backlog of $72,000, compared with $724,000 at the end of the same quarter in the previous fiscal year.
Source:
"Superconductor Technologies Reports First Quarter 2011 Results"
Superconductor Technologies Inc. press release (May 4, 2011)
http://phx.corporate-ir.net/phoenix.zhtml?c=70847&p=irol-newsArticle&ID=1559144&highlight

IOP Publishing (May 15, 2011)

In its journal *Superconductor Science and Technology*, IOP Publishing has published a study in which researchers examining Bi2212 reported that the capabilities of this material are limited by the formation of bubbles during the fabrication process. Bi2212 is presently the only high-temperature superconductor that can be fabricated into a flexible round wire for use in magnet construction. For magnet applications, the wires must exhibit a high critical current density that can be sustained in the presence of large magnetic fields. Previous studies have shown that the critical current varies markedly according to the wire length, leading researchers at the Applied Superconductivity Center and the National High Magnetic Field Laboratory at Florida State University to conclude that this variability may be caused by the connectivity of Bi2212 grains within the wires. Bi2212 wires are fabricated using the powder-in-tube (PIT) method. To clarify the processes occurring between the critical melt and re-growth steps in this process, the researchers rapidly cooled wire samples at different times during the melting process. Using scanning electron microscopy and synchrotron X-ray microtomography, the researchers observed that the small powder pores that are inherent to the PIT process agglomerate into large bubbles upon entering the melting stage. This process results in the division of the Bi2212 filaments into discrete segments with excellent connectivity that are blocked by the residual bubbles, impairing the long-range filament connectivity and suppressing current flow. The results suggest that a key approach to improving the critical current density of this material may be to make the material denser prior to the melting stage. Various means of accomplishing this densification process are now being examined.

Source:
"Bubble formation with filaments of melt processed Bi2212 wires and its strongly negative effect on the critical current density" (*Superconductor Science & Technology* **24** 075009)
http://iopscience.iop.org/0953-2048/24/7/075009
http://www.iop.org/news/11/may/page_50926.html

American Superconductor Corporation (May 24, 2011)

American Superconductor Corporation (AMSC) has announced that Daniel P. McGahn, President and Chief Operating Officer, has been appointed Chief Executive Officer and a member of the Board of Directors, effective June 1, 2011. Mr. McGahn will succeed Gregory J. Yurek, who is retiring after founding AMSC and serving the company for more than two decades. Dr. Yurek will continue to serve as Chairman of the Board until AMSC's annual meeting of stockholders in August and as a Senior Advisor to the company for the next two years. Dr. Yurek commented, "The past 24 years have been challenging, exhilarating and rewarding. Together with a great team at AMSC, we have been a super conductor technology pioneer and evolved into a dynamic power technologies company. Having worked with Dan for nearly five years, I am confident in his ability to lead the company through today's obstacles and into another era of growth." Regarding the succession, John Vander Sande, Lead Director of AMSC's Board of Directors, commented, "Dan has impressed all of us in his time at AMSC. He is the ideal person to lead AMSC forward upon Greg's retirement. The Board has the utmost confidence in Dan's ability to achieve a new level of success by accelerating AMSC's business diversification. We are indebted to Greg for the significant contributions he has made to AMSC during the past 24 years and are pleased that he has agreed to serve as a Senior Advisor to smooth the transition process."

Source:
"AMSC Announces CEO Transition"
American Superconductor Corporation press release (May 24, 2010)
http://phx.corporate-ir.net/phoenix.zhtml?c=86422&p=irol-newsArticle_Print&ID=1567401&highlight

American Superconductor Corporation (May 31, 2011)

American Superconductor Corporation (AMSC) has announced that the reporting of its financial results for the fiscal year ending March 31, 2011, will be delayed and has requested an extension of up to 15 days to file its Annual Report with the Securities and Exchange Commission. The company stated that additional time is required to prepare and audit the company's financial statements for fiscal 2010, including a review of some revenues associated with shipments to customers in China during the second, third, and fourth fiscal quarters; this review will most likely result in the reversal of the recognition of a material amount of revenue that the company had included when estimating revenues of "less than $355 million" for the full fiscal year in a press release dated April 5, 2011.

To align its spending with near-term revenues, AMSC has implemented a hiring freeze and has significantly reduced travel and discretionary spending in addition to reducing its global head count by 10%. In addition, AMSC is reviewing options to secure additional financing that would enable the company to complete its acquisition of The Switch, a power technologies company headquartered in Finland.

AMSC's financial results were adversely impacted by the refusal of Sinovel Wind Group Co., Ltd. to accept shipments at the end of March 2011 as well as their failure to pay AMSC for certain contracted shipments completed in fiscal year 2010. AMSC is continuing regular executive-level discussion with Sinovel and expects that it will continue to do business with this customer.

Source:
"AMSC to Delay Reporting Fourth Quarter and Fiscal Year End Financial Results"
American Superconductor Corporation press release (May 31, 2010)
http://phx.corporate-ir.net/phoenix.zhtml?c=86422&p=irol-newsArticle_Print&ID=1569300&highlight

NMR

Bruker (April 11, 2011)

Bruker has extended its Ascend™ series of high performance, compact NMR magnets to now cover a range from 400 MHz to 850 MHz. Ascend magnets feature advanced superconductors and proprietary magnet technology, enabling smaller, lighter magnet coils that allow significant reductions in physical size, weight, magnetic stray field, drift, and cryogen consumption. In particular, Bruker's proprietary superconducting joint technology enables the drift behavior to be reduced by 50 % of the level featured by the previous generation of magnets, thereby optimizing magnetic field stability. Together, the above-mentioned features make Ascend magnets easier to site, safer to run, and less expensive to operate.

Source:
"Bruker Expands its Ascend™ NMR Magnet Series for Higher Performance, Easier Siting, and More Economic Operation"
Bruker press release (April 11, 2011)
http://www.bruker-biospin.com/pr110411-5.html

Bruker (April 11, 2011)

Bruker has announced the release of the CryoProbe™ Prodigy, a game-changing CryoProbe that enables a tremendous boost in sensitivity at an affordable price. The broadband CryoProbe Prodigy uses nitrogen-cooled RF coils and preamplifiers to enhance sensitivity by a factor of 2 – 3 times compared with room-temperature probes. The CryoProbe Prodigy is compatible with the Avance III™ line of NMR spectrometers.

Source:
"Bruker Announces Game-Changing, Affordable CryoProbe™ Prodigy for 3-fole Sensitivity Boost and 10-fold Throughput Enhancement for Routine NMR"
Bruker press release (April 11, 2011)
http://www.bruker-biospin.com/pr110411-1.html

Bruker (April 11, 2011)

Bruker has received two separate orders for 395-GHz Solid State DNP-NMR systems that utilize Dynamic Nuclear Polarization to enhance the sensitivity of solid-state NMR experiments. This new instrument augments the field strength choices for commercial, high-performance DNP-NMR equipment. The 395-GHz Solid State DNP-NMR system is comprised of a 395-GHz gyrotron as the high-power microwave source, Bruker's Ascend 600-MHz 89-mm widebore superconducting magnet, and ultra-fast Avance™ III electronics for NMR detection. The first 395-GHz system will be installed at Bruker's US application facility, where it will be available for continued development, applied research, and customer demonstrations. The first commercial 395-GHz system will be delivered to the University of Guelph (Canada), while a second order for a 395-GHz system has been placed by the Max Planck Institute for Biophysical Chemistry (Germany). Dr. Werner Maas, President of Bruker BioSpin, commented, "We are extremely pleased with these first orders for our novel 395 GHz DNP-NMR systems. The unique research that is ongoing, enabled by the sensitivity breakthrough offered via the DNP enhancement, is creating a paradigm shift in solid state NMR. We are confident that the adoption of this technology by these outstanding researchers will lead to very exciting new science in biological systems."

Source:
"Bruker Announces Two Major Orders for Novel High-Field 395 GHz Solid State DNP-NMR Systems in Canada and Germany"
Bruker press release (April 11, 2011)
http://www.bruker-biospin.com/pr110412.html

Medical

Elekta AB (April 18, 2011)

The Swinburne University of Technology (Melbourne, Australia) has acquired an Elekta Neuromag TRIUX magnetoencephalography (MEG) system for studying brain activity. The system, which is scheduled to become operational in mid-2011, will be sited in a new Advanced Technology Center. The MEG system will be used to study cognitive and visual processes, neurological diseases/disorders, and mental health disorders.

Source:
"Australian Center Readies Brain Research Program for Addition of Elekta MEG System"
Elekta AB press release (April 18, 2011)
http://www.elekta.com/healthcare_international_press_release_20071249.php

Basic

Brookhaven National Laboratory (April 12, 2011)

Researchers at the U.S. Department of Energy's Brookhaven National Laboratory, in collaboration with the Paul Scherrer Institute and the University of Zurich in Switzerland, have discovered that sandwiching a barrier layer between two superconductors can enable superconducting behavior at significantly higher temperatures. The research builds on observations of the 'Giant Proximity Effect' noted in cuprates, in which the supercurrent is able to flow through a thick barrier. As thick layers are relatively easy to fabricate, utilizing the Giant Proximity Effect could simplify on-chip device uniformity – a requirement that has been a major technical hurdle for the development of large-scale integrated superconducting electronics. To further explore the Giant Proximity Effect, the research group engineered complex cuprates using molecular beam epitaxy to synthesize samples of thin films containing layers of lanthanum-cuprate superconductors doped with varying levels of strontium—thereby creating a series of superconductors with varying transition temperatures. The samples were then studied using a novel technique called low-energy muon spin rotation to detect the presence of superconductivity in the outer and inner layers of each sample. By mapping the magnetic fields, the researchers successfully observed the Giant Proximity Effect and found that a thick barrier of superconductor with a T_c of 5 K was capable of transmitting a supercurrent at a temperature four times higher when it was sandwiched between two superconductors with a T_c of 40 K. The group's observations also confirmed that the entire barrier layer is affected by the Giant Proximity Effect. The group's work was published online in *Nature Communications.*

Source:
"Giant Proximity Effect Enhances High-temperature Superconductivity"
Brookhaven National Laboratory press release (April 12, 2011)
http://www.bnl.gov/bnlweb/pubaf/pr/PR_display.asp?prID=1263

Brookhaven National Laboratory (April 27, 2011)

