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Superconductivity Web21

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New Year Message

Shosuke Mori, President

International Superconductivity Technology Center

At the beginning of this New Year I would like to present my New Year message.

Last year, the East Japan Earthquake caused an unprecedented disaster, mainly in the Tohoku region and the Pacific Ocean side of the Kanto region, leading to the Fukushima Daiichi Nuclear Power Plant accident, which resulted in a number of electric power shortages nationwide.

ISTEC's laboratory facilities were partially damaged by this earthquake and also we had to face power usage limitations. In spite of those circumstances, all employees made efforts not to cause any further inconvenience or delay in research and development activities by repairing damaged facilities as quickly as possible, as well as coping with power saving measures such as spreading the load of facility operations.

Since the earthquake disaster occurred, a stable supply and efficient usage of electricity has become more recognized as an urgent issue. However, superconducting technology is a dream technology that can contribute to efficient energy usage and reduce the impacts of global warming, but also is a technology to bring about breakthroughs in a variety of industrial fields such as medical and electronics that utilize superconducting magnets, high functional sensors and various other device applications.

Since the establishment of ISTEC in 1988, the research and development activity have steadily advanced achieving many fruitful outcomes, and has now become Japan's core institution for superconductivity. This year in particular, the "Yttrium-based superconducting power equipment" project is in its final year and we endeavour to do our utmost to achieve the developmental aims towards realization. Additionally, this year we would like to accelerate our efforts for the entire superconducting technology development, in projects such as superconducting devices, SQUIDs and new materials exploration, with closer collaboration with industrial, academic, and government organizations. Moreover, this year, we will work hard to ensure the successful transfer of ISTEC to a public interest incorporated foundation with a new structure, in order to strengthen our role and responsibility of superconductivity research and development for public interest.

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I appreciate your continued support and cooperation this year. I will close my New Year message by wishing you all the best for this year.

(Translated by ISTEC)

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Welcoming 2012

Yuh Shiohara, Director General
Superconductivity Research Laboratory

Happy New Year!

Firstly, I wish to offer my heartfelt condolences to the people affected by the East Japan Earthquake that struck on the 11th March last year. I pray for a quick return to normality as soon as possible.

Japan experienced an unprecedented national crisis from the combination of a huge earthquake, a huge tsunami and a nuclear power station accident, resulting in a state of emergency the likes of which we have never encountered before. A recovery from this disaster is urgently needed. However, the strong Yen and economic stagnation stemming from global financial crisis after the Lehman Shock still continues, and we enter 2012 with unsolved issues ranging from economic and employment measures to social security and global environmental concerns.

At Superconductivity Research Laboratory (SRL), research scientists and staff have combined efforts not to cause any further delays or problems in our research and development activities by repairing damaged research facilities and equipments immediately. A shift-work pattern has been also introduced in order to spread the workload and limit usage of electricity to reduce daily peak power consumption.

With regards to superconductor technology, in March of last year, an "Energy Saving Technology Strategy 2011" plan was drawn up and implemented by the Agency of Natural Resources and Energy, which falls under the Ministry of Economy, Trade and Industry, and New Energy and Industrial Technology Development Organization (NEDO). This future development and Japan's rapid progress in superior energy saving technologies state, "*a strategic approach is desired to make Japan's world leading superconductor technologies a core technology for implementing practical energy saving systems*". Therefore, it is highly anticipated that Japan's superconductor technologies will be at the forefront for energy saving technology initiatives. I believe this will definitely help Japan's reconstruction from the earthquake disaster.

Professor Shoji Tanaka, Honorary Director General and Advisor of Superconductivity Research Laboratory, International Superconductivity Technology Center, passed away on 11th November last year. Professor Tanaka is renowned as the first person to ignite the high temperature superconductor fever worldwide. Professor Tanaka, always instilled that Japan should contribute internationally to the basic research on the properties and materials for high temperature superconductors and exploration of new high temperature superconductor materials, leading to an innovative research and development aiming for practical applications.

This year will be the 25th anniversary since the discovery of Yttrium-based high temperature superconducting oxide materials with a superconducting critical temperature exceeding, for the first time, the liquid nitrogen temperatures. By continuously following the will of Professor Tanaka and the research outcomes achieved over the past twenty or so years, SRL as the core of world superconductor research and development, will endeavour to do its utmost in vigorously advancing the research and development in an array of superconductor fields including energy applications, such as the exploration of new superconducting materials, high temperature superconducting wires and tapes, thin film electronic devices and electrical power equipment. It is anticipated that the research and development activities will result in solutions for energy saving, environment and energy, global warming and finally provide the impetus for earthquake disaster reconstruction.

I appreciate your continued guidance, support and cooperation from each member organization and all of you this year.

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Topics: Summary of the "Research Progress Meeting for the Rare Metal Substitute Material Development Project"

Nobuyuki Sadakata, Associate Director
Technological Development Division
Industrial Superconductivity Technology Research Association

On 9th August 2011, a research progress meeting entitled "Rare Metal Substitute Material Development Project" took place in the large meeting room at ISTEC. The project involved investigating potential substitutes for Nd-Fe-B permanent magnets by advancing electromagnets by development of Yttrium-based composite materials for ultra-lightweight and high performance motor applications. The duration of the project was from March 2010 to May 2011. The member consortium involved, the Industrial Superconductivity Technology Research Association (iSTERA Associates: International Superconductivity Technology Center, Fujikura Ltd, Showa Electric Wire and Cable Co., Ltd.), Tohoku University, Nagoya University, Kyushu University and Waseda University, and the project was commissioned by the New Energy and Industrial Technology Development Organization.

Yttrium-based composite materials contain low concentrations of rare earth elements, as kind of Rare Metals . Also, multilayered tape-shaped thin superconducting layers have the ability to handle large currents of some several hundreds amps. Considering such benefits applied to future rotating machines, which use permanent magnets containing rare earth elements, a permanent magnet can possibly substitute for an electromagnet composed of Yttrium-based composite materials, and thus offers the future potential of being lightweight and increasing the efficiency of motor components.

The research outcomes were presented at the meeting, highlighting themes such as, ①Technology development of long Yttrium-based composite materials to reduce the consumption of rare earth metals, ② Technology development to improve the yields of materials (Rare Mtetals) in fabrication process of Yttrium-based composite materials, and ③Preliminary R&D on rotating machines using Yttrium-based composite materials. Specifically for theme ①, a demonstration verified an average I_c greater than 200 A/cm width and 300 A/cm width (@77K, self-field) for 1 km and 10 m long composite tape, respectively. For theme ②, static deposition verified a raw material yield greater than 40 % over the entire deposition area, with the deposition yields confirmed whilst on Reel-to-Reel moving substrate . For theme ③, a design simulator was developed and proved that the consumption of rare earth metals could be reduced to 1/130 of current motor. Furthermore, a fabricated umbrella-shaped field model coil has foreseen the prospective future for the design of rotating machines. Additionally, the design outlook for a cryocooler seems brighter with the confirmation of a rotating machine operated at high number of revolutions and cooled using liquid Ne, remaining stable at 30K, allowing the interfacial heat transfer coefficients to be obtained. These results highlighted the achievements in the research targets. The future looks towards establishing the mass production and the industrialization of Yttrium-based composite materials for ultra-long wires. Our future efforts in research and development activities will be focused on achieving a practical application of superconducting equipment for industrial use, aiming to reduce the rare metal consumption, and expanding the existing market or creating new market opportunities for the high temperature superconducting industry.

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Outline of research outcomes

Themes	Targets	Achievements
① Technology development of long Yttrium-based composite materials to reduce the consumption of rare earth metals.	① Wire characteristics of 300A/cm width (@77K, Self-field) with the fabrication of an long wire over 1km, which utilizes Yttrium-based composite materials.	①Achievement *Average I_c>300A/cm width for 1km long wires *400A for 10m long wires
② Technology development to improve the yields of materials (Rare Metals) in fabrication process of Yttrium-based composite materials.	② A raw material yield greater than 40% to be achieved during the continuous deposition of superconducting layers.	②Achievement *Raw materials yield 56% (J_c > 0.5MA/cm^2)
③ Preliminary R&D on rotating machines using Yttrium-based composite materials.	③ Yttrium-based composite materials to lead the superiority of 500kW and 1000rpm-class rotating machines.	③Achievement *Consumption of rare metals <1/130 for 500kW conceptual design. *Confirmed the feasibility of an umbrella-shaped coil as well as thermo-siphone cooling system

Future development

The fabrication technology for ultra-long (>1km) wires
→The establishment of a mass production structure for ultra-long wire

Guideline proposal for the development of Y-based superconducting rotating machines

[Rotating machine] Continuous research → The development towards the realization of applications → **Reduction in the consumption of rare metals**

[Ripple effect] Promoting to realize an array of superconducting equipment

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Topics: Bright Prospects for Iron-based Superconducting Wire Applications

Keiichi Tanabe, Deputy Director General
SRL/ISTEC

The superconductor grain boundary characteristics are key obstacles in fabricating practical superconducting wires and tapes. As a part of a "Funding Program for World-Leading Innovative R&D on Science and Technology," initiated by the Japan Society for the Promotion of Science, Professor Hideo Hosono and his research group at Frontier Research Centre of Tokyo Institute of Technology, and in joint-collaboration with the research group at International Superconductivity Technology Centre, have verified that iron-based superconductors have more advantageous grain boundary characteristics than their copper oxide-based counterparts. On this occasion, the research group reported the successful fabrication of high performance thin films onto polycrystalline flexible metal substrates.

The development of an iron-based superconductor that Professor Hosono's research group reported three years ago is still a remarkable achievement, producing a superconductor with a maximum transition temperature of 56 K, just below the highest recorded transition temperature of a copper oxide-based superconductor. Additionally, as iron-based superconductors have a large upper critical field of 50-100 T, along with a small anisotropy compared to copper oxide-based superconductors, it is highly anticipated that wire applications involving magnets that generate large magnetic fields exceeding those of metal-based superconducting wires will emerge.

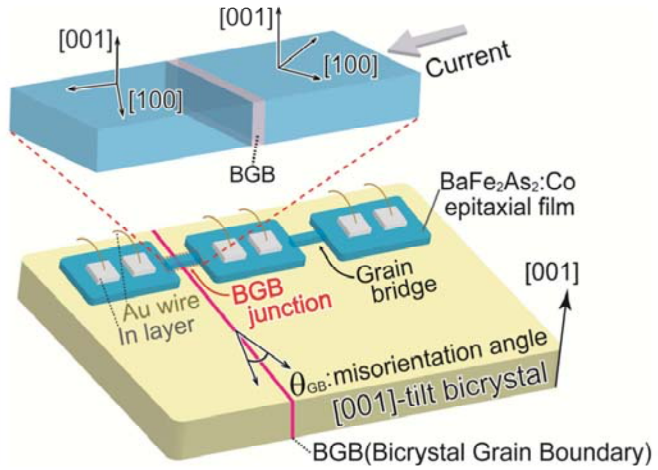

Fig. 1 To evaluate current-voltage characteristics, a $BaFe_2As_2$:Co epitaxial thin film fabricated on a bicrystal substrate was patterned into micro-bridge structures (misaligned boundary junction). The pink line shows the grain boundary of the bicrystal substrate, and the upper figure is an enlarged view of the bicrystal grain boundary junction formed on the bicrystal substrate.

