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Superconductivity Web21

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Topics: World Project Now for Superconductor

Save Earth by Superconductor

This year ISTEC has started the 2013 special feature on the current world projects for HTS superconductor and its application.

In this August issue, Prof. Minwon Park of Changwon National University of Korea introduces the recent Korean HTS activity. They are actively developing HTS applications including renewable energy areas.

ISTEC
YUTAKA YAMADA
(Japanese Version will be appeared in November issue.)

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Recent R&D Status of HTS Power Devices in Korea

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Nowadays the HVDC HTS power cable, DC reactor, HTS SFCL, tri-axial HTS power cable, and HTS wire are being jointly developed by many companies, research laboratories, universities, and so on with government support.

When looking into history of HTS power cable in Korea, DAPAS (Development of Advance Power system) project developed world-class HTS power cables (22.9 kV and 154 kV). GENI project is an abbreviation of Green superconducting Electric power Network at Icheon substation. This project installed 22.9 kV HTS cable (500 m) and SFCL in 154 kV Icheon substation to develop commercialized model of HTS equipment and operating techniques. Now 100 m HTS cable with transmission class voltage of 154 kV and the capacity of 1 GVA is testing in Gochang power test center and it is expected to demonstrate in KEPCO power system until 2014.

JEJU project is HVDC HTS DC power cable R&D project funded by Korean government launched targeting DC HTS cable system for deployment in the global market. KEPCO drew up the deployment plan for ±80 kV DC HTS cable to Jeju smart grid demonstration site where HVDC lines between substations will be connected, and LS Cable will develop the ±80 kV to ±200 kV level DC HTS cable. The target of project is the development of production technique, application technique of real system, operation technique, and standardization to expand application of a transmission level HTS DC cable for high capacity and efficiency. The period of project is from July 2011 to June 2016, and total research funds are around 60 MUS$/5yrs. Participating institutions are mainly KEPCO, KEPRI, LC Cable & System, Korea Electrotechnology Research Institute(KERI), and a few universities.

A DC reactor operates under DC current to reduce the current’s ripple or harmonics in the power system or some specific applications. However, the DC reactor experiences a great deal of electrical loss due to resistance in their copper winding. The HTS DC reactor project, therefore, has a goal to develop the core technology and to manufacture the 400 mH and 400 A class toroid type HTS DC reactor with high energy efficiency. The period of project is from 2011 to 2014, and total research funds are 1.5 MUS$/3yrs. Participating institutions are Uiduk University, Changwon National University, and Vector Field Korea, Inc.

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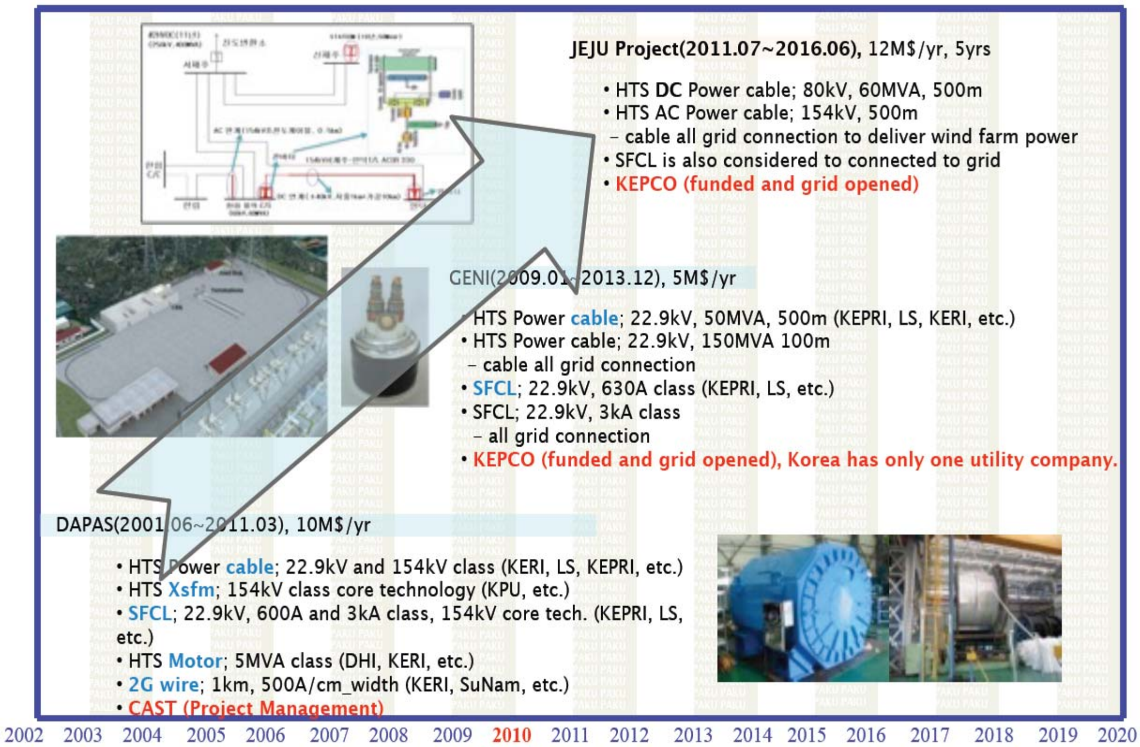

Fig. 1 R&D status of HTS power devices in Korea

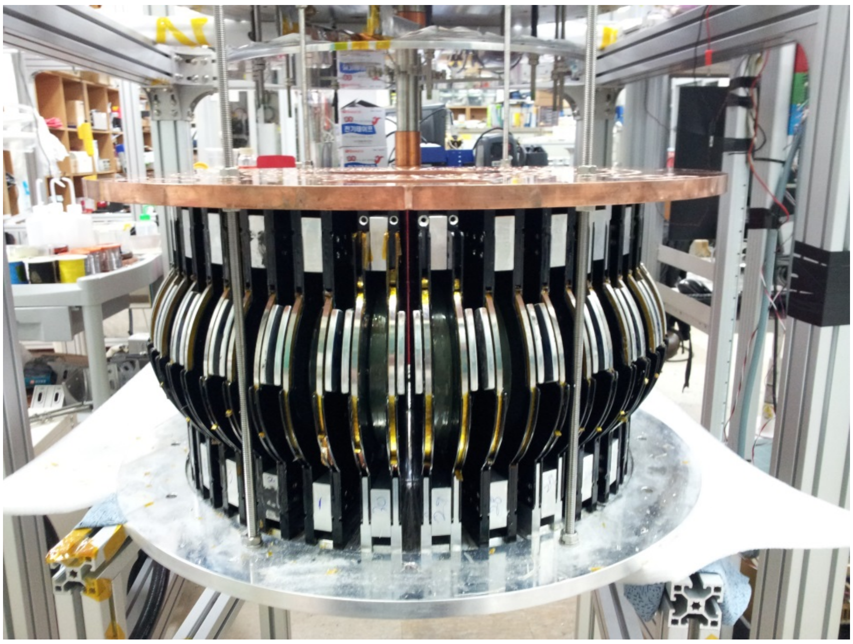

Fig. 2 Photo of 400mA 400A class DC reactor HTS coil

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A superconducting fault current limiter (SFCL) is one of the actions for the enhancement of the transient stability as well as a solution for the fault current problem in Korean power plants. A 22.9 kV SFCL has been successfully operated at the Icheon substation in Korea since 2011. A new project for the development of a 154 kV SFCL started in July 2011. The target of project is the development of 154 kV class SFCL system and application technique of real system. The period of project is from 2011 to 2016, and total research funds are 8 MUS$/3yrs.

A tri-axial HTS power cable has several advantages, such as a large power transmission capacity because of its high current density compared with conventional cable in the same voltage level. The tri-axial HTS power cable contains a core, three-conductor layers, and a shield layer in a cryostat. It has a multi-layer structure that consists of HTS wires that are twisted clockwise and counter-clockwise along the same axis. The spaces between the layers of the cable are filled with cryogenic dielectric material. LN_2, which is a refrigerant to obtain the superconducting state of the cable, is injected into the inner core pipe and then exits through the outer cryostat. The tri-axial HTS power cable project has the goals about the design of the tri-axial HTS power cable core, manufacturing of the 1.5 m class model cable, and RTDS based power hardware-in-the-loop simulation. The period of project is from 2011 to 2014, and total research funds are 0.4 MUS$/3yrs.