Researchers at the U.S. Department of Energy's Brookhaven National Laboratory (BNL) are using a precise atom-by-atom layering technique to fabricate an ultrathin transistor-like field effect device for studying the conditions that turn insulating materials into high-temperature superconductors. This transition can be studied by applying an external electric field to increase or decrease the level of 'doping'—i.e., the concentration of mobile electrons in the material—and observing how such changes affect the ability of the material to carry a current. To accomplish this using cuprates, however, extremely thin and perfectly uniform films, as well as an electric field measuring more than 10 billion volts per meter, are needed. The BNL team used molecular beam epitaxy to create perfect superconducting thin films one atomic layer at a time, precisely controlling the thickness of each layer. This technique was then applied to the fabrication of an ultrathin superconducting field effect device that enables the charge separation necessary for the above-mentioned studies to be achieved. Using this device, the researchers have found that as the density of mobile charge carriers is increased, a cuprate film transition from insulting to superconducting behavior occurs when the film sheet resistance reaches 6.45 kilo-ohm (exactly equal to the Planck quantum constant divided by twice the electron charge squared). The results also suggest that in addition to electrons pairing in the superconducting state, the electrons also seem to form localized and immobile pairs in the insulating state—a condition not known to occur in any other material. The technical breakthrough enabling the fabrication of the superconducting field effect device has been described in *Nature.*

Source:
"Exploring the superconducting transition in ultra thin films"
Brookhaven National Laboratory press release (April 27, 2011)
http://www.bnl.gov/bnlweb/pubaf/pr/PR_display.asp?prID=1268

Rice University (May 3, 2011)

Researchers at Rice University have offered a theoretical explanation of how two dissimilar types of high-temperature superconductors behave in similar ways. Specifically, they explained how the magnetic properties of electrons in two dissimilar families of pnictides might give rise to superconductivity. One of the parent families of pnictides is a metal that was discovered in 2008; the other is an insulator discovered in

late 2010. Each material, if prepared in a particular way, can become a superconductor at roughly the same temperature. Theoretical physicists have been attempting to determine what might account for the similar behavior between such different compounds. The Rice University researchers believe that the explanation involves subtle differences in the way the iron atoms are arranged in each material. Pnictides are laminates that contain layers of iron separated by layers of other compounds. Chinese scientists recently found a way to selectively remove iron atoms, leaving an orderly pattern of “vacancies” behind. Qimiao Si, the lead researcher for the present paper, suspected that the similarities between the old and new compounds could be explained by the way that electrons behave collectively as they are cooled to the point of superconductivity. Co-author Rong Yu elaborated, “We found that ordered vacancies enhance the tendency of the electrons to lock themselves some distance away from their neighbors in a pattern that physicists call 'Mott localization,' which gives rise to an insulating state. This is an entirely new route toward Mott localization.” Second co-author Jian-Xin Zhu, a scientist at the Los Alamos National Laboratory, added, “What we are learning by comparing the new materials with the older ones is that these quasi-localized spins and the interactions among them are crucial for superconductivity, and that's a lesson that can be potentially applied to tell experimentalists what is good for raising the transition temperature in new families of compounds.” Si concluded, “The new superconductors are arguably the most important iron-based materials that have been discovered since the initial discovery of iron pnictide high-temperature superconductors in 2008. Our theoretical results provide a natural link between the new and old iron-based superconductors, thereby suggesting a universal origin of the superconductivity in these materials.” The group’s theories have been published online in *Physical Review Letters*.
Source:
“Study helps explain behavior of latest high-temp superconductors”
Rice University press release (May 3, 2011)
http://www.media.rice.edu/media/NewsBot.asp?MODE=VIEW&ID=15727

Boston College (May 21, 2011)

Researchers from Boston College, in collaboration with the Chinese Academy of Sciences, the National Institute of Standards and Technology, Oak Ridge National Laboratory, and the University of Tennessee, have used neutron scattering and scanning tunneling microscopy (STM) to examine the interplay between antiferromagnetism (AFM) and superconductivity. Their observations have revealed that AFM, which was previously thought to be a rival phase of superconductivity, may instead coexist with superconductivity. Using a copper oxide doped with additional electrons, the group observed that AFM activity persists as the high-temperature superconductor becomes superconducting. Specifically, the neutron scattering and STM experiments revealed that spin excitations exist during both AFM and superconductivity. While neutron scattering can directly probe spin excitations, STM can identify the behavior of the electrons. Together, this evidence shows the spin excitations in the electronic spectrum, signaling that electron coupling has occurred. The results provide further evidence of the importance of spin excitations to superconductivity in addition to providing a deeper understanding of the interplay between various phases. The group’s research has been reported in *Nature Physics*.
Source:
“Once thought a rival phase, antiferromagnetism coexists with superconductivity”
Boston College press release (May 23, 2011)
http://www.bc.edu/offices/pubaf/news/2011/madhaven05252011.html

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Feature Article: Advancements in Superconducting Industrial Equipment Technology

- Trends in Superconducting Industrial Equipment Technology

Hiroyuki Ohsaki, Professor
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An example of the industrial application of superconducting technology is the metallic Niobium-titanium (NbTi) superconducting wire magnets that are commercially employed for a silicon single-crystal pulling process. As the magnets require cryogenic cooling the additional energy burden adds to the cost of industrializing this process. Nevertheless, this commercial application of superconducting technology has been achieved due to both the fabrication of high quality and high performance materials and the realization of an efficient process, enabling this technology to be accepted and diffused into the mainstream market place since the mid 1990s. However, as the realization of a low-cost high temperature superconducting wire remains an issue, it is hoped that high-temperature superconducting magnet technology leads to practical applications due to the superiority in operational performance offered and the contribution to energy savings.

The Magnetic Billet Heating (MBH) method generates heat by rotating billets in a high magnetic field. This method has attracted a great deal of interest in recent years as an alternative-heating route for non-ferrous metal billet extrusion such as aluminum and copper. Since 2004, both Zenergy Power and Bültmann have undertaken research and development in MBH, and in 2008, resulted with the installation of a heating system in the aluminum billet extrusion factory of WeserAlu. The system clearly proved and verified the superior characteristics of MBH by heating a 6-inch diameter aluminum billet. The system was later also installed in other regions of Germany and Italy for heating aluminum and copper. The limiting inhomogeneous temperature distribution within the billet has realized an improvement of the process speeds and productivity, producing an efficient system by reducing both operational and maintenance costs.

In Japan, research and development of a High Temperature Superconducting Synchronous Machine is a flourishing area, attracting a significant deal of attention for the future development of motors for ships and cars.

The knowledge that a bulk superconductor holds superior magnetic flux pinning characteristics has instigated research and development for many years towards an application utilizing this characteristic. Even though nothing has been achieved in terms of practical applications, it is highly expected that ongoing research and development endeavors aimed for various potential applications will prove fruitful.

In February 2010, the Minister of Land, Infrastructure, Transport and Tourism, informed the Transport Policy Council to hold an enquiry regarding Chuo Shinkansen connecting Tokyo and Osaka, in which the public have a great interest. The enquiry focused on the assignments of company bodies responsible in the business operations, the construction and infrastructure decisions regarding the plan for the proposed Chuo Shinkansen. The discussion took place at the Chuo Shinkansen subcommittee meeting and the interim report was submitted in December 2010. The report took into consideration the expected volume of demand and the construction costs in determining the optimum route for the Chuo Shinkansen, with the option of the South Alps loop connecting its shortest distance as a possible route. Central Japan Railway Company was deemed suitable as the main body responsible for the business operations and the construction of the routes from Tokyo and Osaka, with consideration of combined management benefits with Tokaido Shinkansen, as well as their development experience in superconducting maglev technologies. The Chuo Shinkansen is highly regarded as possibly the first superconducting maglev. The development, verification and design have progressed towards the realization of practical technologies and systems, targeting its first operation between Tokyo and Nagoya in 2027. In parallel, technological development is continuously progressing, focusing on improvements in areas like cost reduction, low-cost maintenance and system safety. It is strongly desired that these areas will not prove too challenging and therefore lead to a possibly early launch of business operations extending further to Osaka. However, an important development theme for superconducting magnets is dependent on the future realization of high temperature superconducting wire applications.

With the large numbers of potential future industrial applications, of superconducting technology it is important to focus on the research and development for industrial equipment targets, which meets the specifications required for practical applications. Current developments for high temperature superconducting wires have led to improved wire performance characteristics, low-costs, advancements in refrigeration cooling technologies and improvements in superconducting coiling technologies. It is therefore desired that further research and development will contribute to producing a forerunner technology, leading to the realization of future practical applications utilizing high magnetic fields, large electromagnetic force, establishing applications with a high degree of functionality.

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Feature Article: Advancements in Superconducting Industrial Equipment Technology

- Advancements in Superconducting Magnetic Separation Systems

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Activities ranging from fundamental to application-specific research and development for industrial equipment have been undertaken in this field. These activities have impacted positively on the practical use of industrial equipment. This article discusses two types of industrial applications; (1) superconducting magnetic separation technology for soil and underground wastewater purification and (2) a system designed to remove iron from coal.

Firstly, water purification technology developed specifically for soil and underground wastewater is discussed. Developed in collaboration with Kajima Corporation and MS Engineering, the system employs a Superconducting High Gradient Magnetic Separation (HGMS) method to collect and recycle iron particulates from discharged wastewater that are used as reducing agents in soil and underground wastewater purification construction work. Successful collection and recycling of these valuable, functional iron particulates using magnets significantly reduced construction costs. The economic benefits were also far-reaching with this technology. Those benefits contributed to promote soil and underground wastewater purification methods (the so-called Enviro Jet method), and established a potential new field of application where superconducting magnet technology can be applied. Especially in Japan superconducting magnets were employed at a civil engineering site for the first time. The initial outcomes were positive and established the potential application of utilizing superconducting magnetic technology at an industrial scale.

Volatile Organic Compounds (VOCs), such as trichloroethylene, are the main chemical substances that cause soil and underground water contamination. A Jet Mixing method is currently utilized for on-site removal of VOCs, purifying the soil and underground wastewater on the spot and eliminating the need for bespoke transportation requirements. The method mixes water with functional iron particulates forming a reducing agent, which is then transported down to the treatment ground by water-jet. The water-jet transports the iron particulates deep underground, exactly where they are required and is beneficial as the treatment process is done on the spot. However, the process has its shortcomings, with approximately half the iron particulates jetted to the treatment site being discharged along with the wastewater to the surface, increasing operational costs. It was envisaged that operational costs would decrease if more iron particulates from the discharged wastewater were collected and recycled. By combining the Jet Mixing method with superconducting magnets to collect and then recycle the iron particulates, we believe, would increase the acceptance of the Jet Mixing method as the preferred choice of an on-site purification tool, propelling its functionality into the mainstream market. To efficiently and economically collect iron particulates with diameters of around 100 µm, superior method using high performance magnets are required - (no other methods offers both the economic viability and efficiency other than magnetism). However the following issues require resolution: 1) treatment capacity – the volume of discharged wastewater is around 400 L/min. The process therefore needs to highly efficiently segregate iron particulates using magnetic force from this flow of wastewater 2) the removal of the soil attached to the iron particulates collected after magnetic separation. Even though the iron particles are magnetically separated and collected, efficient removal of the soil attached and pure metallic filtering when recycling is a must for quality control issues. 3) The collection efficiency of the iron particulates from the discharged wastewater – poor collection efficiency increases operational costs. The HGMS method utilizing a superconducting magnet is seen as the optimum route to address these issues.