The groups have employed pulse laser deposition to fabricate a high quality $BaFe_2As_2$:Co epitaxial films (T_C at around 21 K) grown on bicrystal substrates exhibiting a 3-45° misalignment, artificially creating the misalignment of crystalline orientations at the grain boundaries of $BaFe_2As_2$. In order to study the grain boundary properties, a bridge structure (misaligned boundary junction) was patterned on this misaligned boundary (Fig.1), and critical current densities at the boundary were evaluated from current-voltage characteristics measured at 4 K and 12 K (Fig. 2). The results showed that with the misorientation angle up to 9° (highlighted by the arrow in Fig. 2), a high critical current density of more than 1 MA/cm^2 was sustainable. The 9° critical angle is greater than that of 3-7° evaluated for Y-based copper oxide superconductors using the same method. Furthermore, there was no rapid drop in critical current density when the angle exceeds 9° (red line and blue line). In fact, the results showed that with a high misorientation angle exceeding 30°, the iron-based superconductor has a superior critical current density at 4 K compared to a copper oxide-based superconductor. These findings imply that the grain boundary nature of iron-based superconductors are able to tolerate grain boundary misalignments of up to 9° without detrimental effects on performance. Professor Hosono's group and the ISTEC group successfully fabricated a thin film on a metal substrate with an IBAD-MgO buffer layer (provided by Los Alamos National Laboratory, USA) exhibiting in-plain misorientation of more than 7°, being of far lower quality than that recently utilized for copper oxides. This iron-based superconducting film had high critical current densities of more than 1 MA/cm^2 (3.5 MA/cm^2 at maximum), values equivalent to the deposition on a single crystal substrate (Fig. 3).

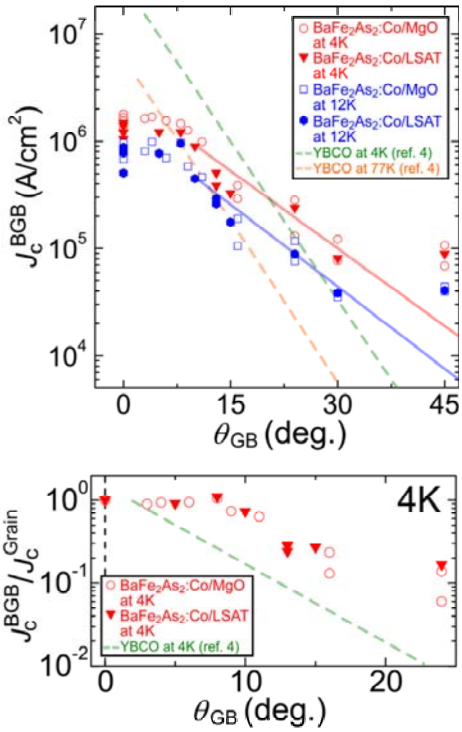

Fig. 2 (a) Misorientation angle dependence of the critical current density for the iron-based suerconductor grain boundary junction. (b)The ratio of the critical current density for the bicrystal grain boundary junctions and grain bridges (the area not including the grain boundary). Both the films on MgO and LSAT bicrystals are similar in their behaviour at the grain boundary junction. A critical current density exceeding 1 MA/cm^2 was sustained until the misorientation angle reached a critical value of 9°, as shown by the arrow in the figure. This critical angle is larger than that of copper oxide (3-7°)

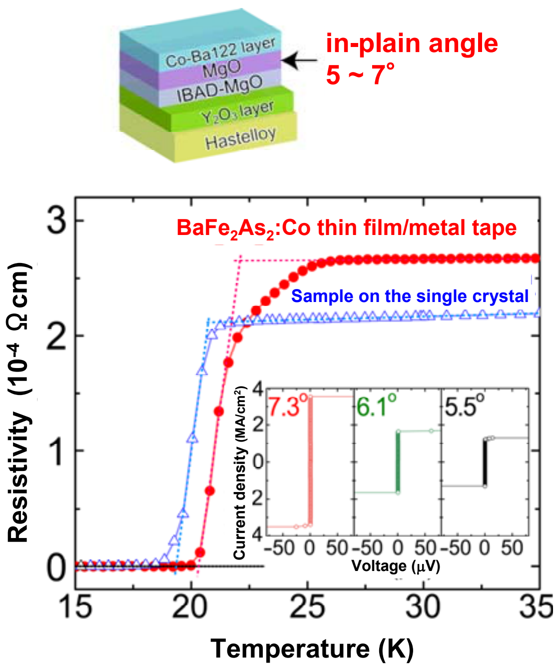

Fig. 3 The superconducting characteristics of BaFe$_2$As$_2$:Co epitaxial films fabricated on a flexible metal-tape substrate with an in-plain misorientation of the IBAD-MgO buffer more than 5° (red). For comparison, the characteristics of a thin film on single crystal substrate are shown (blue). The figure insert shows the current density – voltage characteristics measured at 2 K for the BaFe$_2$As$_2$:Co epitaxial films on the metal-tape substrate with different misorientation values. The entire samples showed critical current densities greater than 1 MA/cm^2 (3.5 MA/cm^2 at maximum), equivalent to that of a thin film deposited on a single crystal substrate.

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Currently, the T_C of an iron-based superconductor is lower compared to a copper oxide-based superconductor. Thus, a Y-based copper oxide thin film operating at a T_C greater than 90 K exhibits greater critical current density values when compared at the same temperature. However, the characteristics of iron-based superconductors, including their smaller anisotropy, their strength in a magnetic field, large critical angle are now apparent, with these results implying the great potential for superconducting wires/tapes applications, in particular, wires that are able to generate greater magnetic fields than their metal-based counterparts at low temperatures. From now, research and development activities are focused towards exploring suitable artificial pinning materials to realize high critical current densities in a magnetic field as well as ways to implement this.

These research findings into grain boundary properties of iron-based superconductors were reported in "Nature Communications" 3rd August (2nd August in London local time) (Nat. Commun. 2:409 doi: 10.1038/ncomms1419 (2011).). Also, the research outcomes regarding the thin film fabrication on a metal substrate was published in "Applied Physics Letters" (Appl. Phys. Lett. 98, 242510 (2011).).

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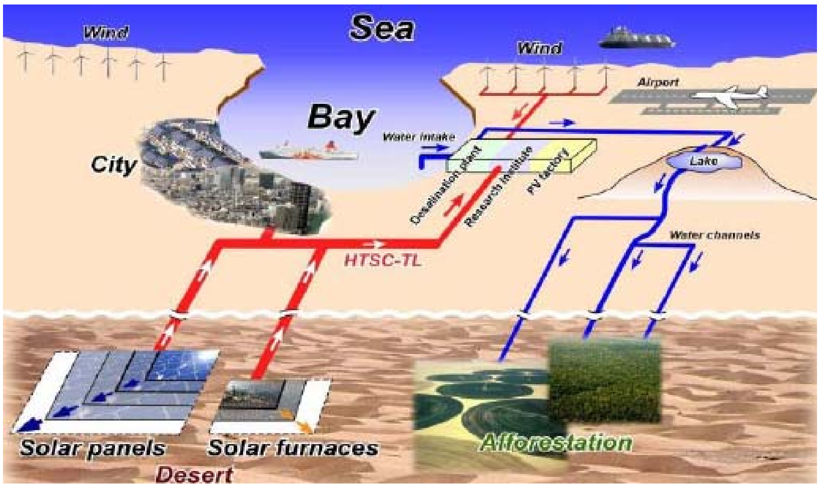
Reporting on the "1st Asia-Arab Sustainable Energy Forum"

Yuh Shiohara, Director General
SRL/ISTEC



Ref. "The Sahara Solar Breeder Project" Homepage

I attended the 1st Asia-Arab Sustainable Energy Forum (AASEF) held in Nagoya city on 23rd-26th August 2011. This Forum was initially planned for Hirosaki city in Aomori prefecture at the end March 2011, however, was postponed because of the East Japan Earthquake that struck on 11th March. The forum was instead held at the local city of Chubo University, a place where research and development into DC superconducting power transmission lines are undertaken.

The University of Tokyo and Chubu University, as the main research bodies, have proposed and initiated the Sahara Solar Breeder (SSB) project, which involves power generation using photovoltaic technology by taking advantage of the vast array of solar energy (solar radiation received in the Sahara desert corresponds to 10 times the total amount of energy consumed by the entire world). For this technology, Si-based solar panels will be used, fabricated from the desert sands (main composition is silica SiO_2). The SSB project combines photovoltaic power generation technology with high temperature superconducting (HTS) DC transmission technology, which can realize long-distance transmission with low losses. This project forms the basis of a new energy supply model that does not utilize energy derived from fossil fuels, thus drawing the attention of oil-producing Arab countries. Researchers from many countries located near the Sahara desert joined the forum, held at the "*Wink Aichi*" situated at the front of Nagoya station. Discussions focused on the realization of the above-mentioned SSB technology. The sponsor counted a total of 80 participants, with 50 Japanese and 30 participants from nine foreign countries (Algeria, the Netherlands, Tunisia, Russia, Turkmenistan, India, UK, Taiwan, Korea).

The 1st AASEF was held together with the DC Superconducting Transmission conference and the SSB forum, which forms part of a joint project initiative, involving researchers in Japan and developing countries to solve global-scale issues. This initiative forms part of the JST-JICA program (Science and Technology Research Partnership for Sustainable Development: SATREPS), and involves the international society to collaboratively tackle global issues such as, the environment, energy problems, natural disasters, infectious diseases, global food problems, etc.

The forum opened the first day (23rd), with a session entitled "Session-1: Opening & General Remarks," which commenced from the morning and finished in first-half of the afternoon session. This session consisted of talks from the Chancellor of Chubu University, the sponsors of the SSB Foundation and RITE/JST. Guest speakers included Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan Science & Technology Agency (JST), the Tunisian Ambassador to Japan and Aichi prefecture governmental officials. A total of eight sessions followed the opening session.

"Session-2: Innovative Si technology-1; More than Siemens"、
"Session-3: Innovative Si technology-2; Beyond Siemens"、
"Session-4: Workshop on Superconducting DC transmission and distribution-1"、
"Session-5: Energy from the desert: PV system and application"、
"Session-6: Workshop on Sahara Solar Breeder plan (semi-closed, parallel session)"、
"Session-7: Workshop on Superconducting DC transmission and distribution-2 (open)"、
"Session-8: International cooperation and future plan"、
"Session-9: Closing remarks"

The sessions were largely categorized into research and development for photovoltaic power generation technology and superconducting DC power transmission. A brief outline of the sessions follows.

Research and Development for Photovoltaic Power Generation Technology

1. Solar cells are expected as a future source providing infinite energy, even after the depletion of fossil fuels. However, mainstream solar cells contain high purity Si that increases manufacturing costs, and therefore the development of a new technology to significantly reduce manufacturing costs is an acute issue.
2. The main components of the Saharan sands are Si oxides (SiO_2). Taking advantage of the sands forms the key to the research and development required to produce low-cost Si solar cell manufacturing.
3. Utilizing the desert sands, Si solar cell manufacturing plants can be situated close to desert locations. Si solar cells are positioned in the Sahara and the electricity generated powers solar cell manufacturing facilities. This in turn allows the production of even more Si solar cells in a "breeding" process, allowing installation in the desert at low cost.

<At the forum, a plan reports an estimated final cost for power generation being 7-8 cent/kWh, assuming mass production of vast quantities of solar cells.>

Superconducting DC Power Transmission Technology

1. In Japan, as the leading country, research and development to improve the performance characteristics of HTS wires that operate at liquid nitrogen temperatures has advanced, with associated costs decreasing to 1/20 over the past seven years. On the other hand, the economic growth of developing countries have led to a significant increase in copper demand, resulting in rising costs of copper.
2. Research and development efforts have advanced DC power transmission, cables and peripherals, (Peltier current lead) and system (cryocooling systems), because of the merits offered by HTS wires in DC applications. Chubu University is at the forefront of R&D efforts into DC superconducting transmission cable systems.
3. Arab countries foreseeing the future "after oil", are investigating resources for electrical energy production from solar power in the desert. In order to export this energy, research and full-scale development efforts are about to commence to investigate High Voltage DC Transmission (HVDC) as a possible export route, as well as superconducting DC transmission technology, which are further efficient and have less resource constraints.