▪ Parameters of tri-axial HTS power cable

Contents	Value
Voltage/Capacity	22.9 kV/50 MVA
Rated current	1260 A_{rms}
DC critical current	4,180/4,580/5,140 A @77 K
Insulation thickness	4 mm (using PPLP)
Type of HTS wire	2G YBCO (width: 4mm)
Number of wires	26 / 32 / 38
Radius of each phase	17.5 / 21.5 / 25.5 mm
Winding pitch	+405 / -545 / +795 mm
Radius of copper shield	29.5 mm

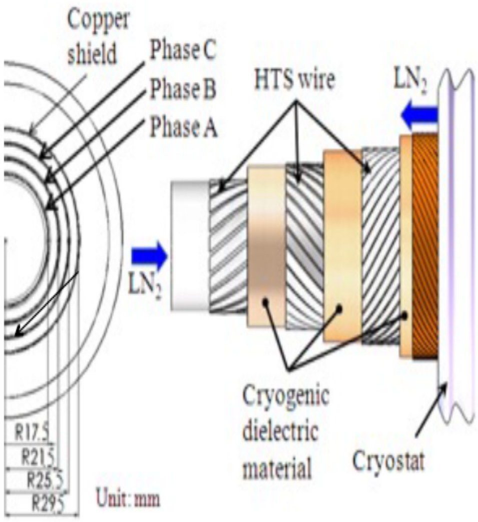

Fig. 3 Parameters of tri-axial HTS power cable

The kA-class HTS wire has to be developed to apply to large scale HTS devices. Also, the problems of HTS wire such as critical current degradation by magnetic field and non-uniformity of long HTS wire have to be solved for commercialization of HTS devices. Therefore, the target of HTS wire project is to fabricate the HTS wire with 1,000 A/cm of critical current under high magnetic field and to develop the kA-class HTS for improving the efficiency of power devices for smart grid. The period of project is from 2013 to 2016, and total research funds are around 13MUS$/4yrs. Participating institutions are SuNam Co., Korea Electrotechnology Research Institute(KERI), Research Institute of Industrial Science & Technology(RIST), Seoul National University, and Changwon National University.

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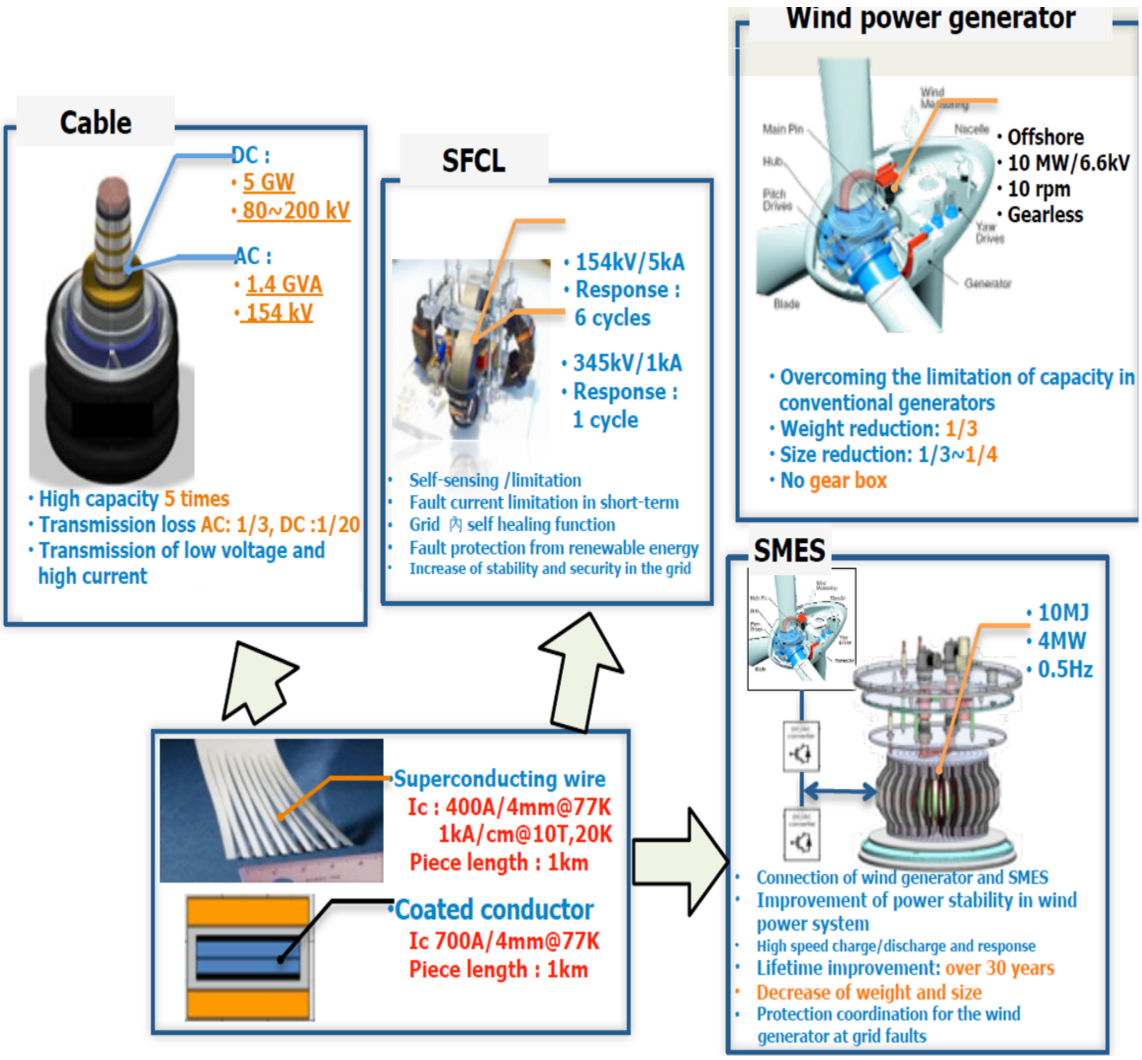

Fig. 4 Future vision of the project of kA-class HTS wire

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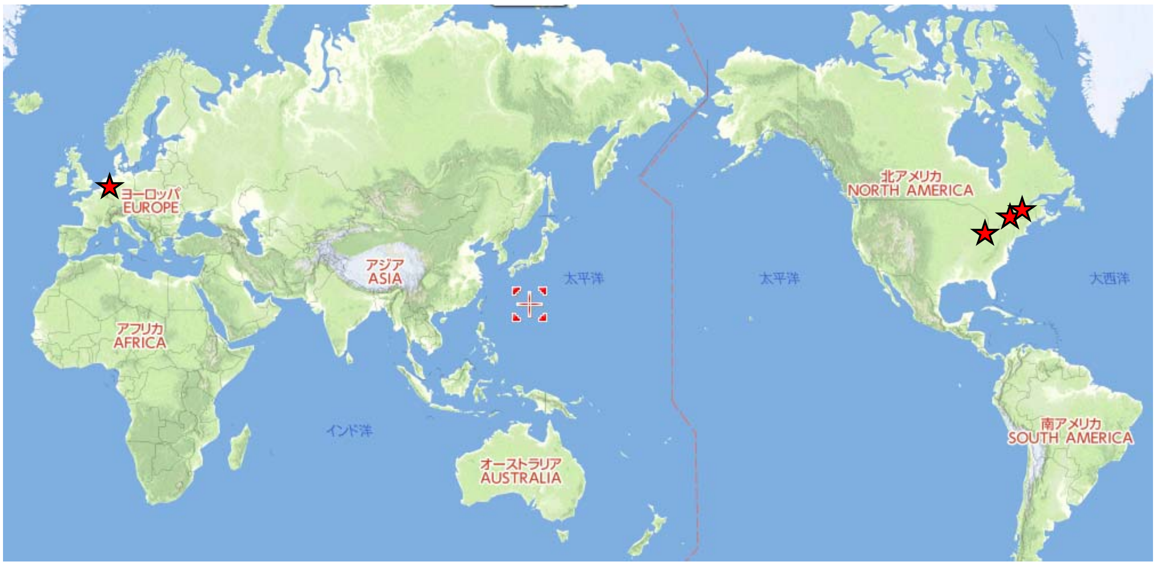
What's New in the World of Superconductivity (August, 2013)

초전도 뉴스 –세계의 동향–

超导新闻 –世界的动向-

chāo dǎo xīnwén - shìjiè de dòngxiàng-

Yutaka Yamada, Principal Research Fellow
Superconductivity Research Laboratory, ISTEC



★News sources and related areas in this issue

▶Wire 선 재료 线材料 [xiàn cáiliào]