To address the above-mentioned topics, the following methods were employed. For issue 1), the HGMS method combining a superconducting magnet and magnetic filter was employed. During working conditions the effectiveness of the magnetic separation was demonstrated with discharged wastewater flowing up to a maximum of 500 L/min. For issue 2), a process combining powerful magnetic filter was introduced which continuously filtered and washed off the soil attached to the iron particulates by the powerful magnetic force, enabling successful collection of almost pure iron particulates). For issue 3), demonstration of this process at a actual construction site showed an iron-particulate collection efficiency from the discharged wastewater greater than 98%, proving the viability of this method as a route to reduce construction operational costs.

A system removing iron from coal is now introduced. Zian Zhu, from the Institute of High Energy Physics, Chinese Academy of Science, set up and developed a system to remove iron from coal at the Rizhao port in China. Experimental testing at the site began in 2009, lasting one year. The tests showed that the system served its intended application and in June 2010 was put into industrial use. The plan now is to build a further 10 similar systems in the future. Previously, systems for iron removal from coal traditionally employed electromagnets. However, due to rapidly increasing demands for coal in China, the necessity to improve operational performance led to the development of a separation system using a superconducting magnet. In 2009, China became a net importer of coal with the import volume rapidly increasing and with demand set to increase even further. The insatiable appetite for coal is influenced by the rapid rise and advancement of high-coal consuming industries such as electricity, steel-making, building materials and chemical industries.

In China, coalmining uses dynamite to extract coal. This process occasionally leaves behind some unexploded ordinance, which gets shipped together with the coal. A report from Ehime prefecture, Japan, found four such unexploded ordinances in a shipment of coal from China destined for boiler fuel. It was therefore recognized that to remove iron-related contaminants such as, detonating caps, wires and transportation pipes from the coal was imperative. This is where a superconducting magnet has proved crucial in the efficient magnetic separation of iron from coal and the research and development of this separation system has already started.

With a total capacity of 10 million tons of coal per annum, this system is able to remove iron from coal (approximately 500 mm thick coal bed), load the coal onto a conveyor belt running at 5 m/s, running the distance of 550 mm from the end. The superconducting magnet produces a magnetic field strength of 0.4 T at the conveyor belt, 3 T at the center coil, rising to a maximum of 5.6 T. The system employs NbTi-based superconducting wires (Cu ratio 4), equipped with a re-condensing refrigerator utilizing liquid Helium dipping shaped coil. The dimensions of the magnet are thus; 900 mm internal diameter, 1200 mm external diameter, 360 mm height, operating at 165 A and producing 224H of inductance. The cryostat bore at room temperature is 630 mm, external diameter 1800 mm, with a height of 2200 mm, taking ten days to cool the cryostat. It is the future intention of Zian Zhu to follow on from this success and attempt to build a system to separate iron-related compounds from Kaoline.

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Feature Article: Advancements in Superconducting Industrial Equipment Technology

- Development of Seismic Isolation Systems based on Superconducting Magnetic Levitation

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Japan presently holds a strong international competitive position with a 40 % share of the world's semiconductor manufacturing equipment industry. Together with Taiwan, Korea, China and other South East Asian countries, they account for approximately 80 % of the annual sales turnover of semiconductor manufacturing equipment. However, these regions are seismically active with a large probability of a large-scale earthquake occurring. The Chuetsu earthquake in 2004, in Niigata prefecture, Japan, was estimated to have caused damages costing 70 billion yen. Current Seismic monitoring systems installed at semiconductor manufacturing plants minimize damage to equipment and add a level of personnel safety. Despite their advantages, these monitoring systems result in production stoppages that are estimated to cost 1 billion yen per day. Therefore, having technology that reduces manufacturing plant downtime or even eliminates the need to stop manufacturing during earthquakes would be most desirable. Hence, such "seismic isolation" technologies are immediately required by industry. Precision tools in semiconductor manufacturing plants employ vibration isolators to attenuate everyday micro vibrations transmitted from an array of sources. However, when used in conjunction with seismic isolation systems, the seismic system affects the operation of the vibration isolators. For that reason, seismic isolation systems operating in conjunction with vibration isolators are considered difficult in principle. However, the design of a seismic isolation system utilizing superconducting magnetic levitation is considered a possible solution to overcome this issue. This system is able to remove all horizontal vibrations from everyday fine vibrations to earthquake-related vibrations, regardless of vibration frequency or the amplitude transmitted. The seismic isolation system therefore ensures the safety and relief of workers, eliminating production downtimes during a large-scale earthquake.

Figure 1 shows a schematic diagram of the proposed seismic isolation system. It is composed of three layers – the permanent magnetic rail (the bottom/first layer), a bulk superconductor and permanent magnetic rail (the middle/second layer), and a top (third layer), bulk superconductor[1]. Figure 2 shows the principle of operation of the proposed system during a vibration test. The lowest layer is vibrated at an oblique angle to the horizontal (45 degrees), with the middle layer constrained to move in one direction only (either left or right), with the in-plane movement removed between the lower and middle layers. The top layer of the seismic isolation system remains stationary with the movement in the

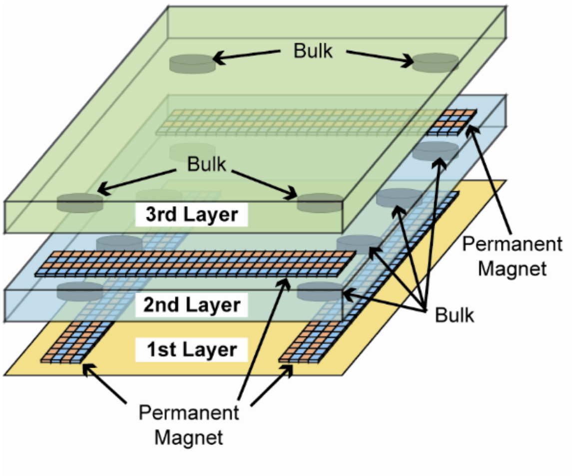

Fig.1 The seismic isolation system based on superconducting magnetic levitation.

left or right directions suppressed between the middle and top layer. In order for the seismic isolation system to suppress vibrations it is important that the magnetic field distribution is homogeneous in the longitudinal direction of the permanent magnet. As the magnetic field gradient determines the levitation force on the HTS bulk, in the longitudinal direction of the permanent magnet this magnetic field gradient does not exist. Therefore the levitation force generated is dependent on the magnetic field gradient along the width of the rail of the permanent magnet. In order to increase the levitation force further, research and development on a hybrid system combining only permanent magnets (PM-PM system), with a HTS bulk and permanent magnet (HTS-PM system) is currently under investigation. Permanent magnets arranged in a Hallbach array are another ongoing research activity[2-3]. Results from this system design do indeed remove the horizontal vibrations transmitted to the top layer, with transmissions due to micro vibrations measuring less than 1 % - equal to or better isolation efficiency than systems currently available. Research and development is still advancing with the aims of maintaining levitation stability when stationary and designing technology to suppress vertical vibrations.

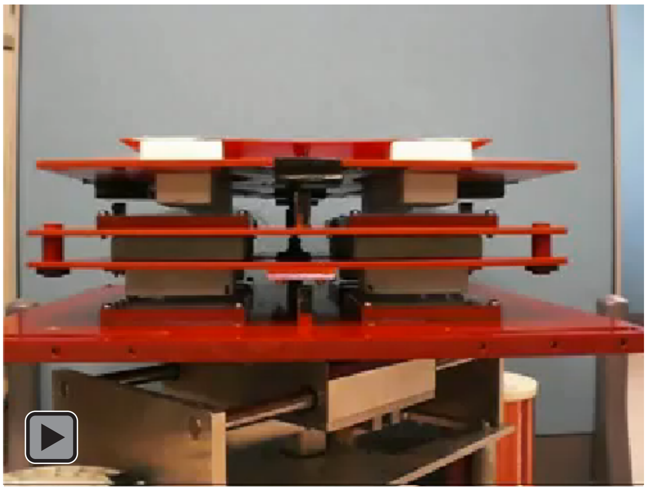

Fig. 2 Employing the principle of superconducting magnetic levitation, a movie of the seismic isolation system shows its operational effectiveness.

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Feature Article: Advancements in Superconducting Industrial Equipment Technology

- Development of High-Temperature Superconducting (HTS) Bulk Actuator

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1. The concept of HTS bulk actuator

Progress in HTS bulk research and development has led to greater critical current densities along with improved mechanical strength, offering superior performance characteristics for highly expected applications ranging from magnetic bearings, flywheels, conveyor systems and motors. Experimental testing and numerical analysis on HTS bulk actuators that would allow remote operations in spatially separated environments have been undertaken in our laboratory[1-3]. Figure 1 shows the development concept of our superconducting actuator. It consists of 2-D arranged electromagnets, which form the stator, the HTS bulk forming the rotor and a control system. The Field Cooling Method traps the HTS bulk actuator and the drive current applied to the stators generates the 3-D magnetic field distribution giving the actuator the capability to move and rotate in both horizontal and vertical directions.