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<As mentioned above, the manufacturing of low-cost Si solar cells involves desert sand, and combined with superconducting DC power transmission technology, which makes possible the realization of long-distance transmission at low loss (refer to upper Figure). A report at the meeting envisaged that electricity generated from intense desert solar radiation would supply vast areas located far from desert regions (EU regions).>

Considering HTS DC transmission technology applications on the basis of Breakeven Length analysis, which takes into account DC transformer loss, cryo-cooling loss and HTS wire cost, over 700-800 km ultra-long distance HTS DC power transmission cables will prove to have superior performance as the substitutes for current AC grids. Excluding the installation of new grids or the replacement of current DC power transmission grids, the Japanese HTS DC power transmission market is still small. However, I realize the necessity to closely monitor the future trends of the SSB project to enable further advancement of superconducting technology in our country, currently positioned as the world-leader, into the potential market, including the ultra-long distance power transmission that the SSB project discussed at this forum.

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Reporting on the "1st Trilateral EU-Japan-US Conference on Critical Materials for a Clean Energy Future"

Yuh Shiohara, Director General
SRL/ISTEC

I attended the "1st Trilateral EU-Japan-US Conference on Critical Materials for a Clean Energy Future" held in Washington D.C., USA, on the 4th and 5th October 2011. This conference was jointly held by the European Commission's Directorate General for Research and Innovation, Japanese Ministry of Economy, Trade and Industry, and The U.S. Department of Energy (DOE) (Refer to the agenda cover sheet shown in upper Figure).

The following invited keynote speakers made presentations on the morning and lunchtime of the first day of the conference.

Keynote Addresses (8:50-9:20 am) Moderator: Bart Gordon, Partner, K&L gates LLP
David Sandalow, Assistant Secretary for Policy and International Affairs, U.S. Department of Energy.
Reinhard Bütikofer, Member, Vice Chair, Group of the Greens/European Free Alliance, Member, Committee on Industry, Research and Energy, European Parliament
Ichiro Fujisaki, Ambassador of Japan to the United States
Implications of Material Supply Challenges for Innovation, Security and Trade (9:20-11:20 am)
Gwenole Cozigou, Director, Chemicals, Metals, Mechanical, Electrical, Construction Industries and Raw Materials, Directorate General for Enterprise and Industry, European Commission
Herbert von Bose, Director, Industrial Technologies, Directorate General for Research and Innovation, European Commission
Cyrus Wadia, Senior Policy Analyst, Environment and Energy Division, Office of Science and Technology Policy, United States
Charles Cogar, Legislative Director, Congressmann Mike Coffman, U.S. House of Representatives
Komei Halada, Managing Director, Center for Strategic Natural Resources, National Institute for Materials Science, Japan
Keiichi Kawakami, Deputy Director General, Manufacturing Industries Bureau, Ministry of Economy, Trade and Industry of Japan
Environmentally and Economically Sustainable Production of Rare Earths (11:30 am - 1:00 pm)

Stephen Collocott, Group Leader, Novel Alloys, Magnetics and Drives, Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia
Anil Arora, Assistant Deputy Minister, Minerals and Metals Sector, Natural Resources Canada
Alain Rollat, Technology Development Manager, Rhodia Rare Earth Systems France
Maurits Van Camp, Coach, Recycling and Extraction Technology Platform, Umicore Belgium
Jim Sims, Vice President, Corporate Communications, Molycorp USA

Photograph: The view from the outside of the venue (Cosmos Club), and the panellists on stage during panel discussions.

Keynote speakers from EU-Japan-US trilateral regions focused on possible supply disruptions of critical materials and the shortage of rare metal and rare earth elements, which are currently supplied by one country, China. The importance of 3R (Replace, Reduce, Recycle) pertaining to those materials was stressed.

Mr. Fujisaki, the Japanese Ambassador in the United States, quoted in his talk the oil crisis that occurred over 30 years ago, and a future where there is a “sudden shortage in the supply” of rare metal and rare earth elements, would lead to price increases of high technology industrial products, for example, the components of Nd(Dy)FeB magnets currently used in the motors of hybrid cars, as well as CeO_2 utilized for computers. He concluded his lecture by stating that this is a “sense of urgency without duplication.” Consequently, Keiichi Kawakami (Deputy Director General, Manufacturing Industries Bureau at the Ministry of Economy, Trade and Industry) introduced the fact that Japan currently utilizes 48% of the entire world consumption volume of rare earth elements, significantly exceeding USA (18%) and France (7%). At his lecture, examples of electric vehicles (EVs), hybrid cars, wind-turbine generators demonstrated applications where critical materials usage is expected to expand worldwide.

Panel discussions took place after the lectures, where the following ABCD&R were discussed as important themes for critical materials initiatives.
A: Alternative, B: Broader International Cooperation C: Conservation, D: Diversification, R: R&D

Two years ago, the USA DOE initiated and launched the APRA-E project. The project focused on the important theme of “Clean Energy, Critical Materials,” and also reported that the budget of the current fiscal

year was just determined one week before the conference. From the 4th round of DOE funding subscriptions, this year, sixty projects in five programs received a grant totalling US$156 million. University of Houston led the REACT (Rare Earth Alternatives in Critical Technologies) program (Joint development with National Renewable Energy Laboratory, SuperPower, Tai-Yang Research, TECO-Westinghouse Motor Company) for "High Performance, Low Cost Superconducting Wires & Coils for High Power Wind Generators" ($3,123,750). Attention needs to be paid to the future development of these programs.
(Reference: http://arpa-e.energy.gov/ProgramsProjects/REACT.aspx)

The following workshop (Parallel lecture of both A & B groups) as well as the closing session took place in the afternoon of the first day and the second day of the conference.

Workshop A: Substitutes and Efficient Use of Rare Earth Magnets

Session A1: Reducing neodymium and dysprosium requirements for magnets (including predictive modeling) (Tuesday, October 4, 15:00-18:00)

- New compositions or structures that are high energy density, low rare earth content
- Heat management approaches that reduce the need for dysprosium

Session A2: Component and system-level substitutions (Wednesday, October 5, 9:30-12:30)

- Induction or reluctance motors
- New approaches to magnetic circuit design
- Advanced hydraulic transmission for drive train systems
- High-temperature superconductor generators (HTSG)/ motors(HTS-SM)

Workshop B: Resource efficiency: reusing, recovering, recycling

Session B1: Materials and processes for environmentally sound, economical separation of rare earths in diverse ore bodies and recycling streams (Tuesday, October 4, 15:00-18:00)

- Organic solvents
- Supercritical solvents
- Nano-porous membranes
- Biological processes
- Ion exchange

Session B2: Recycling technologies and optimization (Wednesday, October 5, 9:30-12:30)

- Design of materials and products for recyclability
- Processes uniquely suited to recycling
- Logistics optimization

Concluding Plenary: Findings and Next Steps (Wednesday, October 5, 14:00-15:30)

- Report out from workshops
- Next steps for collaboration

Workshop A (Substitutes and Efficient Use of Rare Earth Magnets)

Session A1: Discussion Lead: Suresh Baskaran, Pacific Northwest National Laboratory

- William McCallum, Ames Research Laboratory, Approaches for Enhanced Rare-Earth- Free Permanent Magnets
- Dimitris Niarchos, Demokritos, A Scientific Response to Scarcity of Rare Earths: REFREEPERMAG
- Migaku Takahashi, Tohoku University, Research and Development of Iron-Nitride-Based New Permanent Magnetic Materials with Less Rare Earth Elements or Free of Rare Earth Elements
- George Hadjipanayis, University of Delaware, High-Performance Magnets with Reduced Neodymium and Dysprosium Content
- Viorel Pop, Babes-Bolyai, Exchange Spring Nanocomposite Magnetic Materials: A Path to Strong, Hard Magnetic Materials with Low Rare Earth Content

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- Laura Lewis, Northeastern University, New Directions in Permanent Magnets: Developing Anisotropy without Rare Earths
- Hirotoshi Fukunaga, Nagasaki University, Numerical Modeling for Magnetic Materials

Session A2: Discussion Lead: Ed Jones, Lawrence Livermore National Laboratory

- Steve Constantinides, Arnold Magnetics, Magnetic Material and Device Design Options
- Akira Chiba, Tokyo Institute of Technology, Development of Rare-Earth Free Motors for Electric Vehicles and Hybrid Electric Vehcles
- John Miller, Oak Ridge National Laboratory, Permanent Magnets and Motors: The Challenge
- Venkat Selvamanickam, University of Houston, High Temperature Superconducting Materials for High-Power, Light-Weight Generators for Wind Energy and Other Applications
- Yuh Shiohara (SRL-ISTEC), Japanese Efforts and Current Status of R&D on Superconducting Motors
- Navin Manjooran, Siemens, High Temperature Materials Needs

The synchronous motor is expected to propel into the future mainstream market as a substitute to the current induction motor because of higher efficiencies. The rotating machine is also planned for hybrid and electric vehicles as well as for large-scale wind turbine power generators. With this background, the initiatives of Japan, USA, and the EU were discussed to further reduce the consumption volume of rare metals and rare earth elements, which form the constituent elements of the Nd(DY)FeB permanent magnet, required for the synchronous motor and the rotor of synchronous rotating machines.

University of Houston, the only overseas representative, gave a lecture on superconducting technology. The contents of the lecture included the introduction of high temperature superconducting technology such as Y-based conductors, cables, transformers and motors. High temperature superconducting technologies applied to wind turbine power generators are quantitatively significant in terms of reducing the consumption of rare metals. The analysis, results, and the technological details associated with this effect were not however given in the lecture. From the Japan side, the author gave a lecture stressing that although the constituent elements of high temperature superconducting oxide materials do include the rare earth elements such as Y and Gd, future developmental outcomes are highly anticipated considering the current developmental progress of rotating machines utilizing Y-based superconducting conductors. The author introduced that the basic theoretical design to realize high magnetic field generation, efficiency improvements and a lightweight system, would be achieved by forming the replacement of the rotor in synchronous motors utilizing Nd(Dy)FeB permanent magnets with Y-based superconducting electromagnet (field rotor). It was also highlighted that superconducting technology applied to large scale offshore wind turbine power generators, which are expected into the market in the not too distant future, would contribute to compact and lightweight wind turbine power generators, with the consumption volume of rare earth metals required for the motor and permanent magnet synchronous power generator being significantly reduced due to the switch to superconducting rotating machines (A superconducting rotating machine consumes 1/100th the amount of rare earth materials compared to a permanent magnet synchronous rotating machine, but delivers the same power output). The author received many encouraging comments, including expectations for further research and development, verification and demonstration of the research outcomes, and finally application realization.

It is thus necessary for us to observe the future trends (development) in order for Japan, which is currently world leader in superconducting technology, to advance further in this field.

It was proposed that the next conference be held in Tokyo at the end of March or at the beginning of April next year.

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Topics: Shinya Hasuo, Senior Research Fellow of ISTEC Receives IEEE Award for Continuing and Significant Contributions in the Field of Applied Superconductivity

Fig. 1 The awards ceremony

Shinya Hasuo, Senior Research Fellow of ISTEC received an IEEE Award (Institute of Electrical and Electronic Engineers) at the "Superconductivity Centennial Conference" held in The Hague, Netherlands, from the 18th to 23rd September 2011.

This award was presented by the IEEE Council on Superconductivity (CSC) as part of IEEE. The award was first launched in2000, and this was the 12th such award. Since the awards commenced eleven years ago, 42 significant researchers have been awarded up to now. Amongst the past awardees, there were seven Japanese in total, (in accordance of awarding order); Professor Kyoji Tachikawa of Tokai University, former Professor Hiromi Hirabayashi of National Laboratory for High Energy Physics, former Director Yoshihiro Kyotani of Maglev System Development Department of Japanese National Railways, Director General Shoji Tanaka of SRL/ISTEC, Professor Emeritus Hisao Hayakawa of Nagoya University, former Scientist Masaki Suenaga of Brookhaven National Laboratory, Professor Akira Yamamoto of High Energy Accelerator Research Organization. All of the past awardees can be found at:
http://www.ewh.ieee.org/tc/csc/index.html

CSC has three-awards categories, and Hasuo, Senior Research Fellow, received an Award for continuing significant contributions in the field of applied superconductivity. This award is given to researchers who have made a significant contribution to the field of applied superconductivity. Other awards include, Max Swerdlow Award, presented for sustained service to the applied superconductivity community, and Carl H. Rosner Entrepreneurship Award, presented to successful entrepreneurs in the commercialization of superconductivity. Combining these awards, in total about four people are presented with the awards at the CSC every year, however, this year was significant because of the commemoration of the 100th anniversary of superconductivity, with a total of eight people receiving awards. R.M.Scanlan of Laurence Berkeley National Laboratory, A.P.Malozemoff of American Superconductor Corporation, J.Wong of Supercon Inc., A.Tollestrup of Fermi National Laboratories, Yukikazu Iwasa of Francis Bitter Magnet

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Laboratory MIT, B.Truck of CEA Caradache, H.Rogalla of University of Twente, and Shinya Hasuo of ISTEC. Three of those awardees were presented with the awards at the MT-22 (22nd International Conference on Magnet Technology) held in Marseille, France, the previous week. The remainder received their awards at this conference.