ORNL's High-T_c Wire Yields Unprecedented Performance

Oak Ridge National Laboratory (August 15, 2013)

Researchers from the Oak Ridge National Laboratory (ORNL) have reported that the ability to control nanoscale imperfections in superconducting wires results in materials with unparalleled and customized performance. The group have shown that superconducting wires can be tailored to meet different operating

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conditions by introducing small amounts of non-superconducting material, thereby influencing the behavior of the overall material. Further manipulation of these nanoscale column defects can be used to control the forces that regulate the wires' superconducting performance. Amit Goyal, ORNL's team leader for research on this topic, explained, "Not only can we introduce these nanocolumn defects within the superconductor and get enhanced performance, but we can optimize the performance for different application regimes by modifying the defect spacing and density." The group has obtained a record performance at 65 K and 3 T, which are common operating parameters for rotating machinery applications such as motors and generators, with a minimum engineering critical current density at all applied magnetic field orientations of 43.5 kA/cm^2 (for wires containing a 50-micron-thick copper stabilizer layer). This performance level is more than twice the level required for most applications. In these wires, the defects are generated using an ORNL-developed self-assembly process that enables materials to be designed in a manner that enables the automatic development of the desired nanoscale microstructure during growth. The group's work has been published in Nature Publishing Group's Scientific Reports.

Source: "ORNL superconducting wire yields unprecedented performance"
Oak Ridge National Laboratory press release (August 15, 2013)
URL:
http://www.ornl.gov/ornl/news/news-releases/2013/ornl-superconducting-wire-yields-unprecedented-performance
http://www.eurekalert.org/pub_releases/2013-08/drnl-osw081513.php
Contact: Morgan McCorkle, mccorkleml@ornl.gov

►Basics 기초 基础[jīchǔ]

Discover Hidden Magnetic Waves in High-T_c Superconductors

Advanced x-ray technique reveals surprising quantum excitations that persist through materials with or without superconductivity

Brookhaven National Laboratory (August 4, 2013)

Researchers at the U.S. Department of Energy's Brookhaven National Laboratory and other collaborating institutions have discovered some unexpected findings regarding the magnetic properties of high-temperature superconductors that challenge some of the leading theories explaining the origin of superconductivity. In a study published online in the journal Nature Materials (August 4, 2013), the group reported that unexpected magnetic excitations (quantum waves that many researchers believe are responsible for regulating high-temperature superconductivity) exist in both non-superconducting and superconducting materials. Mark Dean, the lead author, commented, "This is a major experimental clue about which magnetic excitations are important for high-temperature superconductivity." The group used x-ray scattering techniques to visualize excitations in samples that were previously thought to be essentially

non-magnetic. Thin films of lanthanum, strontium, copper and oxygen (LSCO) were used for the observations, as these particular HTS materials can be tuned to exhibit a wide range of different electronic behaviors. John Hill, a co-author of the paper, added, “This is the only system that lets us examine the entire phase diagram, from a strongly correlated insulator all the way to a non-superconducting metal…We could measure magnetic excitations both before and after the ideal doping levels for superconductivity.”
The materials were grown using a custom-built atomic layer-by-layer molecular beam epitaxy machine (ALL-MBE), which was uniquely equipped to monitor the synthesis of LSCO films in real-time, thereby enabling the atomic composition of each layer, including adjustments to the doping levels, to be controlled and resulting in highly uniform films with flat, mirror-like surfaces. To detect the Ångstrom-scale quantum ripples, a technique known as resonant inelastic x-ray scattering (RIXS) was applied, with the measurements being performed using the Advanced X-ray Emission Spectrometer at the European Synchrotron Radiation Facility (ESRF) in France. In earlier studies using neutron scattering, magnetic excitations appeared to vanish in overdoped LSCO samples, supporting the theory that waves play an essential role in superconductivity. The RIXS technique, however, is much more sensitive to magnetic excitations with certain wavelengths and is also capable of detecting otherwise imperceptible signals. The discovery that excitations do not depend on the doping level means that the relationship between HTS and the waves in these films is more complex than previously suspected.

Source: “Scientists Discover Hidden Magnetic Waves in High-temperature Superconductors” Brookhaven National Laboratory press release (August 4, 2013)
URL: http://www.bnl.gov/newsroom/news.php?a=11564
Contact: Justin Eure, jeure@bnl.gov or Peter Genzer, genzer@bnl.gov

Teleported by Electronic Circuit

ETH Zurich (August 14, 2013)

Researchers at ETH Zurich have successfully teleported information from one point to another in a solid state system using a device similar to a conventional computer chip but in which information is stored and processed according to the laws of quantum physics, rather than the laws of classical physics used in conventional circuits. Using this system, the researchers were able to teleport information across a distance of about 6 mm (from one corner of the chip to the opposite corner) without transporting a physical object carrying the information. Unlike the transfer of microwave pulses in mobile communications or optical pulses in fiber optic connections, quantum teleportation only transports the information, not the information carrier, using quantum mechanical properties such as entanglement between the sender and the receiver. This entangled state between a physically disparate sender and receiver enables information entered at the sender to be shared and read at the receiver. In other words, information entered at point A disappears when it is read at point B, without the information actually travelling from one point to the other. The system that was used to teleport the information consists of superconducting electronic circuits, a point which is significant because such circuits are an important element in the construction of future quantum computers. The present system is also extremely fast—much faster than most previous teleportation systems—enabling approximately 10,000 quantum bits to be teleported per second. As the next step in

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their research, the group plans to increase the distance between the sender and receiver in the device, with the goal of realizing quantum communication over longer distances comparable to those that have been achieved using optical systems. The group's presently reported work has been published in Nature.

Source: "Teleported by electronic circuit" ETH Zurich press release (August 14, 2013)
URL: http://www.ethz.ch/media/detail?pr_id=1179
http://www.eurekalert.org/pub_releases/2013-08/ez-tbe081413.php
Contact: Andreas Wallraff, andreas.wallraff@phys.ethz.ch, ETH Zurich

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

First Quarter 2013 Financial Results and Provides Business Outlook: Grows Revenue and Narrows Net Loss

AMSC (August 7, 2013)

AMSC has reported its financial results for its first fiscal quarter, ending June 30, 2013. Revenues for the first quarter totaled USD $23.1 million, compared with $28.7 million for the same period in the previous fiscal year. The net loss for the first quarter was $10.5 million, compared with $10.3 million for the same period in the previous fiscal year. AMSC's non-GAAP net loss for the first quarter was $8.1 million, compared with $11.0 million for the same period in the previous fiscal year. As of June 30, 2013, the company's cash, cash equivalents, and restricted cash totaled $39.5 million. For the second quarter, AMSC expects its revenues to exceed $23 million and its net loss to be less than $17 million. Its non-GAAP net loss is expected to be less than $12 million. Daniel P. McGahn, AMSC President and CEO, commented, "AMSC continued to execute [its] plan for the first fiscal quarter, growing revenues by 13% and reducing net loss by 47% on a sequential basis from the fourth quarter of fiscal 2012. In fiscal 2013, we remain focused on effectively managing our cash position, while driving profitable revenue growth. We are reaffirming our guidance that we expect annual revenue growth of at least 25% in fiscal 2013 over fiscal 2012. We have a solid presence in several established markets and continue to seek opportunities to enter emerging markets where we see significant opportunity."