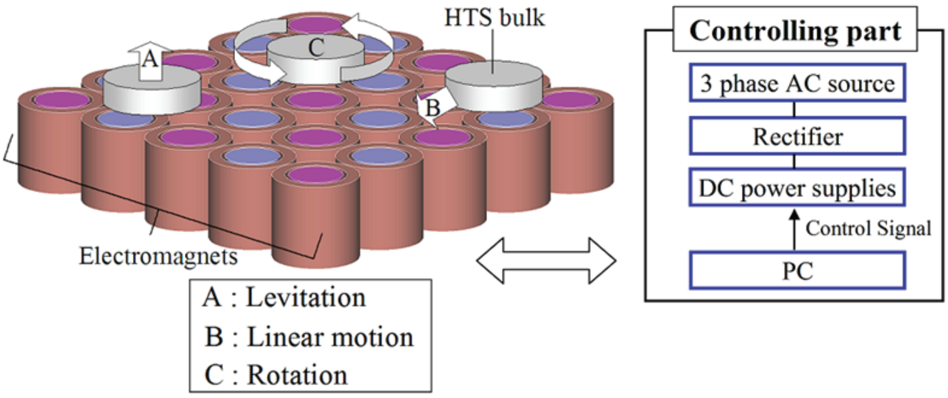

Fig. 1 A 3-D schematic of the superconducting actuator

2. Designs of the electromagnets

In order to establish stable levitation and operational characteristics of the proposed superconducting actuator, the magnetic field distribution of the stator electromagnets as well as controlling their strength are all important parameters. Initially two types of electromagnets were investigated. The left hand side of figure 2 shows one portion of a cylindrical electromagnet made to investigate the operational characteristics. In order to have finer control of movement and rotation of the actuator, 8-pole electromagnets were

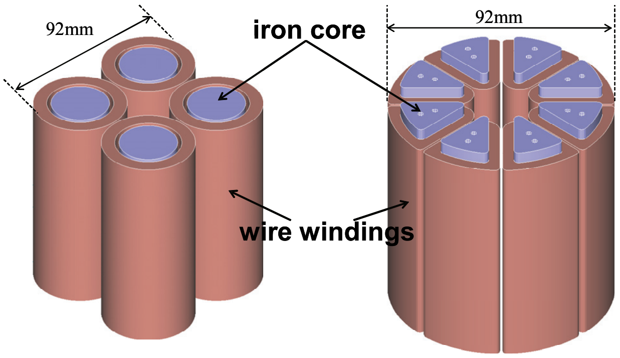

Fig. 2 Cylindrical shaped electromagnet (left hand side) and 8-polar electromagnet (right hand side)

constructed, which are shown on the right hand side of figure 2. The left-hand-side contour map in figure 3 shows the magnetic flux distribution generated on top of an energized 8-pole electromagnet arranged in a NSNSNSNS pattern. The right-hand-side contour map in figure 3 shows the measured trapped magnetic flux distribution of the HTS bulk.

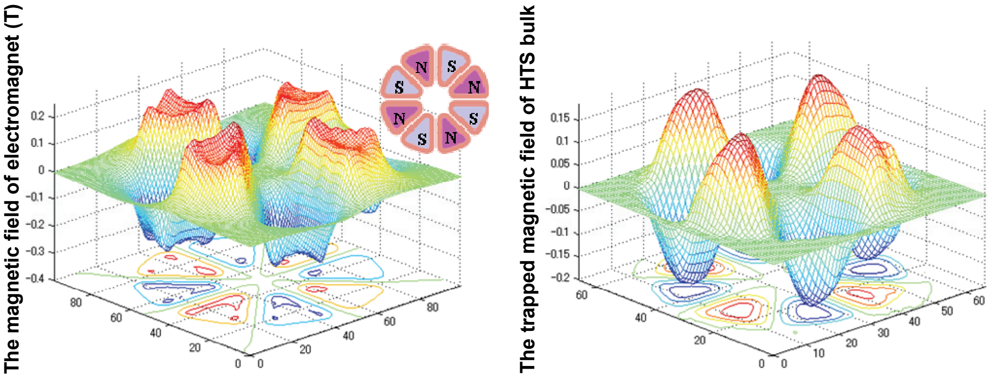

Fig. 3 Magnetic flux distribution generated by 8-polar electromagnet at NSNSNSNS magnetization pattern (left drawing) and the trapped magnetic flux distribution of HTS bulk (right drawing)

To improve the magnetic flux distribution and strength of the electromagnets, arranging the electromagnets in a quadrangle shape, along with optimizing the design of the shape, the size of the iron core and the thickness of coil were undertaken. Measuring the characteristics of the electromagnetic fields by Numerical Electromagnetic Field Analysis when 10A DC is applied, measured diagonally (as indicated by the dotted line on top of electromagnets), of both the cylindrical (iron core diameter 28mmm) and quadrangle-shaped (iron core one side 28mm) electromagnets is shown in figure 4. The findings show that the magnetic flux distribution is greater towards the inner side of the electromagnet, with a greater improvement in magnetic field strengths of the quadrangular-shaped magnets. Further investigations comparing the characteristics of the cylindrical and quadrangular shaped electromagnets were undertaken. The levitation force applied to the HTS bulk was measured as a function of the actual iron-core diameter under the same conditions for each shape of electromagnet. The results show superior levitation characteristics of the quadrangular shaped electromagnet compared with the cylindrical electromagnet.

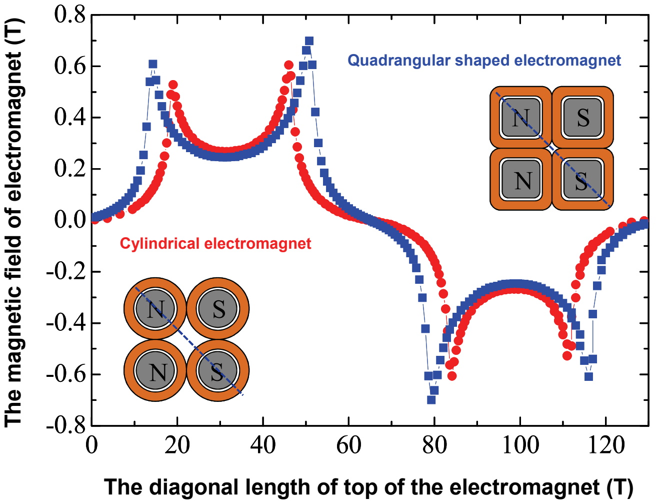

Fig. 4 Magnetic field distribution characteristics of cylindrical and quadrangular-shaped electromagnet geometries as measured by numerical electromagnetic field analysis

3. Investigations of DC/AC drive current control methods

Figure 5 shows the schematic of the electromagnet assembly for the DC control system. Horizontal transport occurs by switching either ON or OFF the DC current to each individual electromagnet. Figure 6 shows the measurement results of the levitation force applied to HTS bulk as a function of drive current required. The findings show that different pole-pattern assemblies give rise to varying degrees of relationship between drive current and levitation force. At low drive currents, compared to NNSS pattern arrangement, the NSNS pattern arrangement shows the magnetic saturation of the icon core assembly. Although the DC control system is a simple technique providing drive currents to the individual electromagnets by either switching ON or OFF, it does suffer drawbacks associated with HTS bulk overshooting and having no speed control in its design. In order to address these issues, research is underway into utilizing an AC control system to realize the smooth transport of actuator and speed control. Figure 7 shows the electromagnets incorporating an AC control system, with figure 8 showing a contour map of the pole patterns including the bulk superconductor. Numerical Electromagnetic Field Analysis is conducted on basis of Finite Element Analysis to determine the AC waveform utilized for AC control system. Multiple bipolar power switches are used to investigate the dependency of frequency as well as the dependency of the magnetization gap[4-5].

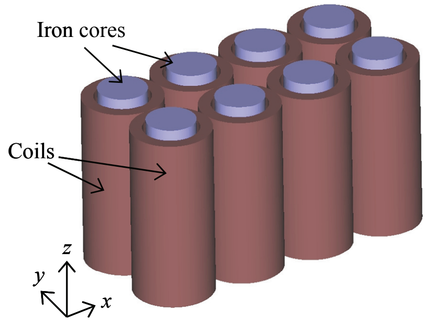

Fig. 5 Schematic of the DC-controlled electromagnet

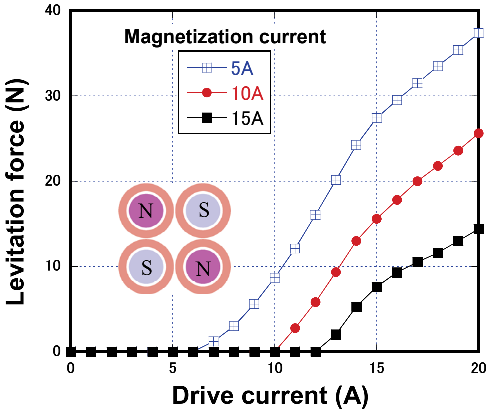

Fig. 6 Measurements of the levitation force by DC control

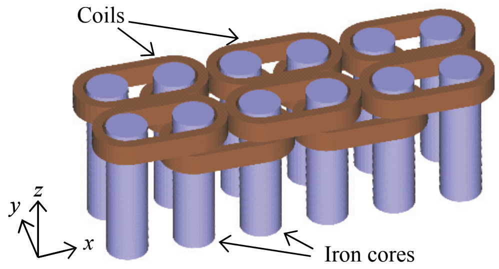

Fig. 7 Schematic of the AC-controlled electromagnet

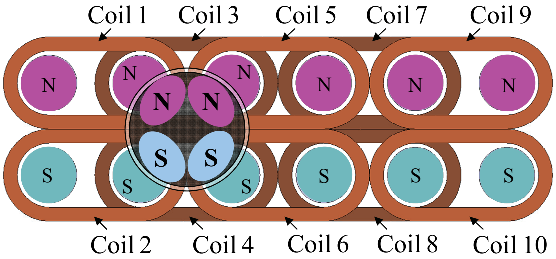

Fig. 8 Top view of the AC-controlled electromagnet along with its corresponding pole pattern

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Feature Article: Advancements in Superconducting Industrial Equipment Technology

- Development of Conveyor System utilizing Superconducting Magnetic Levitation

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Recent technological advances in superconducting magnetic levitation have instigated an increase in the necessity of conveyor system applications. Utilizing the pinning force in a superconductor, efforts are focused on the development of a stable levitation conveyer system without the need for complex control systems and which consume no electricity for its levitation. A levitation conveyer system that employs pulse-field magnetization (PFM) to overcome the inability to modify the levitation characteristics of superconductors is currently under development.

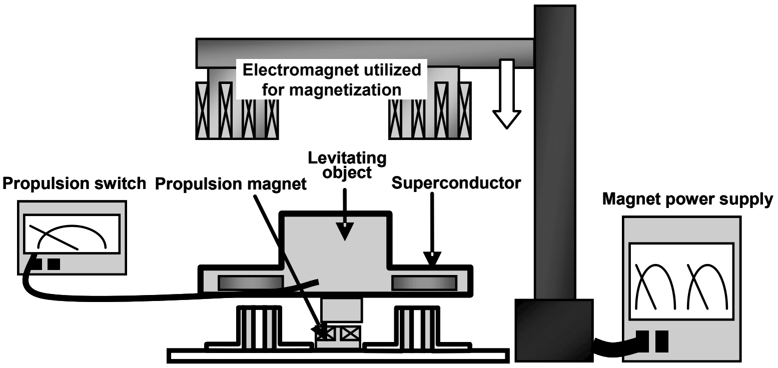

Fig.1 The system overview

The overview of the system employed in this development work is shown in figure 1. A linear-induction motor propulsion system is utilized in this study, consisting of a pulsed power supply to drive the magnets and an AC-powered, three-layer switch required for propulsion. The superconductors, (dia 20 mm), are positioned at the four corners of the container, fixed and then cooled by liquid nitrogen. Based on the analysis of magnetic fields, we fabricated a magnetic rail shown by the schematic in figure 2. Permanent magnets with their poles facing each other are arranged to concentrate the magnetic flux in the yoke of the magnetic rails. The magnetic yoke equalizes the magnetic field distribution along the magnetic rail. The PFM (1) magnetization method combines the electromagnet into one section of the lower part of the magnetic rail. The magnetic field distribution generated by the PFM at the electromagnet is set in the same magnetic field direction as the permanent magnet and designed to prevent the trapped magnetic field distribution anomaly usually associated with a superconductor. The PFM (2) employs the electromagnets described in the schematic shown in figure 1. The mechanism to magnetize from above enables the design of bigger electromagnets. The arm assembly shown in the figure moves in the direction indicated by the arrow and magnetically attaches to the conveyer. A decline in the magnetic distribution on the part of the electromagnet used for PFM (1) results in a decrease in levitation height, however, the PFM (2) system design improves this situation.