Figure 1 Shows Senior Research Fellow, Hasuo being presented with the award by the Chair of the Award Committee of CSC, M.Nisenoff. The left of Hasuo is the Chair of CSC, E.K. Track.
The plaque is approximately A3 size. The following words were engraved on the plaque, with the signatures of Track and Nisenoff.

Fig. 2 The words engraved on the plaque

This medal presented at the conference is made from superconducting material, Niobium. The diameter of the medal is approximately 5 cm.

Fig. 3 The medal awarded (the left picture shows the obverse and the right picture shows the reverse)

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What's New in the World of Superconductivity (November, 2011)

Senior Research Fellow, Shinya Hasuo
Superconductivity Research Laboratory, ISTEC

Contract

Bruker (November 9, 2011)

Bruker has received a major order from the new Central European Institute of Technology (CEITEC) in Brno, Czech Republic, for four ultra-high field AVANCE™ NMR systems. Once installed, these systems will establish CEITEC as the premier biological NMR research facility in Central and Eastern Europe. Three of these systems will include superconductor technology, enabling the use of smaller magnetic coils that enable a significant reduction in cryostat size as well as a significant reduction in operating costs.

Source: "Bruker Announces Four Ultra-High Field NMR Orders from the Central European Institute of Technology (CEITEC) to Enable Advanced Biological Research"
Bruker press release (November 9, 2011)
http://www.bruker-biospin.com/pr111108.html

Settlement

AMSC (November 9, 2011)

AMSC has reported its financial results for the second quarter of fiscal 2011, ending September 30, 2011. Total revenues for the second quarter amounted to US $20.8 million, compared with $98.1 million for the same period in the previous fiscal year. This year-over-year decline is primarily due to the lack of revenue from AMSC's former customer Sinovel Wind Group. Co., Ltd. The net loss for the quarter was $41.7 million, including approximately $28.2 million in charges related to the previously announced termination of AMSC's proposed acquisition of The Switch Engineering Oy, Sinovel litigation expenses, and corporate restructuring activities and impairments. As of the end of the second quarter, AMSC had $108.3 million in cash, cash equivalents, marketable securities, and restricted cash. The total backlog, excluding contracts related to Sinovel, was approximately $298 million. AMSC President and Chief Executive Officer Daniel P. McGahn commented, "We generated a sequential increase in revenues while also reducing our non-GAAP net loss and cash usage compared with the prior quarter. Among our key contributors to revenue during the quarter were wind turbine manufacturing customers such as Inox Wind in India, Doosan Heavy Industries in Korea and Dongfang Turbine Company in China. On the Grid side of our business, we grew our D-VAR® revenues and reached several recent milestones. These milestones include the energization of South Korea's first superconductor power cable system with our partners Korea Electric Power Corporation and LS Cable & System, the successful testing of a transmission-voltage fault current limiter with the U.S. Department of Energy and our partners Nexans, Siemens and Air Liquide, and the restart of Project HYDRA in New York with the Department of Homeland Security's Science and Technology Directorate and our partners ConEdison and Southwire. A diversified mix of Wind and Grid bookings enabled us to increase our total backlog by over 30 percent sequentially in the second quarter. This has helped position us for a stronger second half of fiscal 2011 from both a revenue and bottom-line perspective. On a go-forward basis

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we will continue to carefully manage our expenses and our cash."

Source: "AMSC Reports Second Quarter Fiscal 2011 Financial Results"
AMSC press release (November 9, 2011)

The new brand

Superconductor Technologies Inc. (November 11, 2011)
Superconductor Technologies Inc. (STI) has introduced Conductus® Superconducting Wire, the new brand name for the company's superconducting wire product family. Adam Shelton, vice president of marketing and product management for STI, commented, "Interest in STI's Conductus Superconducting Wire has grown steadily. We believe STI's proprietary technology and manufacturing expertise will enable broader market commercialization by addressing three industry requirements: supply/availability, price and performance." The name Conductus has historical significance, since much of the technology that STI uses today originated at Conductus, a California-based company that was acquired by STI in 2002. STI's unique Reactive Co-evaporation Cyclic Deposition and Reaction (RCE-CDR) High Temperature Superconducting deposition process is expected to provide STI with key advantages for the successful commercialization of HTS wire for large, emerging markets.

Source: "Superconductor Technologies Inc. Introduces Conductus® Superconducting Wire Product Family"
Superconductor Technologies Inc. press release (November 11, 2011)

Photon detector

NIST (November 14, 2011)
Scientists at the National Institute of Standards and Technology (NIST) have demonstrated that a superconducting detector called a transition edge sensor (TES) is capable of counting as many as 1000 photons in a single pulse of light with an accuracy that is limited mainly by the quantum noise of the laser source. Until this achievement, accurate counts of more than approximately 50 photons had not been feasible. The findings could eventually be applied in quantum information processing, telecommunications, and optical metrology at low light levels. Thomas Gerrits of PML's Quantum Electronics and Photonics Division commented, "When the uncertainty of the photon-number determination is sufficiently low and the detection efficiency is close to unity, by detection one can decode information that was encoded in the amplitude (photon number) of a pulse of light." A TES consists of a thin layer of superconducting material placed on an insulating substrate. The entire device is then cooled below the critical temperature of the superconducting thin film. A small voltage is then applied across the film, resulting in a slight electrical resistance in the middle of the superconducting transition region – an area that is neither a superconductor nor a conventional conductor. Whenever an incident photon strikes the device, the photon's energy is absorbed—thereby heating the superconducting film and raising its resistance. Once a very large number of photons have been absorbed, the heat saturates the device, forcing it past the transition edge and into the non-superconducting regime. In the present research, the research team focused on determining how well a TES could resolve larger photon numbers. Instead of measuring the change in resistance, however, the scientists measured the thermal relaxation time, or the amount of time required for the TES to shed its heat and return to the upper edge of the transition region. This time interval was found to be a sensitive indicator

of photon numbers up to about 1000. The findings have practical applications, such as low-light-level homodyne detectors for optical quantum states.

Source: "Adding up Photons with a TES"
NIST press release (November 14, 2011)
http://www.nist.gov/pml/div686/tes.cfm

Accelerator

CERN (November 16, 2011)

CERN has initiated the High Luminosity LHC study with a workshop that will bring together scientists and engineers from 14 European institutions as well as from Japan and the USA in a project supported by the European Commission's seventh Framework program (FP7). The goal of the project will be to prepare the ground for an LHC luminosity upgrade that has been scheduled to occur around 2010. Participants at the first workshop will begin the initial design phase of the project, which will attempt to increase the LHC's luminosity by a factor of 5 – 10 times higher than the present design value. The international nature of this workshop is representative of the field of particle physics and vital for the success of the project. The LHC upgrade will require the development of new technologies in a variety of fields including high-field magnets, radiofrequency cavities, and electrical transfer lines, all of which will be based on superconducting technology.

Source: "CERN has 2020 vision for LHC upgrade"
CERN press release (November 16, 2011)

Basics

University of Toronto (November 6, 2011)

Researchers at the University of Toronto have demonstrated for the first time the key mechanism behind how energy levels align in transition metal oxides. The discovery represents a significant breakthrough in the development of sustainable technologies such as dye-sensitized solar cells and organic light-emitting diodes (OLEDs). The group has lain out a blueprint that conclusively establishes the principle of energy alignment at the interface between transition metal oxides and organic molecules. The discovery could enable scientists and engineers to design simpler and more efficient organic solar cells and OLEDs to further enhance sustainable technologies. The group's research has been published in *Nature Materials*.

Source: "University of Toronto engineers solve energy puzzle"
University of Toronto press release (November 6, 2011)
http://media.utoronto.ca/media-releases/engineering/engineers-solve-energy-puzzle/

Swedish Research Council (November 18, 2011)

Scientists at Chalmers University of Technology have successfully created light from a vacuum, observing an effect first predicted over 40 years ago. The experiment is based on a counterintuitive principle of quantum mechanics: that a vacuum is, in fact, full of various particles (known as virtual particles) that are continuously fluctuating in and out of existence. The Chalmers scientists have succeeded in transitioning photons from a virtual state to become measurable light through a phenomenon known as the dynamical Casimir effect. The experiment involves the use of SQUID component. By changing the direction of the magnetic field several billions of times a second, the scientists were able to create a "mirror" that vibrates at a speed as high as 25 % of the speed of light. The "mirror" transfers some of its kinetic energy to virtual photons, helping them to materialize. As a result, photons appeared from the vacuum as pairs that could be measured as microwave radiation. The group's findings, which may have applications in the field of quantum information and have contributed to our finding of basic physical concepts—such as vacuum fluctuations, have been published in the journal *Nature*.

Source: "Chalmers scientists create light from vacuum"
Swedish Research Council press release (November 18, 2011)
http://www.chalmers.se/en/news/Pages/Chalmers-scientists-create-light-from-vacuum.aspx

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Feature Articles: SQUID･Medical Equipment
- The Fabrication of Ramp-Edge junction HTS-SQUID and its Noise Characteristics

Seiji Adachi, Deputy Director
R&D Division of Electronic Devices
SRL/ISTEC

A SQUID is an ultra sensitive magnetic sensor taking advantage of the superconducting phenomenon, requiring a cryocooling system for its operation. It can therefore be argued that this requirement is detrimental compared to other devices that operate at room temperatures. However, the sensitivities offered by a SQUID cannot be achieved by utilizing other physics phenomena. There exists an array of SQUID applications for medical and biotechnology applications (magneto-encephalography, magneto-cardiography, immunuoassays, low magnetic field MRI), analysis and evaluation applications (non-destructive testing for materials/foods/electronics components, magnetic force microscopy, magnetic exploration (mineral exploration, ruins exploration). Demonstrations of such systems have been performed, and some applications have been commercially exploited as industrial products. What underpins the conditions that determine whether a product can diffuse into the public mainstream market are factors such as, the system performance meeting user demands, the reliability, the cost and the ease of use. Thus, research and development efforts have focused on these areas but are now at a crossroad in terms of future superconducting applications.

Recent research efforts at ISTEC have led to a fabrication process for high temperature superconducting (HTS) SQUIDs employing a ramp-edge Josephson junction, with evaluation and demonstration tests of practical systems able to meet the demands specified by applications. Until now, the use of bicrystal or step-edge type Josephson junctions were the mainstream because of the relatively easier fabrication process. However, with the introduction of a new chip fabrication process including, the development of ramp-edge type Josephson junctions and superconducting crossing wire technology, has enabled a greater degree of freedom in circuit design, resulting in the realization of chips with far greater complexity than was ever possible in the past.

Essential factors for chip fabrication are improvements in yields and characteristics. The former issue requires complete process management. The bottlenecks in yield deterioration occur due to the fabrication process of Josephson junctions. Recently, elaborate efforts to modify the design layout have been investigated by increasing the density of SQUIDs produced from a single substrate in an attempt to increase yields. After repeated trials and errors, issues to improve characteristics still remain problematic. Amongst the numbers of trials conducted thus far to enhance junction characteristics include, reducing the amount of copper in the upper superconducting electrode by up to 20 %. For a magnetometer fabricated onto a 15 x 15 mm^2 substrate, the results measured white-noise characteristics of 10 fT/ Hz (@77 K, 1 kHz). Optimizing the chip design layout to increase yields has led to the possible fabrication of chips with 10~80 fT/ Hz (@77 K, 1 kHz) characteristics, with a yield of approximately 80 %, assuming there are no process problems other than those associated with junction fabrication.