Source: "AMSC Reports First Quarter 2013 Financial Results and Provides Business Outlook" AMSC press release (August 7, 2013)
URL:
http://files.shareholder.com/downloads/AMSC/2362775124x0x682753/af53ee69-201a-46cc-bd96-d1e856064521/AMSC_News_2013_8_7_Commercial.pdf
Contact: Kerry Farrell, kerry.farrell@amsc.com

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Feature Article: Reporting on The 2013 Forum on Superconductivity Technology Trends
- ISTEC's Recent Progress in The Technological Development of High-temperature SQUIDs

Keiichi Tanabe, Deputy Director General
SRL/ISTEC

A Superconducting Quantum Interference Device (SQUID) is an ultra-sensitive magnetometer utilizing macroscopic quantum effects specific to superconductivity. For example, a SQUID (low temperature SQUID) utilizing low temperature superconductor Nb is currently employed for biomagnetic measurements such as magneto-encephalography. On the other hand, a SQUID (high temperature SQUID) utilizing high temperature Y-based superconducting materials exhibits inferior field sensitivity characteristics compared with low temperature SQUIDs, however, it is best suited for compact, low-cost measurement systems and for use in the field since only liquid nitrogen cryocooling is required. SQUIDs also exhibit a certain level of high magnetic field sensitivity over a DC to high frequency range, and because of their cooling and the use of quantum effects, have extremely stable magnetic field sensitivity irrespective of environmental temperature, which other magnetometers do not demonstrate. ISTEC developed the thin film multilayer-type high temperature SQUIDs employing the fabrication methods and expertise gained from their experience in oxide-based HTS integrated circuits during a previous project supported by NEDO. Thin film multilayer-type high temperature SQUIDs exhibit high field sensitivity that is five or more times greater compared to conventional high temperature SQUIDs employing a single-layer HTS thin film. Here, adoption of ramp-edge Josephson Junctions rather than grain-boundary Josephson Junctions pave the way for the potential fabrication of sensors having greater tolerances in field applications, and sensor arrays or complex sensor structures required by many applications. The benefits of these characteristics have already been exploited using a 5-channel SQUID array in non-destructive testing equipment used to evaluate the performance of multi-filamentary-processed Y-based tapes, and in a practical electromagnetic exploration system for metal resources, which has been successfully developed under the JOGMEC project. Under other JOGMEC projects, development of a prototype metals exploration system based on measurements of small magnetic field gradients and fundamental research aiming at the application of SQUIDs to oil fields were also done last year, which resulted in success. A joint research study between ISTEC, Tokyo Metropolitan University and other research institutions has been developing a geomagnetic observatory system with the aim of detecting feeble magnetic field changes that accompany crustal ruptures and trigger earthquakes. The system was installed at Iwaki city in Fukushima prefecture, and continuous observations of the earth's magnetic field are ongoing.

Under JST's S-Innovation program launched in 2009, ISTEC focused on R&D aimed at the realization of a pioneering bio and non-destructive sensing systems, collaborating with Hitachi, Hitachi High-technologies Corporation, Kyushu University, Okayama University and Toyohashi University of Technology. ISTEC has been responsible for developing a high temperature SQUID with greater performance characteristics and providing prototype SQUIDs to joint research partners. The magnetometer in ultra-low field NMR/MRIs and non-destructive testing systems is exposed to magnetic fields of around 10-100 mT. Such applications are

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potentially considered the most promising end products of this project. The R&D aim is then to develop a high temperature SQUID able to operate in this environment. ISTEC has developed a SQUID module in which a high temperature SQUID installed within a magnetic shield is coupled with the external pick-up coil, comprising of normal conducting materials such as copper wire. The SQUID itself is a gradiometer to cancel out environmental noise, as shown in Figure 1. In order to increase the coupling efficiency with the normal-conducting pickup coil, the multi-turn input coil was formed utilizing a single-layer superconducting thin film and fabricated on a different substrate, which is then positioned over the SQUID gradiometer. The pickup coil wiring was soldered to the electrode pad of the input coil. A plastic cap formed an airtight seal around the SQUID and input coil, and by only altering the pickup coil specifications for a specific system it serves as a common modular system. The DC and low frequency field sensitivity drops with the use of a normal conducting pickup coil. However, liquid nitrogen cooling has reduced resistance and increased sensitivity at frequencies greater than 1 kHz, which are equivalent compared to the utilization of superconducting pickup coil. Sensitivity or field noise of around 35 fT/Hz$^{1/2}$ has actually been verified.

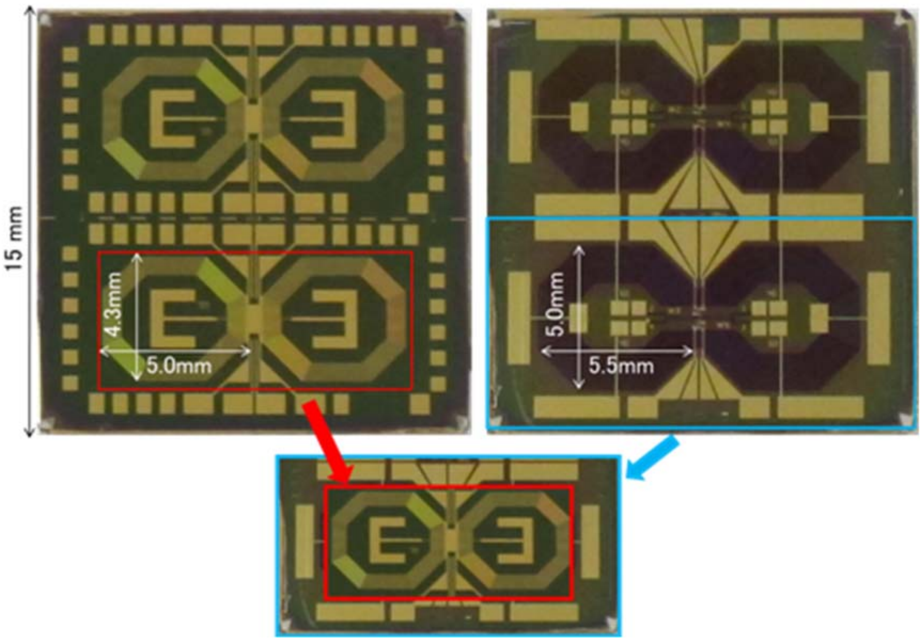

Fig. 1 An HTS SQUID for use with an external pick-up coil, developed by ISTEC under the JST's S-Innovation program. The upper left picture shows the input coil chip, and the upper right picture shows the SQUID gradiometer chip. Each is cut and stacked, as shown by the picture at the bottom.

There are issues associated with increasing noise due to flux trapping when a high temperature SQUID is utilized in an unshielded environment. Firstly, to avoid flux trapping within the superconducting thin film during cooling in the Earth's field, the wire width should not exceed 5 μm. An input coil having several turns is formed around the SQUID loop to improve magnetic field sensitivity, leading to the development of a "hybrid" high temperature SQUID with enhanced pickup coil coupling efficiency. A maximum sensitivity of 18 fT/Hz$^{1/2}$ close to that for the multilayered SQUID with the input coil overlaid on the SQUID loop has been verified. However, even utilizing such SQUIDs creates flux trapping via weak current flow caused by the

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thermoelectric effect triggered by temperature gradient during cooling of the sensor. Work will focus on eliminating flux trapping by using a heater to increase the sensor temperature to more than T_c and then re-cool. It was recently understood that homogeneous heating and cooling could potentially suppress flux trapping, producing low flux noise at low frequencies of around 1 Hz. Future R&D aims are to optimize the sensor cooling process and the removal of traps, and also review the process to eliminate "weak" parts causing sensor flux trapping.

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Feature Article: Reporting on The 2013 Forum on Superconductivity Technology Trends - Metals Exploration using SQUITEM

Masaki Sugisaki
Metals Exploration Department
Japan Oil, Gas and Metal National Corporation

Fig. 1 Overview of SQUITEM Unit 3

TEM is one geophysical exploration technique utilizing electromagnetic characteristics widely used for the exploration of metal ore deposits. A copper wire transmitter loop is placed above ground and a pulsed signal applied, and by measuring the magnetic field generated by dielectric current after current interruption allows variations in underground resistivity to be obtained. Over recent years, metal ore deposits have been discovered at much greater depths, and a TEM system that proves to be more accurate at determining the ore depth and providing greater detailed information than conventional systems is highly desired. The Japan Oil, Gas and Metal National Corporation (JOGMEC) have focused on developing a TEM system (SQUITEM) that exploits a high temperature superconducting quantum interference device (HTS-SQUID), a high sensitivity magnetic field sensor. This system is now in use for exploration of metal ore deposits.

Conventional induction coil magnetometer measures time derivatives (dB/dt) of the magnetic field whereas a SQUID magnetometer can directly measure the magnetic field itself (B-field). Direct B-field measurements create greater delays of signal time attenuation compared to dB/dt measurements leading to greater data acquisition measured at deeper penetration depths. Additionally, the significantly reduced noise levels and wider operating frequency bands afforded by the SQUID when compared to other magnetic sensors employed for metal ore exploration allows measurements to be taken from greater depths.

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JOGMEC, together with ISTEC and Mitsui Mineral Development Engineering Co., Ltd (MINDECO), undertook a project to develop the next generation SQUITEM (SQUITEM Unit 3) resulting in the completion of SQUITEM Unit 3 in 2012, as shown in Figure 1. The investigations for devices, FLL circuits, and field noise shield methods resulted in an improved SQUITEM Unit 3, offering greater operability and portability compared to conventional systems. Also, the large slew rate (magnetic field changes that the system can track per unit time) is an advantageous characteristic of this system allowing data acquisition from greater underground depths, which was a struggle with conventional systems.