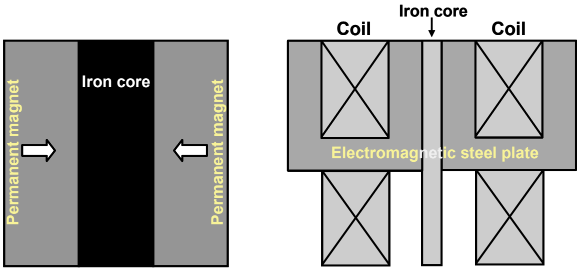

Fig. 2 The magnetic rail system

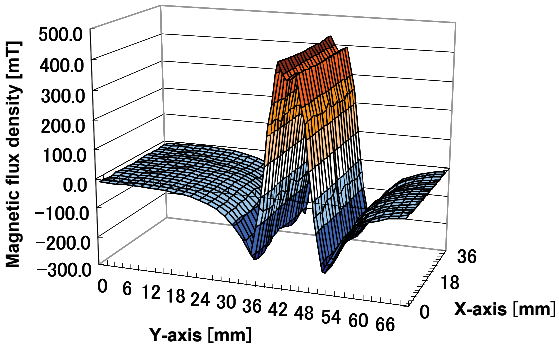

Fig. 3 The measured magnetic flux density of the magnetic rail

Figure 3 shows the results of the measured magnetic flux density in the Z direction, 1 mm above the magnetic rail. The magnetic flux density in the Y direction, located around 0 mm, is almost negligible even though the iron core of the linear propulsion motor is located there. The magnetic flux density of the magnetic rail shows very little change in the X direction. These results prove that stable levitation is possible.

Figure 4 shows the propulsion force when the levitation gap is increased to 3 mm. Aluminum cooling increases the electrical conductivity leading to the measured propulsion force being seven times greater than at room temperature. Compared to the cooled aluminum itself and the aluminum combined with electromagnetic steel plate, the magnetic flux concentrates onto the plate resulting in the measured propulsion force being three times greater.

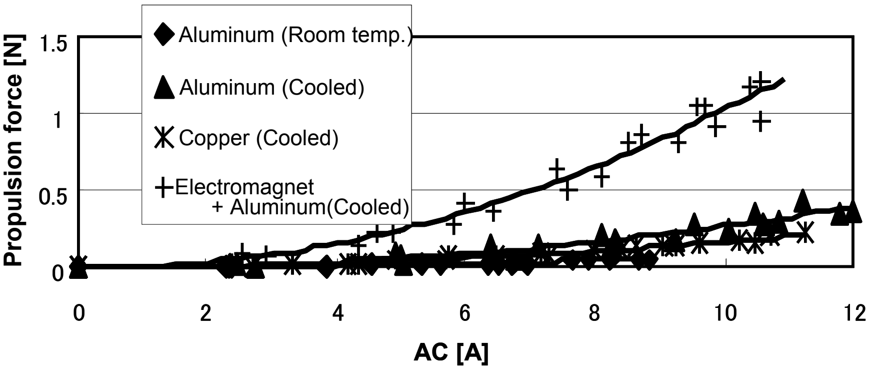

Fig. 4 Propulsion force

Figure 5 shows the relationship between the changes in the levitation characteristics with the maximum magnetic flux density, before and after using PFM method (1). The initial levitation gap was 5 mm, with applied voltages of 200 V and 250 V for PFM method (1) and (2), respectively. For method (1), and maximum magnetic flux density exceeding 0.2 T, the levitation characteristic varies almost proportionally to the magnetic flux density.

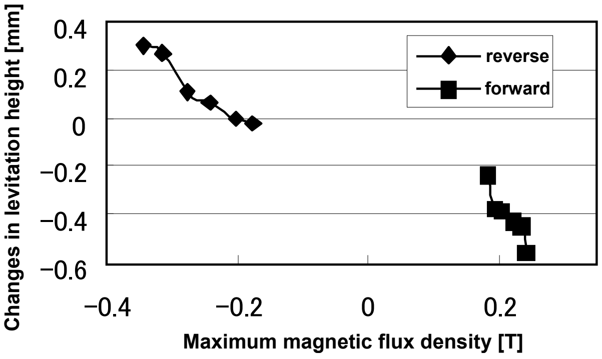

Fig. 5 Changes in levitation height for PFM method (1)

After utilizing method (2), the dispersion of magnetic flux density trapped in the superconductor was measured 1 mm above the surface of the superconductors. Figure 6 shows the trapped magnetic flux density generated in the forward direction, when the pulse-field is applied in the same direction as the permanent magnets. Figure 7 shows the trapped magnetic flux generated in the reverse direction, or when the pulse-field is applied in the opposite direction to the permanent magnets. The findings reveal that changes in the trapped magnetic field by the PFM method was confirmed on the surface. However, when operated in the reverse direction subsurface changes in the magnetic field were small. The results demonstrate that PFM can be employed to change the levitation height as it is largely related to the trapped magnetic field generated at the subsurface compared to the surface.

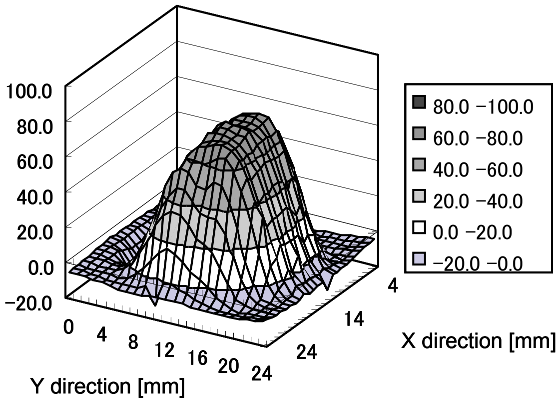

Fig. 6 Trapped magnetic field distribution
in the forward direction

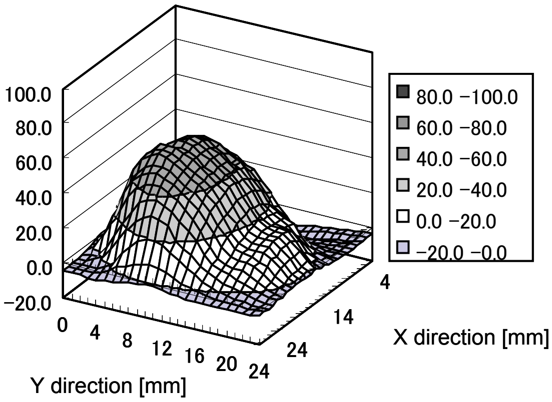

Fig. 7 Trapped magnetic field distribution
in the reverse direction

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Feature Article: Advancements in Superconducting Industrial Equipment Technology

- Advancements in Superconducting Motor Technology for Ship Propulsion

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Steep rises in oil prices, global warming prevention and tougher international regulations of exhaust emissions, has forced the marine industry on reducing fuel consumptions and cutting carbon emissions even further. Technology is being developed to replace the conventional diesel ship propulsion systems with electric propulsion systems operated using a superconducting motor. The superconducting motor consumes less electric power and is more compact allowing it to fit into restricted spaces on board a ship, enabling a ship hull design to become more streamlined with less water resistance. Another benefit is to reduce energy loss since the motor drives the ship's propellers directly without the reduction gear. Together, these advantages of superconducting technology can significantly reduce the fuel consumption.

It is a recent memory that in the USA a 36.5 MW power-output superconducting motor for ship propulsion was recently developed, successfully completing full-load tests1). In Europe as well as in Korea, megawatt power-output superconducting motors for ship propulsion have been under developing2). In Japan, superconducting motors have been developed utilizing a bulk superconductor in a rotating magnet pole-filed3) as well as axially arranged iron-core coils made from Bi-based wires4). A recent development of megawatt-class superconducting motor5) has been rapidly advancing with join efforts form Kawasaki Heavy Industries, Ltd, Tokyo University of Marine Science and Technology, National Maritime Research Institute, Japanese Super-conductivity Organization Co., Ltd, and Sumitomo Electric Industries, LTD. The research efforts of this group have led to the development of a prototype system (shown below), with a designed power output of 1MW. Just last year, the group has demonstrated that when two out of six superconducting coils were installed on each pole the motor's output reached 450kW, an outstanding efficiency rate of 98% - the highest record in Japan. The results from these tests imply that the motor's power output will reach 1MW when all superconducting coils are installed. With support from NEDO, the group is continuously carrying out research and development activities to realize a 3MW power-output superconducting motor by 2012.

Megawatt-class superconducting motor

The challenges remaining include, testing the long-term operation and the endurance with varying external loads of the superconducting motor. Additionally, the developments of a highly efficient cooling system enable to withstand ship motions in stormy sea states, performance enhancements of high temperature superconducting wires and further cost reduction are necessary for the potential future applications for superconducting motors in the maritime industry. It is highly expected that research and development advances further towards the realization of these applications at industrial level in the near future.

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Feature Article: Advancements in Superconducting Industrial Equipment Technology
- Development of High Temperature Superconductor Induction/Synchronous Machine (HTS-ISM) for Transportation Equipment Applications

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Utilizing high temperature superconductor windings in a squirrel-cage design, the group's research and development aims are the High Temperature Superconductor Induction/Synchronous Machine (HTS-ISM) for transportation equipment applications1). This project was launched as the "2009 Energy Conservation Technology Development Project (Second Public Offering)", commissioned by NEDO (New Energy and Industrial Technology Development Organization). Over the short interval of one year and three months and due to the efforts of project members at the forefront in this industry, as well as strong backup provided by NEDO, the following outcomes have been achieved.

Initial research steps involve experimental study on fully-superconducting HTS-ISM installed in several small, kW-class machines. Investigations proceeded cautiously as there have been no successful reports of a fully-HTS with high-speed synchronous rotation modes exceeding 1000 rpm in radial-gap shaped synchronous machines. Initial investigations thus focused on the stator windings with particular effort dedicated to employing a racetrack double pancake coil and searching for optimum coil assembly and cooling methods. The hard work resulted in successful synchronous rotation at 300 rpm2) followed shortly by successful continuous synchronous rotation at 1800 rpm3). By taking advantage of the nonlinear current transport characteristics of the HTS windings in a squirrel-cage design, we experimentally confirmed the slip rotational mode as fail safe, developed analysis code for transient characteristics4) based upon voltage equations and tested the characteristics of stable rotation control5).