For SQUID applications tested until now, the magnetic field signal magnitudes have been in the

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femtotesla (fT=10^{-15} T) to nanotesla (nT=10^{-9} T) range. Low temperature superconducting (LTS) SQUIDS are utilized for magneto-encephalographic and magneto-cardic measurements, where low noise, restricted to the several fT-level is desired. Current technology does not permit magneto-encephalographic measurements to be achieved, however it is considered that other varieties of SQUID applications have the potential to be realized. By utilizing LTS SQUIDs for such applications, where only the SQUID can realize the ultimate operating performance, relying upon less complex HTS SQUID systems for other applications will lead to a brighter outlook for HTS SQUID applications. Of course system development requires that many hurdles be overcome, not only for improvements in chip noise performance but, also additional factors need to be tackled in the development to meet the desired specifications of each application, where issues such as frequency characteristics, slew rate, drive system electronics like FLL circuit, removal technology of environmental noise, cryocooling technology etc, are all important. Nevertheless, as far as the chip fabrication process is concerned, it has achieved the status of “ready” towards the system development required for practical use.

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Feature Article: SQUID·Medical Equipment
- Mapping the Electrical Properties of Solar Panels Using High-T_c SQUID

Toshihiko Kiwa, Associate Professor
Graduate School of Natural Science and Technology
Okayama University

1 Introduction

Presently, the use of natural, clean and sustenable energies is highly desired. Amongst the potential energy sources available, power generation using solar cells offers a simple solution for our energy needs. The quality evaluation of solar panels is generally undertaken by measuring the output current-voltage characteristics at the terminals. Many JIS standards are established according to each solar cell category. However, it is difficult to determine solar cell conversion efficiencies and evaluate other defects from only output measurements between the terminals. Thus, it has become necessary to individually map the electrical properties of each solar panel surface. A number of research and development efforts are underway for measuring techniques that will address this requirement. One such system utilizes a CCD camera to measure the amount of electroluminescent (EL) light emitted from the vicinity of a defect, allowing the detection of micro-cracks, however the inability to detect defects not associated with the EL light remain issues that require addressing. In recent years, Prof. Itozaki, and his research group at Osaka University have proposed non-destructive testing of solar cells using laser SQUIDs. Recent successes of this group have allowed the electrical properties to be mapped in 3D by varying the laser wavelength. In our research group, a mapping system has been developed, designed to investigate the electrical properties of solar cell by applying an AC modulation voltage to the solar cell and measuring the magnetic field distribution generated by the current flowing in the panel.

2. The mapping system to determine the electrical properties

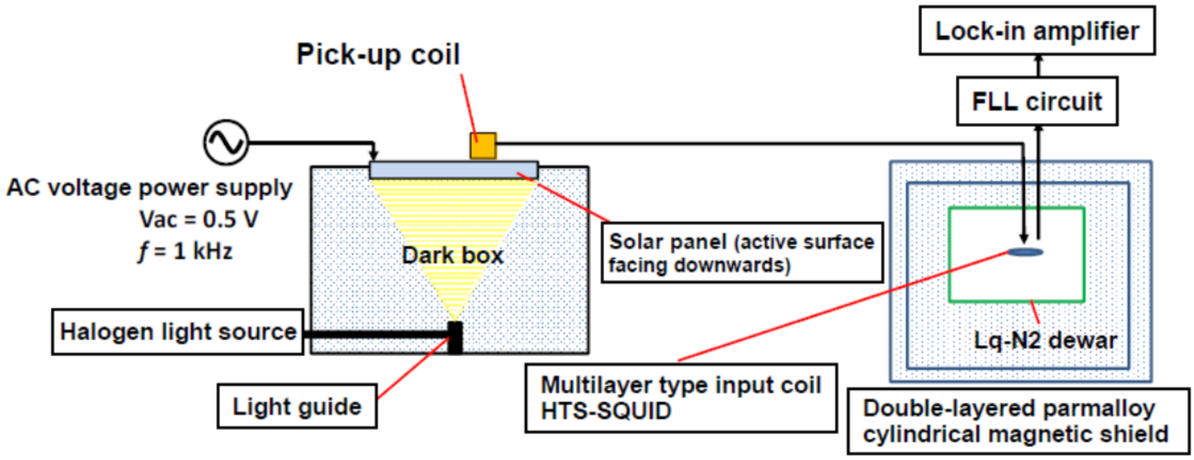

Fig. 1 Schematic diagram of the differential resistivity mapping system

Figure 1 shows the schematic of the mapping system developed to map the electrical characteristics. An AC voltage and an offset voltage V_{dc} are applied to a solar panel that is mounted inside a dark box. A pick-up coil mounted on the back of the solar panel detects the magnetic field component generated by the

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flow of current. The pick-up coil has an internal diameter of 10 mm x 20 mm, with 200 windings, and the measured magnetic field is transferred through this input coil to a HTS SQUID housed within a double-layered parmalloy shield. The measured magnetic field signal is then lock-in amplified. At this time, the acquired signal is the differential (dB/dV) between the magnetic field and the voltage. With the direction of the detected magnetic field set to the same orientation as the solar panel, the size of magnetic field is then pro-rata to the current, which is detected just under a pick-up coil placed on the solar panel. Therefore, the reciprocal of the acquired dB/dV signal reflects the voltage-current derivative ie. the differential resistivity of the solar panel).

Figure 2 shows the dV/dB distribution acquired when the offset voltage was set at 8.8 V or 1.0 V. The variance in the distribution is attributed to differential resistivities over the panel surface. This distribution varies according to variations in applied voltage or changes in load resistance. The differential resistance reflects the series resistance of pn junction at the limits of an infinite load resistance, as well as the junction resistance at the limit of a zero-load resistance. It is therefore regarded that the dV/dB distribution mapped by the system developed in this study, reflects those resistance components. By further improving spatial resolution and realizing the acquisition of phase information, it is hoped that future development will allow analysis of the relationship between the electrical properties of the solar cells.

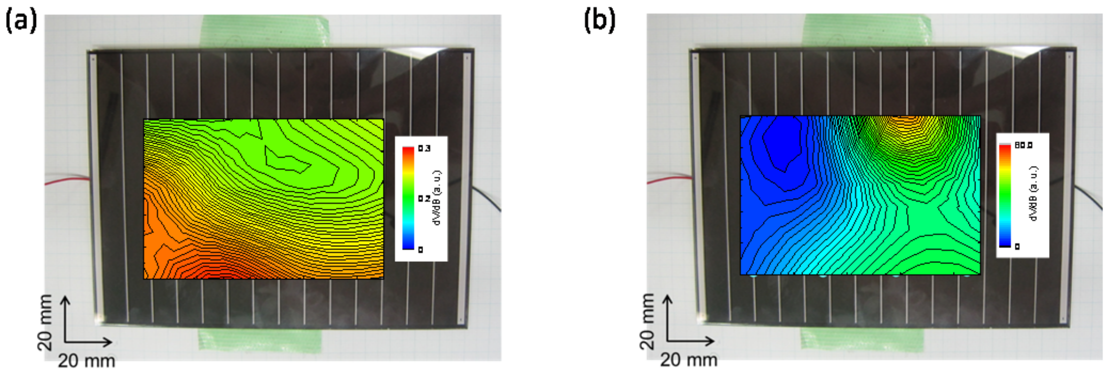

Fig. 2 dV/dB distribution (a) V_{dc}=8.8 V, (b) V_{dc}= 1.0 V

3. Summary

This article introduced a HTS-SQUID system developed to map the electrical characteristics of solar cells. The measured distribution reflected variances in both series and junction resistance of solar cells.

The research outcomes in this article were undertaken by the Strategic Promotion of Innovative R&D's Program, funded by the Japan Science and Technology Agency (JST).

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Feature Articles: SQUID･Medical Equipment
- HTS-SQUID Gradiometer for Non-destructive Detection of Braided CFRP

Yoshimi Hatsukade, Associate Professor
Department of Environmental & Life Sciences
Toyohashi University of Technology

The fabrication of lightweight airplanes and automobile structures to attain additional energy savings and achieve improvements in fuel economies is being currently fulfilled using Carbon Fibre Reinforced Plastics (CFRPs). CFRPs are lightweight compared to general metals, and superior in specific strength and specific rigidity. In recent years research and development efforts have sought CFRPs with greater strength and superior functionality. Developmental efforts in braiding bundles of carbon fibres have led to braided CFRPs, (long and narrow textiles interwoven with the fibres oriented at an angle of 45°) (Fig. 1). The structure of this composite material is continuously oriented with the fibre bundles able to support any load. This results in superior characteristics in strength and elasticity over conventional CFRPs, allowing moulds to be made that conforms to the final shape of the product. Moreover, the judicious selection of fibre materials, the core yarn and an epoxy resin enhanced with the addition of a carbon nanofiller can tailor the strength of the CFRP. These characteristics have led to a number of new braided fibrous assemblies.

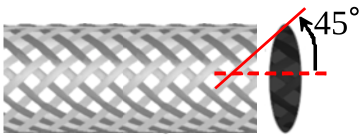

Fig. 1 Schematic image of tubular braided carbon fibre bundles (above)
and picture of the CFRP sample (below)

The mechanical characteristics and destructive mechanisms of these new materials are determined from stress-strain destructive tests and by microscopic observations. On the other hand, the acquisition of information within the materials is usually undertaken by acoustic emission, X-ray, non-destructive detection technology utilizing ultrasonic waves. However, the shortcomings of these analysis methods are in detecting/localizing breaks or cracks and quantifying defects in carbon fibre bundles, which can be several μm in diameter.

To address these issues a research group based at Toyohashi University of Technology have investigated the conductivity of carbon fibres at the time of breakage. Utilizing the high sensitivity and spatial resolution offered by a high temperature superconducting (HTS) SQUID gradiometer, a non-destructive approach for the detection of breaks in braided CFRPs has been explored as a possible evaluation route. The research group employs a 1mm-size first-order planar-type HTS SQUID gradiometer as a current detector. In order to visualize the current distribution in the braided CFRP, a 2D-scan of the magnetic field generated by the application of current applied to the carbon fibre of the braided CFRP is evaluated.

The above-mentioned method was employed for a tubular braided CFRP sample shown in Figure 1. Figure 2 shows the distribution of the pseudo current in the sample. For a sample with no damage, with the current input on the left-hand side, excluding the upper and lower parts of the sample, an almost uniform flow of current is observed towards the right-hand side of the sample (top of Fig. 2). Contrary, an artificial crack of about 1mm in size was initiated in the upper centre of the sample dividing the continuity of a few fibre bundles. This results in a low current density along the cut bundles near the crack, with the rest of the fibre bundles in a region far from the crack being unaffected (bottom of Fig. 2). These findings revealed that a current flowed in the braided CFRP bundles with a high conductivity rate, however regions where the bundles have been broken due to a crack, the current transmitted via the contacting bundles.

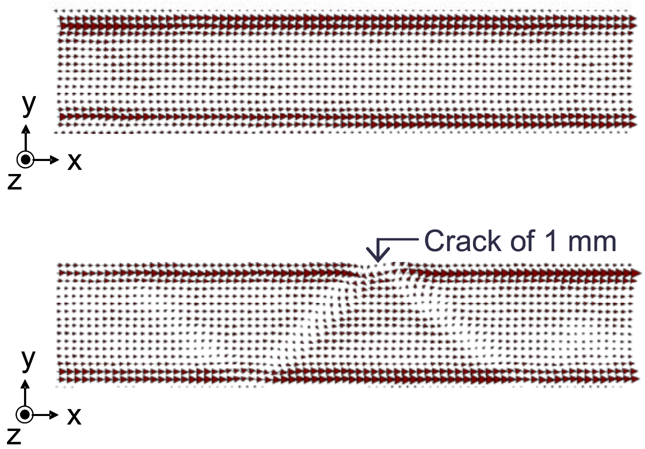

Fig. 2 Current density distributions within the braided CFRP measured by HTS-SQUID gradiometer. Cases shown include an undamaged sample (above) and a sample with a crack located top-centre (below)

This report describes a possible method to not only detect and localize cracks in a fibre bundle, but also determine the individual characteristics of fibres within a braided CFRP, (the fibre bundle orientation uniformity, the fibre density, contact between the bundles). A joint research effort between Hamada and Nakai research groups based at Kyoto Institute of Technology, conducted tensile tests and analyzed the destructive mechanism of braided CFRP by employing both destructive and SQUID-based non-destructive analysis. Further developments in braided CFRPs are expected, with diffusion into the mainstream market only when the mechanisms are better understood and the defects are quantifiably detected. Towards this aim, a series of research activities involving multilayer HTS-SQUID gradiometers equipped with a ramp edge-type Josephson Junction, developed by SRL/ISTEC are underway.