Field performance evaluation tests have confirmed spec improvements such as slew rate (measured value 10.5mT/sec) and noise levels (measured value 20-25 fT/hz$^{1/2}$@10kHz). Additionally, much deeper and more accurate analysis compared to conventional systems (induction coil magnetometer) has been achieved. Figure 2 presents the TEM data analysis, showing a comparison of actual strata resistivity measured by borehole logging. Analysis has shown the characteristics of much deeper underground strata resistivity compared to conventional systems (induction coil magnetometer), and clearly illustrates the superiority of SQUITEM Unit 3.

JOGMEC plans to use SQUITEM Unit 3 for their future metals exploration project.

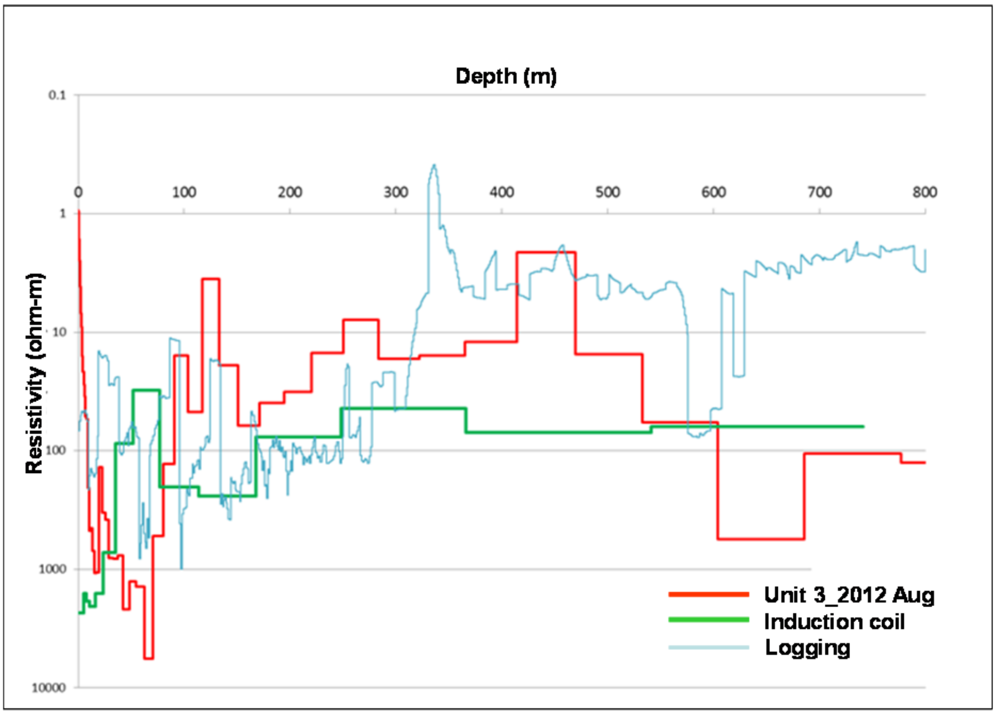

Fig. 2 Inverse analysis results of resistivity

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Feature Article: Reporting on The 2013 Forum on Superconductivity Technology Trends
- Developmental Status of the Superconducting Single-Photon Detector

Hirotaka Terai, Research Manager
Kobe Advanced ITC Research Center
National Institute of Information and Communication Technology

A Superconducting Nanowire Single Photon Detector (SSPD) offers attractive features that include high detection efficiencies, high-count rates, low dark-count rates and low-timing jitters over a wide range of detectable wavelengths. SSPDs have been widely applied to quantum information and communication field applications, including quantum key distribution (QKD) systems[1)]. Recent noteworthy worldwide research developments into SSPDs have produced remarkable improvements in system detection efficiencies and count rates, particularly their use in multi-pixel arrays for example. This article introduces the latest research and development trends including the recent achievements in our group.

The SSPD detection efficiency is determined by three factors, namely the coupling efficiency between the optical fiber and the SSPD, the nanowire's optical absorption characteristics and the probability that a photon absorbed by the nanowire generates an electrical pulse. Various methods have achieved coupling efficiencies close to 100 %. Therefore, two other factors that increase nanowire absorption and improve the probability of pulse generation to a maximum upper value need to be addressed and optimized in order to realize high detection efficiencies. Last year, an SSPD system having achieved a detection efficiency of 93 % was reported by the National Institute of Standards and Technology (NIST)[2)]**.** At almost same time, the MIT (Massachusetts Institute of Technology) Lincoln Laboratory also reported an SSPD system with a detection efficiency exceeding 70 %[3)]. A typical SSPD is made of an NbN thin film nanowire (around 5 nm thick). NIST, however, reported using a WSi nanowire, which exhibits better film homogeneity and critical temperatures of around 3.7 K, lower compared to NbN. The bias current close to the critical current of nanowire must be supplied to obtain fully high detection efficiency in a conventional SSPD. However, in a WSi SSPD the detection efficiency is almost saturated for a bias current less than half the critical current of the nanowire. This implies that the dark count rate can be reduced below 1 cps if we can suppress the effect of stray photons due to the blackbody radiation from the room temperature by an appropriate filtering. Another common feature of the SSPD devices developed at both NIST and Lincoln Laboratory is a double-side cavity. Here, the nanowire is enclosed within a cavity designed using reflective layers either side, which are aimed at confining photons within this cavity and thereby enhancing electric field concentration at the nanowire. This cavity structure allows an optical absorption of nearly 100 %, exceeding the filling factor (the nanowire area is typically around 50 % of the entire light receiving area). Improvements in optical absorption efficiencies together with increases in pulse generation probabilities have led to dramatic improvements in SSPD system detection efficiencies during the past year. The critical currents in WSi nanowires are however small, around 4 μA @120 mK and their low critical temperature results in low output SN ratios that cause large system jitters of more than 100 ps. Additionally, the operating temperature of WSi SSPD is below 1 K, requiring the cooling by costly adiabatic demagnetization refrigerator or He3 refrigerator.

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Our group has developed a 6-channel SSPD implemented in a compact 0.1 W Gifford McMahon (GM) refrigerator, which can be continuously driven using an AC 100 V power supply, producing a system detection efficiency greater than 67 % at a dark count of 100[4]. Figure 1 shows the cross-sectional structure of the SSPD developed by our group along with observed device characteristics that include the bias current dependence of a system detection efficiency, a dark-count rate, and a timing jitter. The double-side cavity structure employed by our SSPD utilizes an NbTiN superconducting thin film, which exhibits higher critical temperatures than WSi. Measured critical currents are around 18 μA, nearly five times larger compared to a WSi SSPD at 2.2 K, producing a maximum 75 % system detection efficiency and a 67 ps jitter. A summary of the SSPD system performance characteristics as developed by each research institution is shown in Table 1. The overall performance attributes ranging from cooling practicalities to jitter characteristics of the SSPD developed by our group clearly outshine the SSPD characteristics developed by both NIST and Lincoln Laboratory. As mentioned previously, superconducting thin films with low critical temperatures are desirable in order to achieve high detection efficiencies. However, the resulting small critical currents in the nanowire lead to trade-offs between increases in jitter characteristics. Thus, important future issues to overcome such trade-offs and ways to maximize system performance need to be addressed by agreeing upon what needs to be targeted.