Following on from the success of above-mentioned small machine, a 20KW-class prototype machine was developed with the understanding that the limiting characteristics such as, critical currents characteristics in the iron core3) and allowable bending radius6), be those characteristics currently offered by commercially available HTS tapes. The design aim of this prototype machine has been to minimize the stator size by investigating factors such as electromagnetic field analysis, coil magnetomotive force and the HTS coil shape geometry. A prototype coil was thus fabricated from HTS tape that met the agreed characteristics. Detailed measurement tests were undertaken to determine the DC and AC transport characteristics3), current transport characteristics within the iron core7) as well as certain reproducibility. Furthermore, considering that the iron core is placed in a cryogenic temperature environment, several candidate materials were evaluated by standard measurement methods for their brittleness8) and iron loss characteristics9) at cryogenic temperatures. Based on the measurement results, a silicon steel sheet was selected as the offering the best characteristics and therefore employed to fabricate a prototype stator as well as rotor core. Various trials were undertaken to optimize the fabrication process and technology necessary to produce the windings for both the HTS stator as well as the rotor. The 20KW-class machine was finally completed after an optimum construction process to produce the HTS windings required for this core was achieved. Although a great deal of time and effort was required to reach this stage, important knowhow and knowledge was gained.

A small-sized cryostat developed for the 20kW-class prototype machine was designed to minimize thermal invasion and developed a cooling mechanism to reduce thermal stresses. Furthermore, various elaborate shaft designs were also prepared. Integrating the 20kW-class prototype machine with the cryostat was finally accomplished producing the drive motor system. The machine is currently undergoing various tests and the results from those tests will be forthcoming.

In parallel, a compact and highly efficient cryocooler for transportation equipment was fabricated using a Stirling-type cryocooler developed over time by Aisin Seiki Co. Repeated detailed investigations on the compressor performance yielded a COP of 0.075[10)] at 77K – close to a world record. We anticipate achieving a COP of 0.1 soon.

This report highlights the ongoing research and development efforts at our research group aimed at HTS-ISM applications for transportation equipments such as, hybrid cars, trains and ships. For example, the development of hybrid cars utilizing applications of superconducting technology is still a large hurdle to climb, however we see the possible realization in future applications for cars exceeding M-size, but excluding large, MPVs or vans. Of course the realization of applying this technology to other forms of transportation is potentially viable and therefore our research and development endeavors will continue with the aim of bringing HTS-ISM technology into the mainstream in the not too distant future.

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Feature Article: Advancements in Superconducting Industrial Equipment Technology

- Magnetic Billet Heater

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1. AC induction heating and its limitations

Since the 1920s[1)] AC induction heating has been used in the metal processing industry. The metallic billets for extrusion are placed inside a copper magnetic coil through which an AC current is applied generating an alternating magnetic field. The alternating magnetic field induces eddy currents within the metal billets, and based upon Joule's law, generates heat by the electrical resistance of the materials. The coil is usually made from water-cooled copper tube to prevent it from melting. For the AC induction process it is the copper coil heating that causes the biggest energy loss. In the case of aluminum heating the energy efficiency of this process is typically 40 to 50 %.

Thus there is room for improvement in the heating process itself. Conventional induction heating employs AC frequency with 50/60 Hz producing eddy currents mainly at the surface of the billet, which take time to heat the entire billet uniformly. Process adjustments are always necessary for AC induction heating as the heating efficiency is dependent upon a number of factors such as, the dimensions of the billet, the alloy composition and the power source employed.

2. A new approach involving DC magnetic heating

Metal induction heating system utilizing DC power source was studied during the 1950s. However, it was more than 30 years later that this was actually realized, in 1990[2)], when an inventor in the USA published a method for DC induction heating with powerful magnets. This method was understood to offer a number of advantages over conventional AC induction heating, however the required technology for DC induction heating to become a reality was not economically viable at that time. Today, however, with industrially manufactured superconducting wires and advanced solid-state drive motors have enabled the realization of DC-powered magnetic heaters for commercial applications[3-6)]. The process of magnetic heating is simple in technological terms offering far greater energy efficiencies than currently offered by AC induction heating. Additionally, billets are heated up with uniform temperature and faster, thereby preventing damage caused by surface over-heating effects.

July 2008 saw the first commercial operation of a DC-powered magnetic heater. The coil operated with a power input of 10W, with zero-resistance electricity flow through a superconductor, is able to generate a strong enough magnetic field necessary to induce heating. As the magnetic field of the DC-powered coil does not vary with time, the billet rotates within the magnetic field inducing eddy currents. However, eddy currents in the material oppose rotational motion forming powerful braking torques, which can only be overcome using electric motors of a size of 100-500 kW. Thus, it is the highly efficient motors that are responsible for billet heating rather than inefficient AC induction coils. Within the rotating billet the energy consumed by the motor is transformed to heat. A schematic of the magnetic induction heater shown on the left-hand-side of figure 1 converts more than 80% of the energy consumed by the motor into heating within the billet.

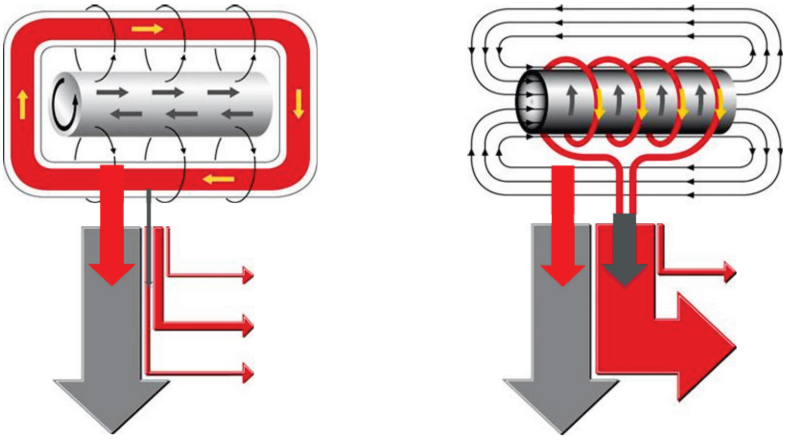

Fig. 1 Energy Loss of HTS magnetic induction heating (left figure) and AC induction heating (right figure).

The effects of utilizing "mechanical" rather than "electrical" frequency resulted in heat energies generated by DC-powered magnetic heating penetrating three times deeper than using AC induction heating process, with no surface effects, providing a more uniform heating profile. Furthermore, the faster heating process removes the risk of local-meltdown of the material and reduces the soaking time for the billets to achieve a uniform temperature profile. Experiments to investigate the temperature profile of aluminum billet, measured by the thermocouple and tap hole, recorded a temperature difference from one end to the other of the aluminum billet, as well as from the centre to the surface of the aluminum billet of ±6°C, compared to ±15°C for an AC induction heating.

3. Simple technical design

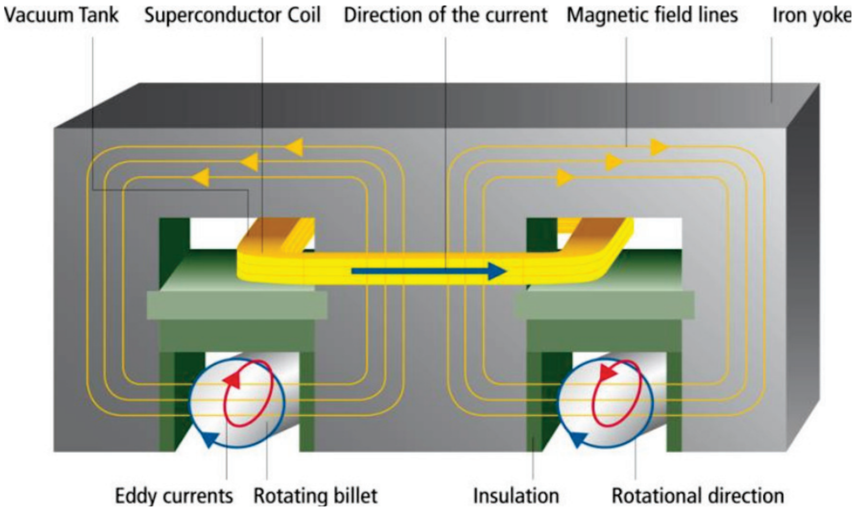

Fig. 2 Schematic drawings of the magnet billet heater

As shown in figure 2, the main system of the magnetic heater is the superconducting magnet. The refrigeration system to keep the magnet at its operational temperature is composed of off-the-shelf components that are commercially available in refrigeration technology. The magnetic field generated by the superconducting magnet passes through two thermally insulated heating chambers that house the rotating billets. Electric motors placed in each chamber provide the rotational energy required for induction energy. The motor is able to slide to receive billets with different lengths, with the hydraulic system supplying the clamping pressure to the motors to stabilize the billet. All the heat generated goes into heating the rotating billets. Compared with conventional gas heaters and AC induction heater, DC magnetic heater is not subjected to significant temperature increases, vibrations or any other mechanical stress factors.

4. Experiences gained from the installation and the operation

The machine is designed to be set-up easily and quickly at site. The compact footprint of the machine ensured that it is easily integrated into the existing production layout. The target temperature of aluminum billet due to homogeneous temperature could be 30 °C lower than that for conventional process. The lower billet temperature made possible the extrusion of aluminum with more complicated and detailed shapes. Moreover, the quality of the surface finishes is improved. The magnetic billet heater increased the productivity by an average of 25 %, with the heating cost of aluminum billets reduced by approximately 50 % when compared with conventional AC induction heating.

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Feature Article: Advancements in Superconducting Wires/Tapes Technology

- REBCO Coated Conductors

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Considering the numerous benefits of cost, in-field characteristics, mechanical strength and ac loss in REBCO coated conductors, development of REBCO coated conductors have made remarkable progress in the national projects mainly in Japan and USA over the past 10 years. The past 10 years has seen the benchmarking characteristic value of I_c (critical current) x L (length) being fiercely contested by researchers world-wide, in particular in both Japan and USA who were always competing to ensure the top spot. In August 2009, SuperPower reported an I_cL = 300 kAm (I_c=282 A/cm width, L=1062 m). After a brief research update interval, in autumn 2010, Fujikura reported results with I_cL = 375 kAm (I_c=609 A/cm width, L=615m) with IBAD-PLD tapes. Furthermore, this year Fujikura improved on the previous value by reporting an I_cL = 467 kAm (I_c= 572 A/cm width, L=816m).