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Feature Articles: SQUID･Medical Equipment
- Non-destructive Evaluation Technology using High Temperature Superconducting SQUID Gradiometer

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1. Introduction

The Research and Development Division of Electronic Devices based at the Superconductivity Research Laboratory ISTEC, aims to promote greater reliability in the fabrication process of thin film multilayer and junctions for electronic devices that utilize copper oxide-based high temperature superconducting materials. The division is also involved in the development of ultra-sensitive magnetic sensors SQUID (Superconducting Quantum Interference Device). Whilst a non-destructive detection system and a system designed to detect metallic contamination utilizing high temperature SQUIDs has been developed, the research support required for superconducting wire development employing a SQUID-based non-destructive detection system has been extended. This article summarizes the current research activities regarding non-destructive detection technology and a detection system mainly aimed at Y-based wires and equipment applications.

2. The characteristics of SQUID-based non-destructive evaluation and its developmental status

Investigations involving SQUIDs have been undertaken for non-destructive detection of materials and structures, in addition to medical and biotechnology applications such as magneto-cardiograph, immunological test and ultra low frequency NMR/MRI[1). A SQUID is an ultra-sensitive magnetic sensor with the ability to measure a magneto-encephalograph at 1 billionth that of terrestrial magnetism. Additionally, being different to other types of magnetic sensors, it has a wide frequency band of operation and there is minimal loss in sensitivity, even at low frequencies of around several tens of Hz.

There are various methods for non-destructive evaluation involving SQUIDs. Amongst those, the R&D Division of Electronic Devices has investigated a non-destructive Eddy Current Test (ECT) method, which involves detecting fluctuations of an AC magnetic field related to flaws in the sample with the application of an AC current. In this method, a coil is energised by an AC current and placed in close proximity to a metallic conductor. Based upon electromagnetic induction, the AC current generates a magnetic field, which induces an eddy current in the test sample. Here, the penetration depth of the induced current against the excitation frequency *f*, which is given as $\delta = 1/\sqrt{\pi f \mu \sigma}$ (μ is the magnetic permeability of the conductor, σ is the conductivity). The lower the frequency of the applied AC magnetic field, the larger the penetration depth of the induced current. Specifically for case of aluminium and silver as test objects, the depth of penetration with an excitation frequency 10 Hz is approximately 20 mm.

Up to now, this method has been applied to assess Y-based coated-conductors, in particular detecting flaws within multifilament-shaped thin processed conductors demonstrating the effectiveness of this method[2). Furthermore, the evaluation system of Y-based coated conductors involves AC magnetic fields at frequencies of around 3 kHz, applied to the surface of the Y-based coated conductor cooled below their T_C. A sensor array with a five-channel-oriented SQUID, having a pickup coil width of 1mm, is able to detect

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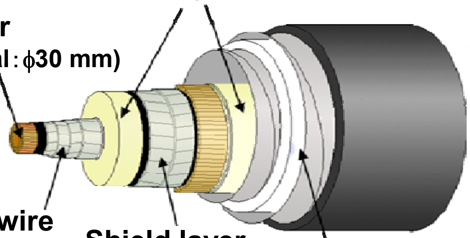
microscopic fluctuations in magnetic field generated by defects or flaws. The system is able to quickly detect (max 80 m/h) local regions with low I_C and areas delaminating within the long wire filaments. Initial tests of this system conducted with 2 mm-thick multilayer aluminium plate stacks, confirmed the ability to detect a deep lying slit-shaped defect located 40-50 mm below the surface using an excitation frequency of approximately 40 Hz[3).

The ability of these non-destructive tests to detect and evaluate defects in Y-based coated conductor strands and multilayer samples provide a promising insight into the future. The next evolutionary step required to advance this research is to apply non-destructive detecting technology to evaluate the superconducting power devices such as, more complex structured power cables.

Amongst the Y-based superconducting power cables thought to be available for commercialization by around 2020, a cable aimed at high voltage applications (275 kV) has a Cu former with an approximate diameter of 30 mm at the centre. It consists of a multilayered structure with 2~3 layered superconducting wires (conductor layer) separated by a thin insulating sheet above the Cu former, above which is approximately a 20 mm thick insulation layer and 1~2 superconducting layers (shield layer), (Figure below, detailed specification currently investigated). The conducting and shield layers are composed of tape-shaped superconducting wires, having a width of several mm, and are arranged in parallel (winding wire structure). Such an arrangement in a superconducting power cable, with the multilayered conductor having a mid-insulating layer, defects or other flaws are difficult to be detected other than by a non-destructive ECT method. The development and improvement in defect detection of the internal conducting area through the thick insulating layer from the shield layer above has been undertaken by combining the ultra-sensitive SQUID with the ECT method. The detecting device comprises of a cryostat (conduction cooling from liquid nitrogen) to cryocool one channel of the SQUID sensor (gradiometer sensor to detect fluctuations in magnetic field gradient), a SQUID control circuit, excitation coil and its power supply, lock-in amplifier and an X-Y stage to scan the testing sample.



The cross sectional image of a 275 kV class superconducting power cable

Until now, investigations to determine the detection capabilities of non-destructive evaluation system have been undertaken using sample multilayered parallel conductors designed to simulate superconducting power cables. The superconducting tapes/wires were simulated by fabricating combinations of Cu tape having a 5~10 mm width and a thickness of 0.05 mm, with an acrylic plate simulating an insulating layer. The results have positively confirmed the feasibility to detect a crack area located at centre of a parallel conductor composed of 5mm-width Cu tapes, from above a 5 mm-thick insulating layer and an upper parallel conductor (simulating the shield layer).

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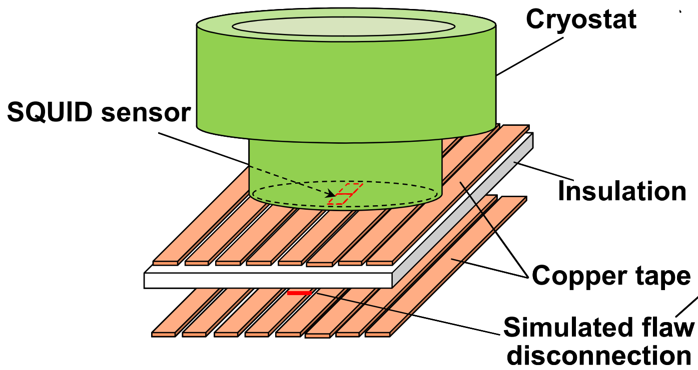
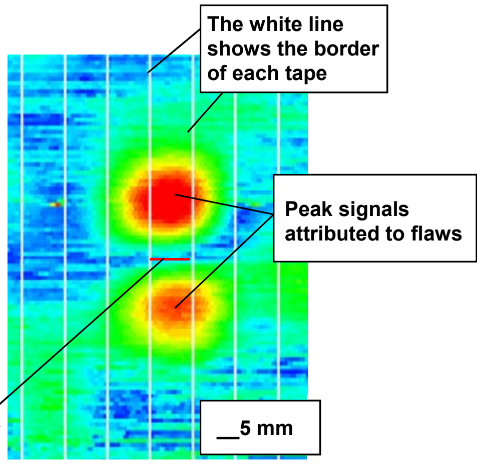


The relative position of the multilayered parallel conductors with the detecting system



A 2D image of the magnitude signal

3. Future prospectus

From simulated tests conducted on a sample having a complex structure with a thick insulating buffer layer, this reports confirms the ultra-magnetic field sensitivity of a SQUID sensor combined with the ECT method has a bright future to detect defects. Future plans are to fabricate a test sample that closely replicates the shape and equipment to demonstrate the feasibility of detecting signals attributed to defects. Additionally, by taking advantage of enhanced sensitivity characteristics of SQUIDs at low frequencies, further investigations are planned to improve the detection technology required to detect deep-lying defects within a material.

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Feature Articles: SQUID･Medical Equipment
- A Laser-SQUID microscope for Solar Cell Defect Evaluation

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Investigations into a SQUID-based microscope have been undertaken to demonstrate the feasibility of an application utilizing high temperature superconducting SQUIDs. In order to improve the spatial resolution for magnetic distribution observation, a needle with a high magnetic permeability is utilized. Investigations have been also undertaken to use a STM-SQUID to apply a tunnel current between the tip of the needle and a sample. The viability of non-destructive and noncontact inspection of a semiconductor has been evaluated by magnetically observing the photo-induced current generated by laser light irradiating a semiconductor material. Herewith, the laser-SQUID microscope is introduced in this article.

A laser-SQUID microscope is a technique that involves irradiating a semiconductor sample with a laser to induce a photocurrent. The SQUID detects the magnetic field generated by the photo-induced current. Any local changes in the characteristics of an irradiated sample are identified by changes in intensity and direction of the current flow and in turn reflected in changes in magnetic field, which are detected by the SQUID. The spatial resolution of the laser-SQUID microscope is therefore dependent upon the laser spot size.

A laser-SQUID microscope has been applied to evaluate solar cells defects. An important determinant in solar cell evaluation is the conversion efficiency. Therefore, it is important to evaluate the distribution of the conversion efficiency over the entire solar panel surface. The Laser Beam Induced Current (LBIC) method involves mapping the current generated from a laser scanning the solar cell surface. However, the downside of this method is that it requires building electrodes and wiring in order to determine the solar cell characteristics. On the other hand, a laser-SQUID microscope requires no electrodes or wiring and thus can evaluate solar cells prior to electrode fabrication. Furthermore, with an elaborate design allowing for laser and SQUID adjustment, makes it possible to assume intensity and direction of the current flowing from the irradiated laser spot i.e. the current vector.

Figure 1 shows a schematic diagram of the principle of the laser-SQUID microscope. The laser is intensity-modulated and focused onto the sample. The needle transmits the magnetic field generated by the current induced in the sample and is detected by a SQUID. The needle is fabricated from a high permeability material and is used to transmit a magnetic field from the tip of the needle. A FLL circuit drives the SQUID and

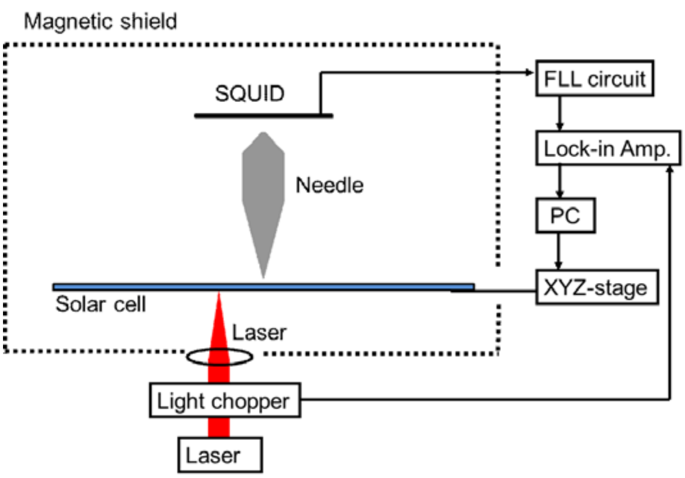

Fig.1 Schematic diagram of laser-SQUID microscope

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a digital lock-in amplifier effectively reduces unrelated signal noise by extracting the same frequency component as the laser modulation frequency, the results of which are stored to a PC. The use of a digital lock-in amplifier demonstrates one of the characteristics of the SQUID microscope. In a conventional scan-type SQUID microscope, only the magnetic field in the sample is measured and thus modulation technology is not applicable. However, the laser-SQUID microscope makes it possible to use active modulation technology as the laser is utilized to induce a magnetic field.