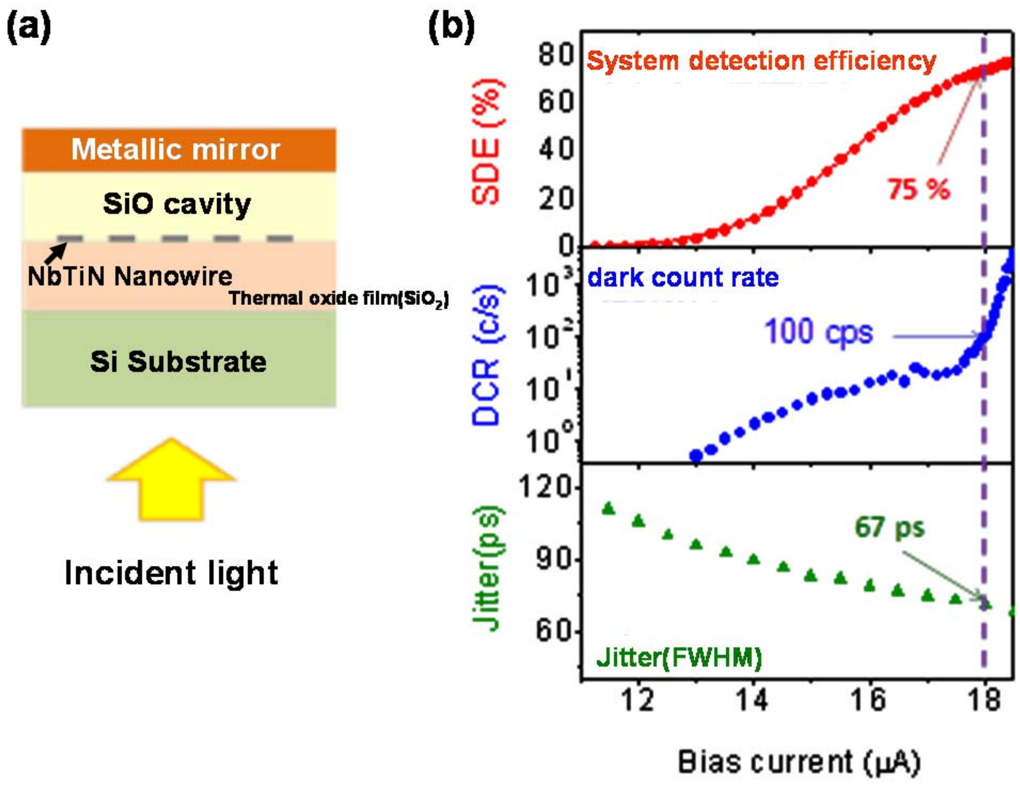

Fig.1 (a) Cross-section of an SSPD double-side cavity structure in the mid-development at NICT,
(b) System detection efficiency, dark count rate, jitter bias current dependency

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Table 1 SSPD performance comparisons

(NIST: National Institute of Standards and Technology, MIT LL: Lincoln Laboratory, Massachusetts Institute of Technology, NICT: National Institute of Information and Communications Technology)

	NIST	MIT LL	NICT
Detection efficiency (γ=1550nm)	93%	>70%	75%
Dark-counts	1 kHz (Using black body radiation)	1 kHz (Using black body radiation)	100 Hz
Jitter	150 ps	40-80 ps	67 ps
Operating temperature	300 mK	2.5 K	2.2 K
Refrigerator	Adiabatic demagnetization	GM	GM
Optical coupling method	Packaging	Nano-positioner	Packaging

Another SSPD characteristic is its high-count rate. Competitively placed semiconductor avalanche photodiodes (APD) are limited to a count rate of around 100 MHz, whereas SSPDs on the other hand have the potential to operate at count rates exceeding 1 GHz. However, the response speeds of current SSPDs are determined by the L_k/R time constant, where L_K and R represent the kinetic inductance and the load resistance of the nanowire, respectively. In order to realize a 100% coupling efficiency to an optical fiber a detection area of approximately 10 x 10-15 x 15 μm^2 is required, which gives the counting rate almost equivalent to that of an APD. To date, there have been two approaches proposed to overcome limitations of count rate by L_K. One method involves dividing the detection area into several pixels, and the other method involves fabricating the nanowire on a waveguide structure.

Multi-pixel SSPD array allows a smaller detection area while keeping the total detection area, enabling higher-speed operations. It would also enable the photon number resolution, which cannot be realized by a single-pixel SSPD. The biggest issue associated with a multi-pixel array is the signal read-out. The increasing numbers of RF cables required for read-out places an ever-higher thermal load on the refrigerator making it difficult to equip with a compact GM refrigerator. Therefore, to reduce the numbers of read-out RF cables signal processing within the refrigerator are required. The author and his group are at the forefront of the world's first cryogenically operated signal processing system utilizing a single flux quantum (SFQ) circuit, and have advanced proof of concept[5). Figure 2 shows an image of the system that includes a multi-pixel SSPD and SFQ signal-processing unit. The SFQ circuit operates at clock frequencies exceeding 100 GHz, and even with 10,000 Josephson Junctions it can operate at low power consuming only several mW. This is advantageous for signal processing in a cryogenic environment. The author and his group have thus far installed a 4-pixel SSPD array and a SFQ signal processing circuit onto a 0.1 W GM refrigerator, successfully verifying cross-talk free operations[6)]. The future plans are to pursue greater speeds by employing larger-scale arrays aimed at developing imaging applications.

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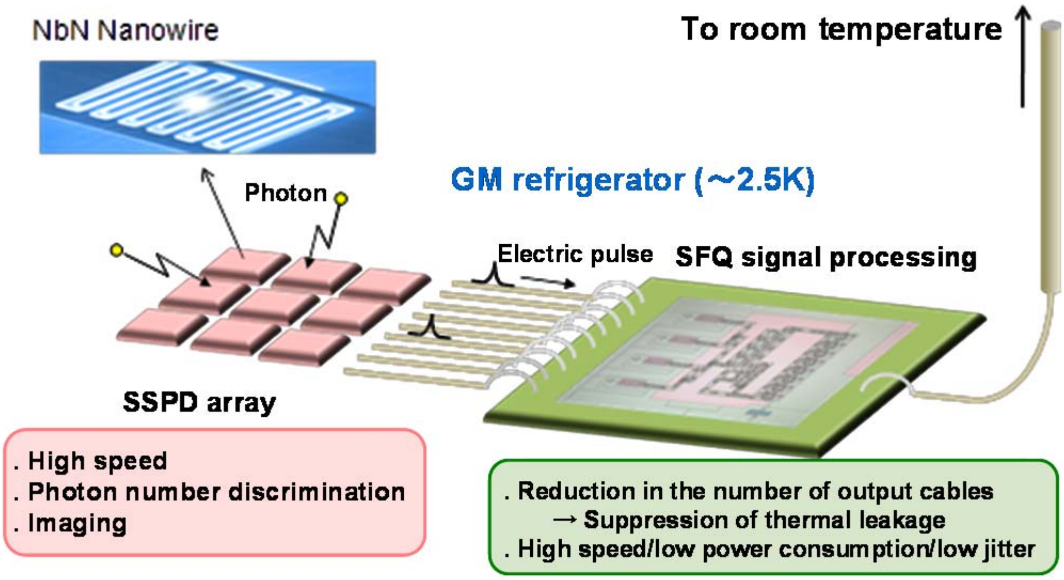

Fig. 2 Picture of a multi-pixel SSPD in mid-development at NICT

A photon travelling in a waveguide becomes absorbed by the nanowire when it is integrated with an SSPD array. A maximum on-chip detection efficiency of 91 % has been realized. Also, signal attenuation times of less than 1 ns with less than 20ps jitters were achieved for short wires less than 40 μm[7]. However, the system detection efficiencies including coupling losses between the fiber and the waveguide, as well as transmission losses of the waveguide are around several % and it is yet unknown as to how much these losses could be reduced in the future. The author considers that it will be difficult to achieve system detection efficiencies exceeding more than 90 %, values that have already been achieved by SSPDs with vertical incident light. Efforts to integrate quantum optical circuits and quantum dots comprising waveguides, and waveguide SSPDs have been already made[8]. The author believes that this research trend will continue in the future.

Lastly, the future development of SSPD applications is noted. SSPDs will continue to be employed in similar fashions involving quantum cryptosystems and quantum optics experiments in the 1550 nm wavelength region. The USA has been employing SSPDs for demonstrating optical links using pulse position modulation systems for ground-to-satellite communications[9]. Applications to such satellite-to-satellite and ground-to-satellite communications are one of the planned future developmental targets. Since SSPDs offer very low jitter characteristics there are prospects for their use in Light Detection and Ranging (LIDAR) applications. Greater accuracy in 3D imaging and remote sensing data acquisitions compared to current methods is now highly anticipated. However, alternatives such as APD and photomultiplier tube (PMT) are strong rivals that operate at shorter wavelengths than visible, and are a region where there has been little SSPD advancement, nevertheless, it is not beyond the realm that an SSPD with the detection efficiency far outside that of an APD and PMT will be realized. Applications to an array of equipment are considered for example, a confocal microscope as a photon detector exhibiting ultimate high sensitivities, low noise (afterpulse-free) characteristics and with a high dynamic range (high count rate). The author believes that by exploiting wavelengths other than 1550 nm will foresee much wider

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potential applications, including not only communication fields but also the biotechnology and medical fields in the future.