The rapid technological advances of REBCO coated conductors have led to recent developments of application devices using them. However, the timing of some applications with their specifications required implies that certain characteristics are not mature and still requires development, e.g. improvement in tape characteristics such as, the in-field strength I_c characteristics, and ability of mass production with high speed and low cost. Additionally, requirements from the applications vary and the specifications currently required exceed what is presently available today. Thus, recent research and development trends for REBCO coated conductors have focused on component technology in order to meet the specifications required from the applications.

Fundamental research for improvement of in-field characteristics has initially focused on short-tape developments for motor and SMES applications that utilize magnetic fields for their operation. Deposition with BZO nanorods using Pulsed Laser Deposition (PLD) and BZO nanodots using Metal Organic Deposition (MOD) have been taken place by many researcher activities to disperse artificial pinning centers. However, these deposition methods have not as yet extended to develop longer tapes, as there are only a few reported examples of research undertaken with longer tapes. The market leaders in this field are SuperPower, and together with Houston University, reported the introduction of BZO nanorods to the YGdBCO superconducting tapes using MOCVD. The stability of the material in a magnetic field was investigated with the addition of Zr, Y and Gd, achieving a current density of ～100 A/cm width @1 T, ～20 A/cm width @3 T at 75 K. With a view to keep processing costs down a high-rate fabrication process was adopted by ISTEC in Japan, which deposited a thick, high current density (J_c) film of GdBCO by PLD. With 50 m wires, we achieved tape characteristics 1.5 times greater than those already reported by SuperPower, with characteristics of 33A/cm width @3 T at 77 K.

Japan leads the way in the development of thinner, low AC-loss tapes aimed for power generation applications such as, cable and transformer applications. In recent findings, IBAD-MOD deposited tapes in addition to IBAD-PLD tapes, showed that for a 50 m length of tape scribed into five-parts along its width, the AC loss was limited to 20 %. A bespoke tape winding technique for coiling was also confirmed responsible for the reduction in ac loss. Even though SuperPower has demonstrated a reduction in ac loss for short lengths tape, there are currently no published reports attributing the effectiveness of coil design in reducing loss. As more recent topics in this field, ISTEC and Kyushu University has discovered a new phenomenon of drastically small levels of hysteresis loss for REBCO coated conductors with a highly textured tstructure. Research is still at an early stage and thus further experiments will be required to confirm the phenomenon, however the implications of this research are significant possibly leading to an array of future applications.

Whilst Japan leads the world in developing individual component technology targeted for specific applications, the USA still remains one step ahead, with mass production potential. In Japan, technological development in this field has been mainly supported under the national projects, with business sponsorship just recently beginning to emerge. In the USA, AMSC and SuperPower have built up mass production capabilities with AMSC for example, having already over 700 km of annual production capabilities. It is my belief that further technological realizations of applications are around the corner with numerous research reports regarding the price of superconducting tapes are recently emerging. By 2015, SuperPower is aiming to produce tapes priced at around $50/kAm, and Fujikura is targeting to supply 500 A wires at 3000 yen/m (6 yen/Am) by 2015. A South Korean company, SuNAM, have recently aroused worldwide attention by joining the tape production and sales arena, publically declared their long-term vision to supply tapes priced at $80/kAm by 2015, and $25/kAm by 2023.

The recent developments in Japan and abroad of REBCO coated conductor technologies have been discussed. Research and development tape characteristics based solely on $I_c L$ benchmarks are no longer reliable measures of performance. Recent technological developments are focused on application-specific requirements, with additional characteristics such as in-field characteristics and low AC-loss becoming important benchmarks to determine tape performance. It is considered that these trends in tape development will trigger further technological advancements aimed more towards the establishment of mass production and low cost manufacturing and further accelerate the development of tapes for practical applications.

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Feature Article: Advancements in Superconducting Wires/Tapes Technology

- Performance Enhancements of Bi-based Superconducting Wires

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1. The process of critical current improvement

Sumitomo Electric Industries, LTD. is producing high-temperature superconducting wires made from $(Bi,Pb)_2Sr_2Ca_2Cu_3O_y$ （Bi2223) under the trade name of DI-BSCCO. They are fabricated by sintering the combined raw materials in a metal tube by the PIT (Powder In Tube) method. The wires are formed into a 4.3 mm wide tape with a thickness of approximately 0.23 mm. The superconducting tape is embedded in a silver matrix and has a multi-filamentary architecture to provide thermal stability and robustness.

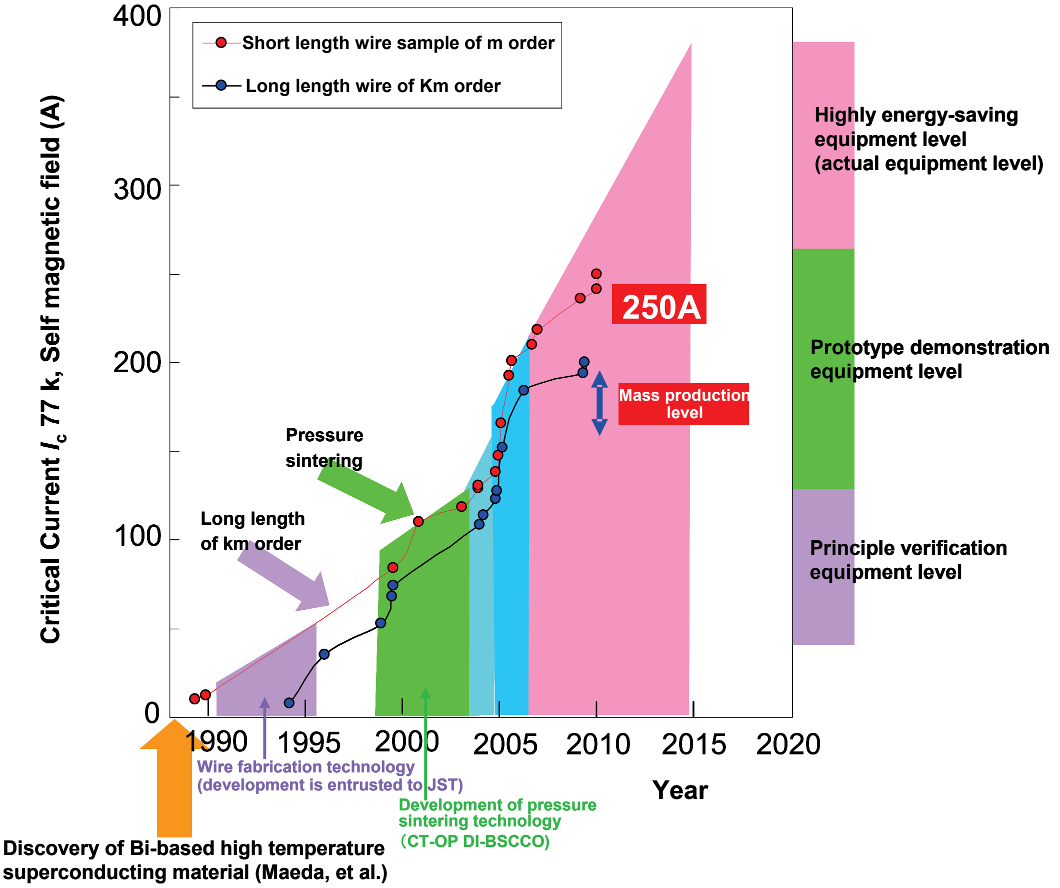


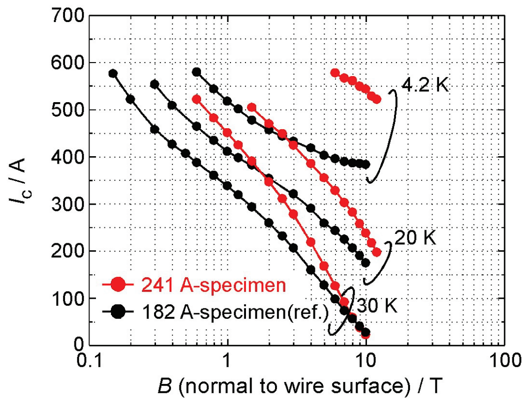
Fig. 1 Sequence of events showing the improvements of Bi-based high temperature superconducting wires

Figure 1 shows the sequence of events that improved critical current capabilities of Bi-based wires. The initial stages of the development and up until 1995, the PIT method with silver became established as fundamental process producing 1 km-class prototype wires. During this time the manufacturing process improved gradually enhancing the critical current characteristics, for a given size of wire achieving 100A at liquid nitrogen temperatures under a self magnetic field. However, it was the development of the pressure sintering method that greatly enhanced wires characteristics. The method reduced local defects that consequently led to improvements in production yields and contributed in improving critical current capabilities as well as increasing mechanical strengths, allowing the Bi-based material system to achieve a status usually reserved for industrial goods. After this, improvements at every manufacturing process step along with the optimization of process parameters for various wire samples, resulted in wires achieving critical currents (77.3 K, under self magnetic field) of 250 A – 233 A for 15 m sample and 200 A for km-class long wire samples, respectively. Presently, a long wire capable of carrying 160-180 A is available for supply at an industrial level. A wire with a high I_c is presently in the middle of mass production process development and a long wire capable of carrying 200 A is estimated to be available at industrial level in the foreseeable future.

2. Others

Without requiring large capital investments the production capacity is estimated to double from current levels of 500 km per annum to 1,000 km per annum in the near future. If demands increase further, it is considered to increase production capacity to meet the demand.

With the variety of applications envisaged for superconducting wires, the characteristics of the critical current are benchmarked according to their liquid nitrogen temperatures and the self magnetic fields. Thus, for applications such as electric cables, it is possible to directly compare the characteristics under the low magnetic field in liquid nitrogen. For magnet applications at 20-30 K, magnetic fields of several T are applied vertically against the wires. Figure 2 shows the magnetic field characteristics at low temperatures of DI-BSCCO wires produced using a standard manufacturing process. High temperature superconducting pinning characteristics at low temperature have been understood to be dependent upon carrier density. By adjusting the carrier density in the same sample, occasionally leads to greater improvements in the magnetic field characteristics at low temperatures than that represented in figure 2. Currently, this data is being collected and summarized along with further investigations into supplying optimized application-specific superconducting wires for the future.



	77 K, s.f.	30 K, 3 T	20 K, 3 T
I_c(trial sample)	241 A	277 A	423 A
I_c(standard Type H)	182 A	205 A	320 A

Fig. 2 Magnetic field characteristics at low temperatures

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Feature Article: Advancements in Superconducting Wires/Tapes Technology
- Process Advancements in MgB_2 Wire Technology

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National Institute for Materials Science

MgB_2 has a higher T_c than conventional metallic superconductors along with strong inter-grain coupling occurring without the need for additional orientation processing. Together with the low cost of Mg and B raw materials these attributes are advantageous for practical applications for MgB_2 wires. Companies have already started manufacturing MgB_2 wires in excess of 1 km. A research group in Italy has demonstrated an open-type MRI system based on MgB_2 wires cooled by a cryogenic refrigeration system. Hospital experimental testing of the MRI system has been undertaken with further research and development geared towards future applications.