Figure 2 displays a typical evaluation result obtained from a polycrystalline silicon solar cell. Fig. 2(a) shows an optical image and confirms the presence of several crystal grains approximately a few mm in size, with the possibility of an electrical defect at the grain boundary. Fig. 2(b) shows a laser-SQUID image with a drop in magnetic field strength linearly along the partial grain boundaries. Moreover, there were some areas observed that had a drop in magnetic field intensity linearly inside grain boundaries. Such findings have been corroborated by LBIC, the image of which is shown in Fig. 2(c), where the laser induces less current i.e. highlighting areas with lower solar cell conversion efficiencies. The findings obtained by both LBIC and laser-SQUID agree, implying that a laser-SQUID microscope can be utilized to undertake non-contact evaluations, equivalent to that offered by the LBIC method.

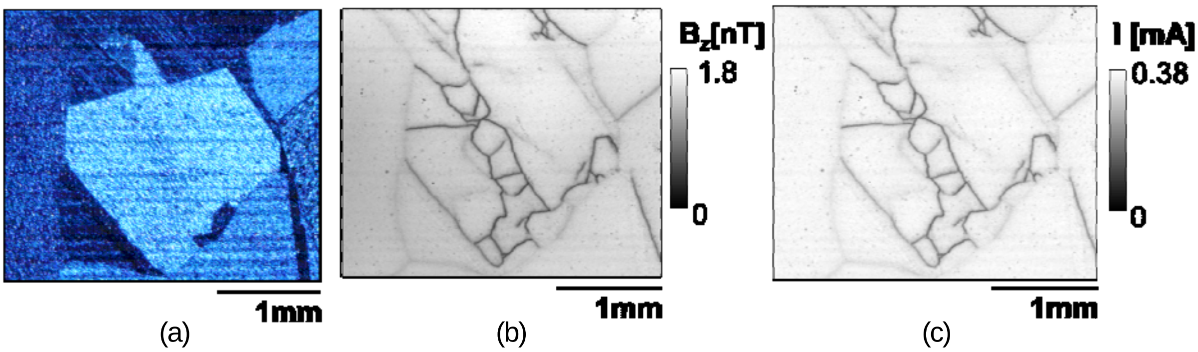

Fig. 2 Defect observation of the polycrystalline silicon solar cell. (a)Optical microscope image, (b) Laser-SQUID microscope image, (c) LBIC image

Apart from solar cell applications, it is expected that the laser-SQUID microscope will be utilized in an array of other applications, such as examining light energy conversion materials, and local observations in the operational status of spin-controlled optoelectronic devices.

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Feature Articles: SQUID･Medical Equipment
- Quantitative Evaluation of Magnetic Immunoassays utilizing SQUIDs

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Magnetic markers are generically referred to as nanometre-size polymer-coated magnetic particles that are immobilized with test reagents on their surfaces. Until now, such markers have been used for the segregation and production of cell and pathogenic bacteria as well as for MRI contrast media. Furthermore, research and development utilizing magnetic markers has been undertaken for biological immunoassays, magnetic imaging, magnetic hyperthermia and drug delivery.

The biological immunoassays used for medical tests such as blood tests, involve the binding reactions between an antigen and its antibody to detect protein and pathogenic bacteria biomaterials, deriving from the types of diseases. In this application, the magnetic markers are selectively bound to the biological target (antigen), and utilizing these bound markers the types and quantities of biological materials are magnetically detected. Additionally, this magnetic method makes it possible to perform immunoassay in a liquid phase, eliminating the “washing process” step. The beneficial characteristics offered by the magnetic detection method over a conventional optical system have recently gained attention as potential new detection method.

The performance characteristics of the magnetic detection method are determined by the measuring system and the magnetic marker. Highly sensitive systems utilizing SQUIDs and various magnetic sensors have been developed thus far. On the other hand, magnetic markers for biological immunoassays have fallen behind in development, instead alternative markers developed for segregation and production purposes are currently used as substitutes. Thus, potentially a more efficient magnetic marker for biological immunoassays is desired.

Figure 1(a) shows the schematic diagram of a magnetic marker. The agglomeration of nanoparticles is unavoidable in the fabrication process of actual magnetic markers, which form nanoclusters. The magnetic properties of these clusters determine the performance of the magnetic immunoassay. However, the characteristics are dependent upon many additional parameters such as the size of the cluster and the coupling strength between magnetic nanoparticles within the cluster. Therefore, quantitative evaluation of the magnetic properties of the markers is required under actual operating conditions. In particular, it is necessary to quantitatively evaluate the size of the magnetic cluster d_H and its

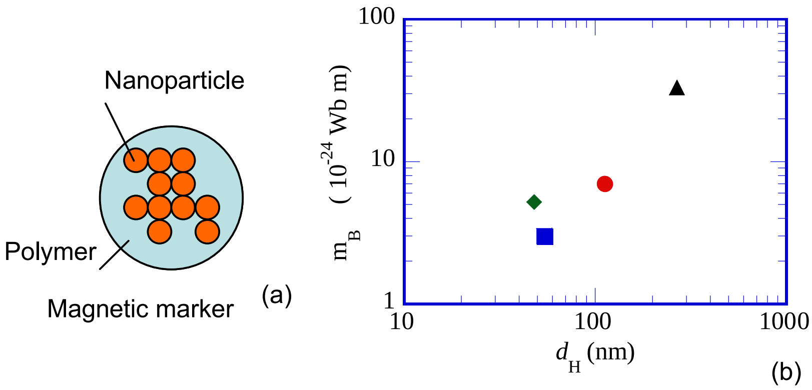

Fig. 1 (a) The schematic of a magnetic marker, (b) The size of a magnetic marker, d_H, and its magnetic moment, m measured for various magnetic markers magnetic moment, m. In magnetic immunoassays, d_H determines the Brownian relaxation time in the liquid, which is the fundamental of a liquid-phase detection method and the magnetic moment m determines the strength of magnetic signal from the cluster.

A method to quantitatively clarify both d_H and m has been therefore developed. Figure 1(b) shows the results measured from a commercially available magnetic marker. These results make it possible to quantitatively evaluate the magnetic immunoassays parameters. The figure shows the value of m increases linearly with d_H, however this dependency is weaker compared to the $m \propto d_H^3$ relationship predicted for a single particle. The reason is that the magnetic markers form nanoclusters.

Figure 2 shows an example of the magnetic immunoassays in a liquid phase. As shown in Figure 2(a), the biological targets were fixed on the surface of polymer beads having a diameter 6.7 μm, which are bound with antigen (Biotin). As a result, after the magnetic markers are put into the liquid, the markers are partially bound to the polymer beads with the rest becoming free markers. The free markers are Brownian-rotated at high speed within the solution, with almost no rotational effects on the bound markers. The results show that both of these markers are very different in their magnetic properties and this difference would allow the possibility to magnetically distinguish between the two sets of markers without the need for a “washing process” step.

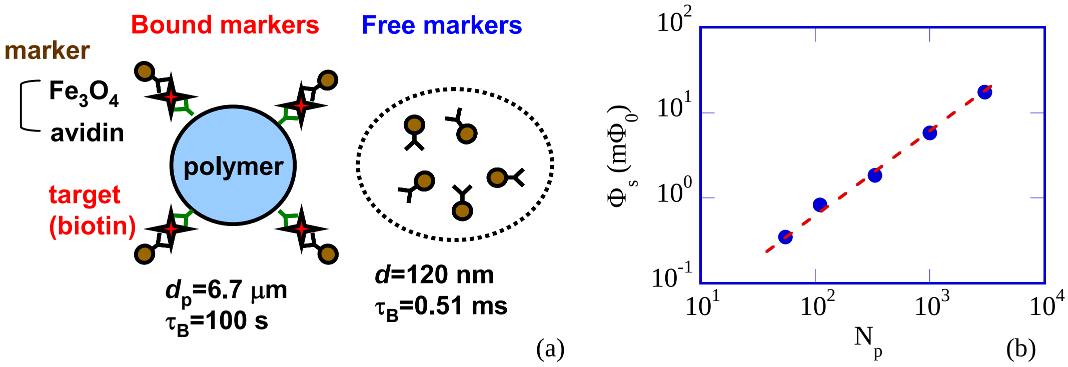

Fig. 2 (a) Magnetic immunoassays in a liquid phase utilizing polymer beads for fixing the Biotin (b) The detection of Biotin. The relationship between the numbers of polymer beads N_P fixed with Biotin, and the magnetic signal

Figure 2(b) shows an example where a protein called Biotin was detected utilizing this detection method. In the figure, the horizontal axis shows the numbers of polymer beads, N_P fixed with Biotin, with the vertical axis representing the magnetic signal detected by SQUID. As shown in the figure, it is possible to detect up to N_P=50. Since 3,000~5,000 of Biotin are fixed on the surface of one polymer bead, the detection of N_P=50 corresponds to the detection of 1.5~2.5x10^5 of Biotin. The detection sensitivity is approximately 6~10 atto-mol/ml, and is understood that the micro detection at the atto-mol level within the liquid phase is possible without the need for a “washing process”.

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Feature Articles: SQUID･Medical Equipment
- The Future Potential of an Ultra Low-field Functional Magnetic Resonance Imaging System (ULF-fMRI)

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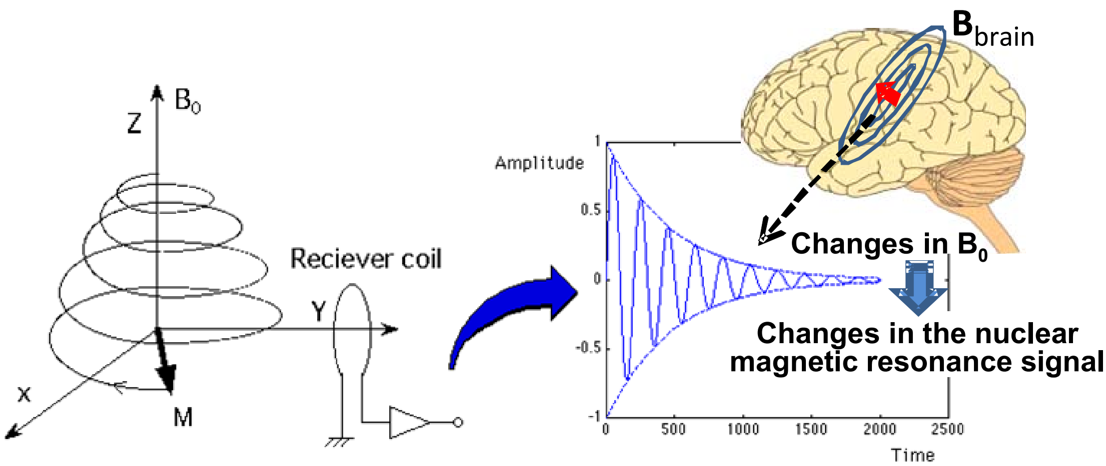
1. Introduction

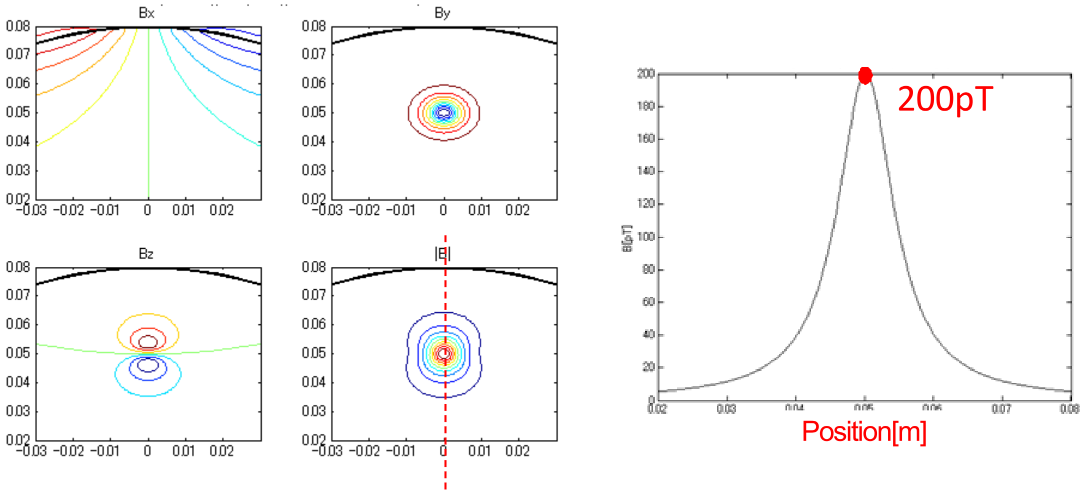
In recent years, low-field magnetic resonance imaging systems utilizing SQUIDs are gaining attention. When a measurement field becomes weaker, the effects related to micro magnetic fields associated with neural activity cannot be ignored. By taking advantage of this phenomenon there is a possibility in the realization of a new fMRI system, hereby known as an Ultra Low-field Functional Magnetic Resonance Imaging System (ULF-fMRI), and is principally different to conventional high-field fMRI. The difference between the two systems is that whilst the conventional high-field fMRI is imaging mainly changes in blood flow (blood oxygenation), the ULF-fMRI is directly imaging neural activity.