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Feature Article: Reporting on The 2013 Forum on Superconductivity Technology Trends - Progress in the Exploration of New Superconducting Materials

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Okayama University

Can we freely design and fabricate new superconducting materials at will, making them superconducting at high temperatures? The answer to this question is the ambition and aim of our laboratory, which has been progressing the development of iron-based superconductors by "controlling the chemical bonds of arsenic". The idea behind this work stems from a pioneering theory proposed by Roald Hoffmann who jointly shared the Nobel Prize in Chemistry with Kenichi Fukui in 1981[1). The theory relates to chemical bonds, which in the case of the transition-metal arsenides in a $ThCr_2Si_2$ type structure, leads to an interplay between the Fermi energy of the transition metal's d-band and the π^* antibonding molecular orbital of As_2. The numbers of electrons in the π^* orbitals therefore changes in accordance with the numbers of electrons in the d-band. An unoccupied π^* orbital forms As_2, which dissociates when this orbital is occupied. Thus, altering the numbers of electrons in the d-band can be used to either form or dissociate As_2 chemical bonding in the solid state at will. When an iron-based superconducting material was discovered in 2008, some research groups in Japan and abroad explored ways whether this idea could be applied to $CaFe_2As_2$, which also has a $ThCr_2Si_2$ type structure.

In fact, it was proved that Rh-doped $CaFe_2As_2$ produced As-As bonding along the c-axis direction of the crystal. The FeAs layers in $CaFe_2As_2$ are responsible for its superconductivity, and because Ca separates them there is no As-As chemical bond between FeAs layers. Rh doping produced the formation of As-As bond between the FeAs layers, which reduced the lattice parameter between the layers discontinuously to around 10 %. Interestingly, the formation of these chemical bonds, i.e. chemical reaction, occurred at low temperatures of 50 K[2)]. Unfortunately, the superconducting transition temperature of 15 K was suppressed when the chemical bond is formed, which is thought to occur because of 3D characteristic strengthening. However, Hoffmann's ideas regarding chemical bond making and breaking in the solid state were verified.

Doping $CaFe_2As_2$ with a variety of other transition metals including Co produced the same result as with Rh doping. However, Pt was exceptional in that $CaFe_2As_2$ exhibits a low solubility of Pt, and therefore, cannot be doped with sufficient amounts of Pt to induce superconductivity. Additionally, there was no occurrence of As-As bonds forming between the FeAs layers. However, forced synthesis using a large amount of Pt has precipitated into a new materials of $Ca_{10}(Pt_4As_8)(Fe_2As_2)_{10}$, exhibiting a new intercalated Pt_4As_8 layer. This compound exhibited superconductivity at a maximum of 38 K[3)], a record superconducting transition temperature equivalent to $(Ba_{0.6}K_{0.4})Fe_2As_2$. Interestingly, the As_2 molecule was included in the Pt_4As_8 layer. Therefore, even Pt doping led to the formation of As-As chemical bonds, although it was via a different way to the one proposed by Hoffmann. Here, it is proposed that since the Pt_4As_8 layer exhibits insulating characteristics, the strengthening of the 2D characteristics of the FeAs layer responsible for superconductivity results in the high T_c. Fe prefers tetrahedral coordination, with the FeAs layer actually

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comprising of a $FeAs_4$ tetrahedron. On the other hand, Pt prefers a square-planar coordination. When mixing elements that prefer different coordination chemistries the nature produced a new compound by compromise, which consists of Pt_4As_8 layers with Pt having a square-planar coordination as a solution.

In 2011, a research group based at the University of Houston reported on the results of $CaFe_2As_2$ doped with a rare-earth element of Pr, which induces superconductivity at a high temperature of 49 K. However, the superconductivity in this material was suppressed when a small magnetic field of 300 Oe was applied; this was not a bulk superconductor. Pr has a smaller ionic radius compared to Ca and leads to As-As chemical bonding between the FeAs layers once Pr-doped. Pr also has a role in electron doping and therefore changes the chemical bonding and number of electrons simultaneously. In this study, we utilized La and P. La has characteristics similar to Pr, allowing electron doping, but not affecting the cell volume since its size is the same as Ca. On the other hand, doping with P, which has an equal electron configuration as As, the numbers of electrons remain the same, but the cell volume can be altered since the ionic radius is smaller compared to As. Thus, *co-doping* La with P makes possible "independent" tuning of the numbers of electrons and the cell volume. Figure 1 shows $CaFe_2As_2$ doped with 18 % La and 6 % P, a 45 K bulk superconductor[4)]. This is a record high value and 5 years since the reported maximum superconducting transition temperature for 122-type iron-based superconductors of 38 K in $(Ba_{0.6}K_{0.4})Fe_2As_2$. Detailed experimental analyses of the crystal structure are currently ongoing. It is proposed that the formation/dissociation of As-As bonding plays a significant role here. Furthermore, whilst this compound maintains high T_c, the amount of rare earth elements utilized has been significantly reduced. Combined with the small anisotropy of the 122-type structure, which is effective in improving critical current densities, the application of this compound to superconducting wires is highly anticipated.

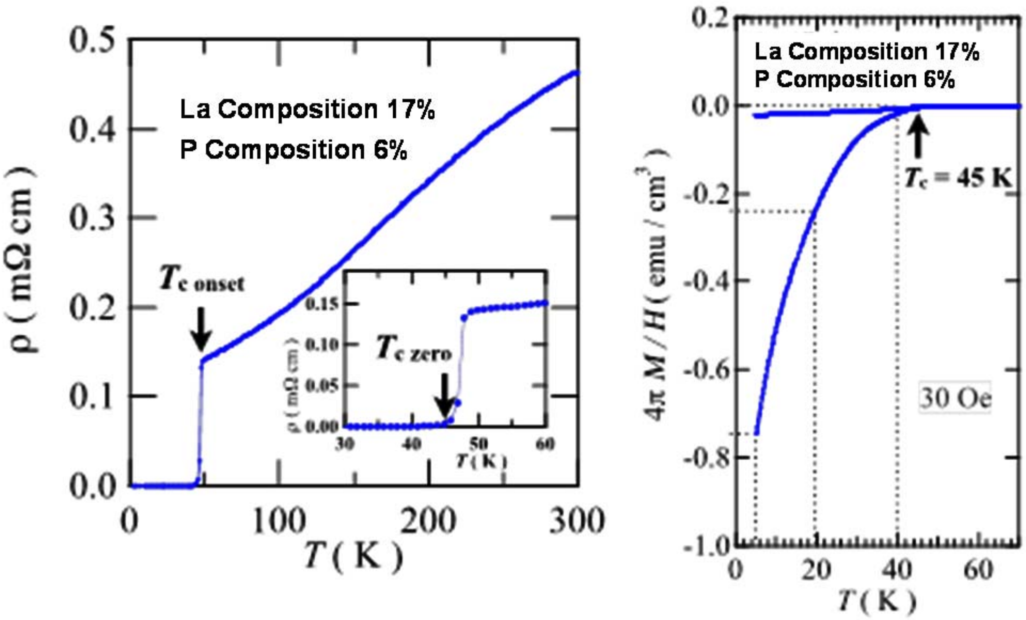

Fig 1 The emergence of bulk superconductivity ; $T_{c\ onset}$=48 K, $T_{c\ zero}$=45 K of iron-based $CaFe_2As_2$ co-doped with La and P. Record-breaking T_c is higher than the 38 K measured for a 122-type superconductor five years ago.

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Feature Article: Reporting on The 2013 Forum on Superconductivity Technology Trends
- Trends in International Standardization of High Temperature Superconductor-related Technology

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Graduate School Kyushu Institute of Technology

The preservation of the global environment by reducing CO_2 is a current topic of debate. Superconducting power technology is itself a highly energy efficient technology that includes transmission cables enabling almost all effective transmission of dc power from solar power generators, superconducting magnetic energy storage and fault current limiters, which are important factors to realize a smart grid. To progress such superconducting power equipment, Japan has advanced its R&D under a project entitled the "Technology development of Yttrium-based superconducting power equipment," led by NEDO. A Technical Committee of Superconducting Power Equipment was organized and generic drafts in principle have been investigated, aiming at the future international standardization of each type of power equipment.

Therefore in the near future, superconducting power equipment is to be introduced into the society within an international standardization framework. To achieve this, it is necessary to enact international standards and to legislate national standards in each country. Considering a 10-year timeframe to complete standardization, its target launch period must be examined.