The so-called PIT method is the mainstream technique currently employed to fabricate MgB_2 wires. The in-situ PIT method starts off with constituent Mg and B powders, experimentally adding various impurity materials into the powder mix in an attempt to improve the superconducting characteristics. The addition of nano SiC into the powder mix is well documented, however the additions of carbon nanotubes and fullerenes have contributed to large improvements of J_c, especially in high magnetic fields. It is understood that C substitution on the B site is behind both the improvements of J_c and H_{c2}. The addition of organic materials such as hydrocarbon (C_9H_{12}) and carbonhydrate ($C_4H_6O_5$), all have been reported to result in improvements of J_c. Compared to the addition of nano SiC, the findings confirm remarkable improvements in J_c with lesser C substitution on the B site. However, the mechanism by which this occurs is still not well understood.

In general, the in-situ fabrication methods of MgB_2 wires results in a very low filling factor of around 50 % because of the volume shrinkage occurring when Mg and B powders are heat-treated to form the MgB_2 compound. Numerous efforts to improve the filling factors have been attempted. One such method is the Hot Press or Hot Isostatic Press (HIP) method delivering an improvement in J_c, two or three times greater compared to ordinary heating treatment. However, fabricating long wires is proving difficult via this method and still needs to be addressed. On the contrary, Cold Isostatic Pressing method is considered a suitable process to fabricate longer wires. In fact, flat wires produced by simultaneously subjecting all four sides of the wire to pressures of 1.5 GPa followed by an ordinary heat treatment have a filling factor closer to 60 %, with a J_c twice as large at 4.2 K, increasing to approximately eight times as large at 20 K and 7 T.

Reports show that mechanical alloying is an appropriate mixing and reaction technique that improves the filling factor, yielding homogeneous nanocrystalline MgB_2 superconductors. It is the formation of these partial MgB_2 nanoparticles that act as the core seeds promoting the formation of the MgB_2 layer. These findings enable researchers to reduce heat treatment temperatures even further and to improve upon the grain boundary pinning characteristics.

Additional processing routes to obtain high-density MgB_2 layers involve diffusion reacting a pure Mg rod with boron powders. A metal sheath tube with a coaxial internal pure Mg rod is filled with amorphous boron powder packed densely into the space between the Mg rod and the metal sheath tube. This composite is cold worked to a wire. During heat treatment the Mg diffuses into the boron layer leading to the formation of MgB_2.

Recent findings from wires produced using this method have shown remarkably high J_c values than previously. From measurements at 20 K and 3T, J_c values in excess of 100 kA/cm^2 have been recorded. However, as J_c shows rapid decline with increasing a magnetic field, further improvements in wire characteristics are crucial for practical applications utilizing stronger magnetic fields. Additionally, J_e (calculated for the total wire cross-sectional area) is still too low and it is necessary to improve J_e to even higher values by means of advanced microstructure control and cross sectional geometries.

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Feature Article: Advancements in Superconducting Wires/Tapes Technology

- Advancement of Iron-based Superconducting Materials

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It has been three years since the research group directed by Professor Hosono, of Tokyo Institute of Technology, discovered iron-based superconducting materials. Followed by copper-oxide based superconductors, iron-based superconductors form a second group of high temperature superconducting materials. Professor Hosono's group first published on their discovery of LaFeAs (O,F) with a T_c of 26 K in February 2008. This led to a flurry of activity with many groups from both Japan and abroad focusing their research efforts on this new breed of superconducting materials. Just two months after the initial findings it was reported that by substituting La with Sm increased the T_c to 55K. The iron-based systems have many compositional permutations available, each offering the potential of discovering materials exhibiting even higher T_c's. As with the copper-oxide superconducting material systems, the peculiar physical characteristics of the iron-based material system are totally different from metallic superconductor systems. Despite concerted fundamental research efforts at the national level, projects launched in Japan, Germany and China have not yet yielded a T_c higher than 55 K. Nevertheless, together with some 30 types of new iron-based materials discovered to date, the research has led to a better understanding of the physical characteristics. Additionally, the progress development on applications involving wires and electronic devices has been gradually made. The aim of this article is to briefly introduce recent research advancements mainly relating to applications.

The iron-based superconducting materials discovered to date all have a layered structure similar to copper-oxide and from the point of layer structure can be categorized into four major classes as shown by table 1. Charge carrying in superconductors occurs via the tetrahedral networks composed of iron, pnictogen (As and P) or chalcogen (S, Se, Te). The first system discovered consisted of an iron-containing layer, alternately stacked with the tetrahedral layers of RE-O (rare-earth oxides), and now often referred to as 1111 system. The addition of alkali-earth metals (Ca, Sr, Ba) and alkali metals (Li, Na etc) alternately layered in the iron structure produced the 122 and 111 systems, respectively. A simple iron-based layered structure incorporating chalcogens became known as the 11 system. Other than those four categories, many other material systems having a perovskite-like block layer structure have been found. Among these four major classes, the 1111 and the 122 systems with a maximum T_c of 38 K have an upper critical magnetic field B_{c2}, equally as high as the Y-based copper-oxide system. Also, anisotropy is an important parameter for wire applications. The 1111 system has an anisotropy of 5 and is close to the Y-based copper-oxide system. However the 122 system has an anisotropy ranging from 1.5 to 2, as small in size as that measured in MgB_2.

A group based at the Chinese Academy of Science has from the initial stages investigated the fabrication of iron-based superconducting wires using the Powder In Tube (PIT) method, aiming their research and development for potential future applications for wire technology. The group reported that with Fe sheath wires, (superconducting materials (Ba,K)-122, Ag as additions and Ag for internal sheath), they achieved results showing a maximum self-field I_c of 37.5 A (J_c> 3750 A/cm^2), at a temperature of 4.2 K. However, I_c drops rapidly in a magnetic field, indicating that inter-grain coupling is weak. In Japan, the National Institute of Materials Science (NIMS) is making efforts to fabricate wires of the 11, 122 and 1111 material systems using the PIT method. Prototype multi-core wires containing 7 cores based on the 11 system have been fabricated. For the 122 system Ag sheath wires, NIMS has recently reported a self-field I_c of 60 A, with large improvement of J_c of 10^4 A/cm^2. In the presence of a magnetic field, J_c initially drops rapidly but in a high magnetic field of around 18 T, the J_c remained around 10^3 A/cm^2. Thus, these findings suggest that it is possible to fabricate wires for use in strong magnetic fields at low temperatures.

Table 1. Categorization and characteristics of the iron-based superconducting material system

Material system	1111 system	122 system	111 system	11 system
Material composition	ZrCuSiAs	$ThCr_2Si_2$	PbFCl	PbO
Materials and T_c	LaFeAs(O,F) 28 K La(Fe,Co)AsO 14 K $NdFeAsO_{1-y}$ 55 K SmFeAs(O,F) 55 K Ca(Fe,Co)AsF 22 K LaNiBiO 4 K	$(Ba,K)Fe_2As_2$ 38 K $(Sr,K)Fe_2As_2$ 38 K $Ba(Fe,Co)_2As_2$ 23 K $BaFe_2(As,P)_2$ 30 K $BaNi_2P_2$ 3 K $K_xFe_{2-y}Se_2$ 32 K	LiFeAs 18K NaFeAs 15K	FeSe 8 K FeSe(*1) 27 K Fe(Se,Te) 15 K Fe(Se,Te) (*2)21K
Anisotropy γ	5	1.5 - 2		1 - 2

(*1) Under Pressure, (*2)Thin Film

The fabrication of high quality epitaxial films is vital to gain an understanding of the grain boundary characteristics essential for wire applications and to investigate the potential device applications. The 122 material system (T_c of 20-25K) carrier-doped by Co substitution is relatively easy to fabricate as a thin film. Reports from University of Wisconsin, Tokyo Institute of Technology and IFW Dresden in Germany, all demonstrate the fabrication of a high quality thin film based on the 122 material system. Within the framework of Funding Program of World-Leading Innovative R&D on Science and Technology sponsored by Japan Society for the Promotion of Science, Professor Hosono's group at the Tokyo Institute of Technology and ISTEC jointly fabricated a high quality thin film on a bicrystal substrate to investigate the J_c dependency on misorientation angle and grain boundary characteristics. The findings showed that whilst there was no significant drop in J_c when the misorientation angle was less than 9°, there was however an exponential drop in J_c when the misorientation angle was greater than 9°, demonstrating that the grain boundaries were weakly coupled. The critical misorientation angle where there is an obvious weak inter-grain coupling is in fact twice larger than that compared to the Y-based copper-oxide system and the slope of J_c at high angles is not as well pronounced. The characteristics of both the copper-oxide and the iron-based superconductors are similar as it is the carrier doping which induces superconductivity. However, the differences in grain boundary characteristics appear due to differences in the carrier-depleted parent materials for the copper-oxide and iron-based material systems, which exhibit insulating and metallic behavior, respectively. This implies that the deposition of a high J_c superconducting thin film on a metal substrate with a textured buffer layer is carried out relatively easily. In fact, this method is currently used to fabricate Y-based copper-oxide tapes. The IFW Dresden group has recently reported their attempts of a 122 thin film deposited on a metal substrate using a textured IBAD buffer layer. On the other hand, the grain boundary formed at a misorientation angle of more than 30° forms an ideal Superconductor-Normal metal-Superconductor (SNS) type Josephson junction, and has been employed in a SQUID, jointly tested at the Tokyo Institute of Technology and ISTEC. The fabrication of a higher T_c 1111-based high quality superconducting thin film was delayed as the carrier doping by F replacement proved difficult. However, a research group in Nagoya University, using MBE, successfully realized a T_c greater than 50 K by diffusing F from an Nd-O-F thin film stacked on top of a Nd-1111 thin film. Using a similar deposition approach, a research group based at Tokyo University of Agriculture and Technology recently achieved a thin film with a zero T_c at 53 K. Further evaluation trials on the superconducting characteristics such as the J_c in a magnetic field are ongoing.

As introduced above, the current iron based superconducting material system presently offers the potential for applications operating mainly at low temperatures and in high magnetic fields. It is expected that discoveries of new materials with even higher T_c and smaller anisotropies are forthcoming. A majority of the materials with high T_c's that have been discovered up to now contain poisonous arsenic. I would like to point out as a conclusion that it was only last year that a material system ($K_xFe_{2-y}Se_2$), containing no arsenic, with a T_c of 32 K was discovered.

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