The international standardization of superconductor-related technology has been discussed at TC90, which is the 90th Technical Committee of International Electrotechnical Commission (IEC), where 13 Working Groups and one ad-hoc group are involved. So far 18 international standards have been regulated, including one for superconducting vocabulary, 16 for testing methods to determine superconducting characteristics, and one for general characteristics and guidance pertaining to superconducting equipment. Additionally, discussions are ongoing for three other testing methods, and also one for each general ranking and testing methods pertaining to superconducting wires. Furthermore, several testing methods and general characteristics and guidance are now planned for discussion in the near future. Presently, there are only a few standards relating to generic rules pertaining to superconducting power equipment, with the majority concerning testing methods. Thus, future efforts need to extend and promptly deal with standards related to general characteristics and guidance on superconducting equipment.

Recommendations have been submitted from WG B1.31 of International Council on Large Electric Systems (CIGRE), which has been responsible for investigating testing methods to standardize superconducting power cables. Based on this, TC90 began investigating the standardization in collaboration with TC20 (electric cable). Along with the investigations undertaken at CIGRE, a draft of general characteristics and guidance has already been investigated at a subcommittee meeting relating to superconducting power cables, which forms part of the Technical Committee of Superconducting Power Equipment.

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Whilst future activities involve preparing further superconducting equipment testing categories the numbers of testing methods to be standardized will rapidly increase. Therefore, each WG committee must fulfill their duty with increasing committee members and investigate the detailed draft standards as soon as possible. Nevertheless, there exist a number of challenging cases that need to be resolved in order to build up an international standardization agreement, for example, product standardization and persevering negotiations, therefore it is important to precisely determine the circumstances and pursue discussions patiently without neglecting the need for the dissemination of information. In parallel, in Japan, we need to be mindful of awkward factors obstructing international standardization, and therefore appeal to government agencies for the deregulation and relaxation of such regulations.

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Feature Article: Reporting on The 2013 Forum on Superconductivity Technology Trends
- Superconductivity Technology for Railway Applications

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Applied Superconductivity, Materials Technology Division
Railway Technical Research Institute

Fig. 1 A 31 m-long superconducting cable installed at a railway line

The Railway Technical Research Institute has undertaken an array of superconductor R&D ranging from fundamental to application research. Amongst these, superconductivity technology for railway applications is introduced herewith.

The development of a superconducting cable aimed at railways applications has commenced by assuming a DC transmission cable used for electric trains. A cable has been fabricated based upon the results of current testing of a superconducting wire, along with a variety of evaluation tests undertaken to determine cable characteristics. A superconducting transmission cable having zero electrical resistance characteristics and applicable for railway use, is anticipated to bring about enhanced regeneration efficiencies, reduced power losses, load leveling and integration of sub-stations, and the suppression of rail potential. With a conviction that natural energy will be utilized for railways in the future, power supply tests connecting the superconducting cable from a solar power generator have also been performed. A 5m-long superconducting cable having 10 kA-class critical current characteristics has been fabricated and current trials, along with liquid nitrogen immersion cooling, have been performed. A 31m-long superconducting cable was introduced to the test line of the Railway Technical Research Institute (Figure 1), based upon the performance characteristics of cable system determined thus far. Presently, demonstration trials comprising of cooling/current tests have been performed employing an actual railway carriage [1]. Additionally, in parallel in the evaluation trials, actual line simulations have been progressively verified. The author and his group will aim to clarify the results of the demonstration trials to determine the consequences of installing the superconducting cable, all with the aim of realizing a cable applicable for railway use.

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Present research pertaining to conventional railways has been undertaken, investigating the likelihood of superconductor technology applicable to railway carriage transformers. Also, the aim is to save energy and therefore an electrical storage device supporting a flywheel having no rotational frictional resistance has been developed, employing magnetic bearings combined with a superconducting coil and a bulk superconductor.

This work was supported by the Japan Science and Technology Agency (JST) Strategic Promotion of Innovative Research and Development , Govt. of Japan.

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Feature Article: Reporting on The 2013 Forum on Superconductivity Technology Trends
- The Expectations and Issues of High-temperature Superconducting Technology Applications for Offshore Wind Turbines

Yukio Suguro, President
Japan Wind Energy Association

1. Wind power generation facilities

A wind turbine is, in general, three bladed constructions as shown by the right figure. Wind power can offers the cheapest costs for power generation and the greatest potential amongst renewable energies, and therefore, has led to the worldwide construction of wind farms. Until now, the construction of a majority of land-based wind turbines has been in windy regions. In 2012, wind turbines delivering a total of 44,711 MW were constructed worldwide, and which currently deliver a total 282,430 MW cumulative. Though Japan is mountainous and exposed to harsh climate conditions that include typhoons etc., in July 2012, a full purchase price system and a feed-in-tariff acts were set forced, and it is anticipated that this will further accelerate future wind turbine construction in Japan. Additionally, larger-scale and greater numbers of offshore wind turbines are anticipated.

2. Offshore wind turbines

Japan, being surrounded by oceans, is anticipated to take advantage of its long shorelines as well as its position as the world's 6th largest exclusive economic zone for the construction of offshore wind turbines. Compared to land-based, offshore wind turbines are considered to offer benefits that include: 1) favorable wind conditions; 2) less wind turbulence; 3) larger-scale systems offering greater profitability and; 4) less effects for noise anxieties due to their isolated and far away installation. It is inevitable that offshore wind turbine installations will face issues including: 1) deep waters around Japan; 2) harsh climatic conditions, which include typhoons etc.; 3) the effects on marine-life and; 4) increasing costs dependent upon the construction methods required for the depth of water.

The following figure is an extract from a NEDO document illustrating a number of potential offshore wind turbine installations.

Europe and USA have progressively seen trends in offshore wind turbine installations. Japan is also advancing the establishment and construction of fixed and floating offshore wind turbines. There are concerns over the potential increased electricity costs of offshore wind turbines because of the higher construction costs such as laying the foundations and installing submerged cables, as well as constructing the supporting structure. Therefore, there is need to realize highly efficient and lightweight turbines which can offset the increased electricity costs, utilizing instead, the surplus power generated during windier conditions.

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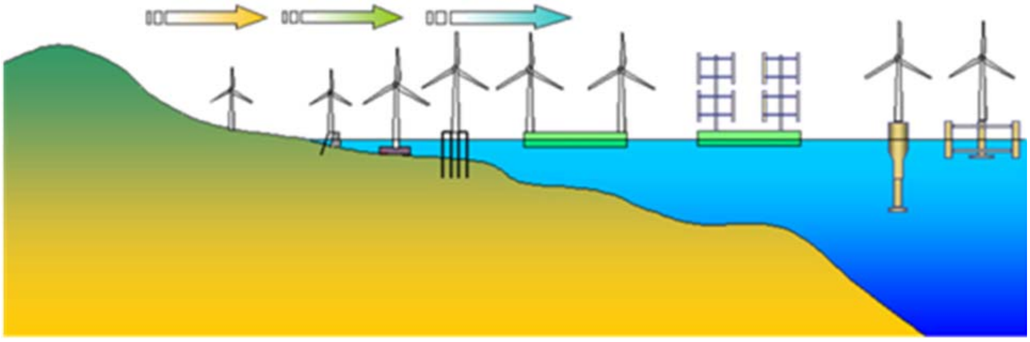

3. High-temperature superconducting technology applied to offshore wind turbines
Costs incurred from offshore power generation need to be reduced by lowering the overall costs from a number of viewpoints related to manufacturing and installation, which may include constructing of larger-scale systems, installing in windier locations and improving reliabilities. Technological issues arising when designing larger-scale systems also need to be solved. It is anticipated that superconductor technology applied to the wind turbine generator will resolve such issues. The benefits afforded by utilizing superconductor technology include: 1) greater magnetic field within the generator can mechanically enable greater power outputs, overcoming the manufacturing limitations associated with conventional normal-temperature generators; 2) a compact generator exhibiting greater magnetic fields can overcome weight and size issues; 3) the weight of the wind turbine generating system can be reduced by reducing the total nacelle load; 4) the lightweight nacelle will lead to a lightweight tower and its supporting structure; 5) the weight of all the components can be reduced by adopting the above-mentioned technology, which can contribute to cost reductions and; 6) superconductivity will lead to greater efficiencies with the realization of zero electrical resistance.
Also, we note that a cooling system is a necessity to maintain a cryogenic environment.

4. Anticipation of energy equipment utilizing high temperature superconducting technology
Superconductor technology can be applicable to not only offshore wind farms, but also applied to electric power storage, transmission systems, and new power networks. This will fulfill Japan's power and energy needs utilizing mainly renewable energies, contributing to an environmental friendly and economically active country, as well as providing Japan with a safe and stable energy supply in the future.

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