The principle of ULF-fMRI
Left: Nuclear magnetic resonance phenomenon (FID), Right: Principal of acquisition of brain function information

2. Magnetic fields in the brain linked to a neural activity

In order to investigate the likelihood of realizing an ULF-fMRI, first it is necessary to determine the magnitude of a magnetic field linked to neural activity. The MEG (magnetoencephalography) is a well-established method to acquire the magnetic field linked to neural activity. However, the downside of the MEG technique is that it externally measures the strength and distribution of magnetic fields in the brain, thus making it impossible to directly acquire magnetic fields in the brain. Thus, a neural activity model associated with MEG measurements is utilized to estimate the magnetic fields in the brain. An auditory evoked magnetic field is a typical MEG measurement where the electric current dipole is often utilized as a neural activity model having a response (N100 m), which is observed at about 100 ms after acoustic stimulation. As an example of our actual measurements taken, the strength of the dipole moment is 60nAm and 125 nAm, left and right, respectively. Assuming that a 50 nAm-class electric current dipole, less than the measured numerical values, was used as the magnetic field source model of neural activity, the magnetic field generated in the brain was calculated. However, the formula to calculate the magnetic field generally used for MEG is for a magnetic field generated externally from a spherical body, and thus the same formula cannot apply when calculating the magnetic field inside a spherical conductor (the head is assumed as a spherically symmetric conductor). Here, utilizing the formula derived by Heller, the magnetic field within a spherical conductor was calculated[1)]. As shown in the figures below, the magnetic field at around 200 pT is generated in areas close to the electrical current dipole. For extraordinary cases, the electrical current dipole facing towards the radial direction does not generate a magnetic field outside of the brain, and because of this, MEG cannot be used to measure this. However, the ULF-fMRI is able to measure this since the magnetic field is generated in the brain.



Magnetic field in the brain as measured by neural activity model (electrical current dipole)
Left: The magnetic field profile (three-dimensional space) and the absolute values of the strength distribution of the magnetic field, Right: Curves of the magnetic field strength (indicating the dashed-line values as shown in the left figure)

3. Issues for the realization of ULF-fMRI

As mentioned prior, the magnetic field linked to neural activity in proximity to the source has a magnetic field strength of more than several hundred μT. Therefore it is possible to influence the Nuclear Magnetic Resonance (NMR) phenomenon, in cases involving measurement fields with field strengths of less than several μT. Burghoff and others in Germany have successfully observed a NMR signal with an ultra-low magnetic field of 0.5 μT [2)], proving the fact it is possible to detect a signal in such an ultra-low magnetic field. However, issues associated with the imaging such as, the accuracy of the gradient magnetic field under an ultra-low magnetic field and ensuring the frequency resolution using a low frequency resonance signal still remain. An example highlighting the latter case is when the measurement field is set at 1 μT with the resulting NMR frequency at around 43 Hz. Utilizing a discrete Fourier transform, the frequency resolution becomes the reciprocal of the time period, with a typical time period of around 10s required to acquire a frequency resolution of 0.1 Hz. With insufficient data points, this method is employed to input 0 for the shortage to make the length of time required. However, even in such a case, considering that the window function is applied to respond to the data length, spectral line broadening due to the window function is unavoidable.

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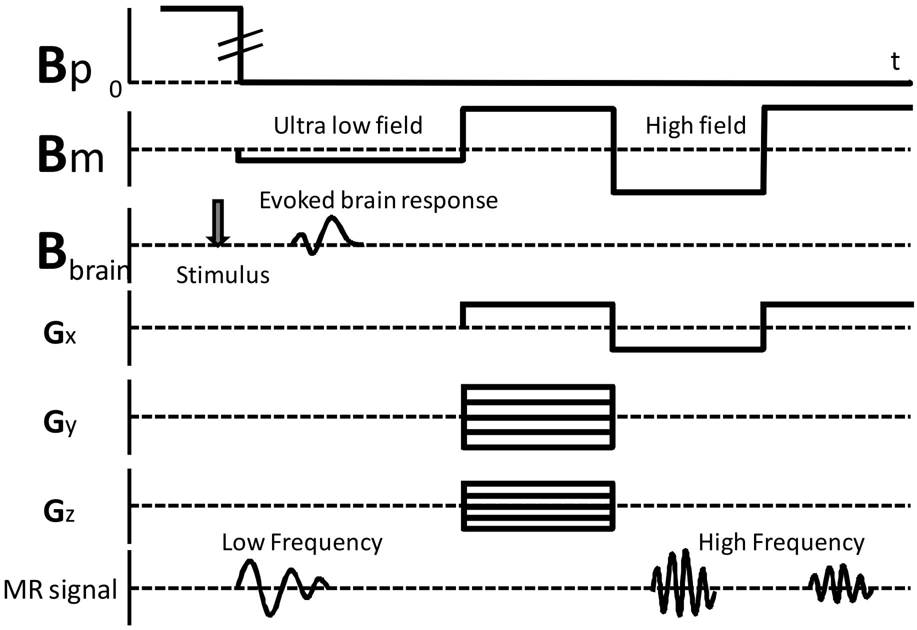
4. Measurement field control sequence utilized for ULF-fMRI

A solution for the above-mentioned issues has been proposed and involves strengthening the measurement field and increasing the signal frequency using the measurement field control sequence at the time of signal detection. This method entails setting the measurement field straight after the blow out of the nuclear magnetic field to an ultra-low setting, and the resulting measured spin is then modified by the magnetic field linked to neural activity. After this, application of a measurement field with reversed polarity can detect the echo signal. At this time, since the signal is linked to the degree of neural activity in an ultra-low magnetic field before the reversed magnetic field, a higher frequency is realized due to the greater magnetic field strength of the reversed field. Additionally, if a gradient magnetic field required for imaging is applied after reversing the polarity of the magnetic field, even greater gradient magnetic field can be acquired and result in securing further system accuracy. The author and his group are currently demonstrating this method with the aim of advancing the research activity towards the realization of ULF-fMRI in the near future.



An example of the measurement field control sequence utilized for ULF-fMRI
Bp: Magnetic field used for pre-polarization, Bm: Measurement field,
B_{brain}: Brain magnetic field, Gx, Gy, Gz: Gradient magnetic fields used for imaging,
MR signal: NMR signal

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Feature Articles: SQUID · Medical Equipment
- Present Status of a Metals Exploration System (SQUITEM) utilizing a High Temperature Superconducting Magnetometer

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1.Introduction

To improve the exploration depth of an electromagnetic method frequently used for metals exploration, over a period of five years from 2001 to 2005, the Japan Oil, Gas and Metals National corporation (JOGMEC) developed a SQUITEM system (unit 1), which utilizes a high temperature SQUID. This was followed in 2006, by the fabrication of SQUITEM unit 2, which offered greater field performance and is the system presently employed by JOGMEC for metals exploration. A three-year project launched in 2009 realized SQUITEM unit 3, equipped with reduced-noise SQUIDs as well as enhancements in slew rate, portability and operational performance. This article follows on from the contents reported in the August 2009 issue. The metals exploration merits propounded by SQUITEM unit 2 are again reported, along with an application example of the system. The developmental progress offered by unit 3 is reported as well.

2. Outline of SQUITEM

The time-domain electromagnetic (TEM) method is one of the geophysical exploration techniques applied to investigate the resistivity distribution in the underground. A copper wire transmitter loop is located at the ground surface and alternating direct current with an on-off period passes through the loop. Once this current is abruptly interrupted, an eddy current is induced, which diffuses into deep underground. The TEM method is used to investigate the resistivity distribution in the underground by continuously measuring the magnetic field generated by induced eddy currents. Full details of this technique were described in the Fall 2009 issue.

TEM is widely employed for detecting the location of metal ore deposits and its relevant geology (such as the argillic alteration zone), which are recognized as having low resistivities. However, recent years have seen metal ore deposits at much greater depths, and employing electromagnetic exploration, which offers greater exploration depths has been desired. Attention has thus focused towards directly measuring the magnetic fields rather than magnetic fields differentiated by time by utilizing an induction coil-type magnetometer in a conventional system. Since the magnetic fields attenuate with time slower than the magnetic fields differentiated by time, data can be taken for much longer times (greater depth) than a conventional induction coil. Compared to other magnetic sensors, a SQUID is highly sensitive in measuring very small magnetic fields with a low

Fig.1 Overview of SQUITEM Unit 2

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noise level. Coupled with its ability to operate at wider frequencies, a SQUID sensor is suitable for a TEM system used for metals exploration allowing the desired exploration depths to be explored.

SQUITEM unit 2 comprises of a controller, battery, SQUID magnetometer, a notebook PC for measurement control, a connection cable between the controller and SQUID magnetometer, a transmission cable used to synchronize the signal from the controller to the transmitter (the system to pass the currents through the transmitter loop) and an amplifier used to enlarge the synchronizing signal (Figure 1). The system operates at a frequency of DC~100 kHz, with a SQUID noise level equating to approximately 100 fT/$\sqrt{}$Hz, and a slew rate of approximately 1 mT/sec.

3.Field application of SQUITEM to metal exploration

An example where SQUITEM unit 2 has undergone extensive use is in nickel exploration in East Botswana, carried out in 2010.

The area investigated is located on the Limpopo mobile belt in Archean rocks, which has a high potential on metal deposits. This investigation targeted the nickel sulphide mineralization hosted inside the ultramafic sill intruded in the granitic gneiss or at the contact between the ultramafic rock and the granitic gneiss.

A transmitter and receiver configuration allowed the measurements to be undertaken, by measuring the magnetic field at the centre of the square-shaped transmitter loop (one side 200 m), with data acquired from a total of 11 survey lines (total length of survey line is 21.8 km, with a total of 250 observation stations positioned every 100 m (partially positioned every 50 m)). Of those, Figures 2 and 3 show the results measured at survey lines used to investigate the southern extension of the already-known mineral deposits.

Figure 2 plots the data profile measured at this survey line. The data profile is made up from each measured-data curve at each time moment (the time elapsed after the abrupt current interruption to the transmitter loop), consisting of the data points measured at each observation station. The horizontal axis plots the position in the survey line and the resulting SQUITEM magnetic field measurement is plotted on the vertical axis. The curves in the profile correspond to twenty time moments, in total from 11.8 μsec to 1.4 msec, after the current shut down. At 576300 mE to 576700 mE, the plot shows a significant peak implying a low resistivity zone in the ground. This low resistivity is interpreted as nickel mineralization because the associated ultramafic rock was already recognized by the historical exploration.

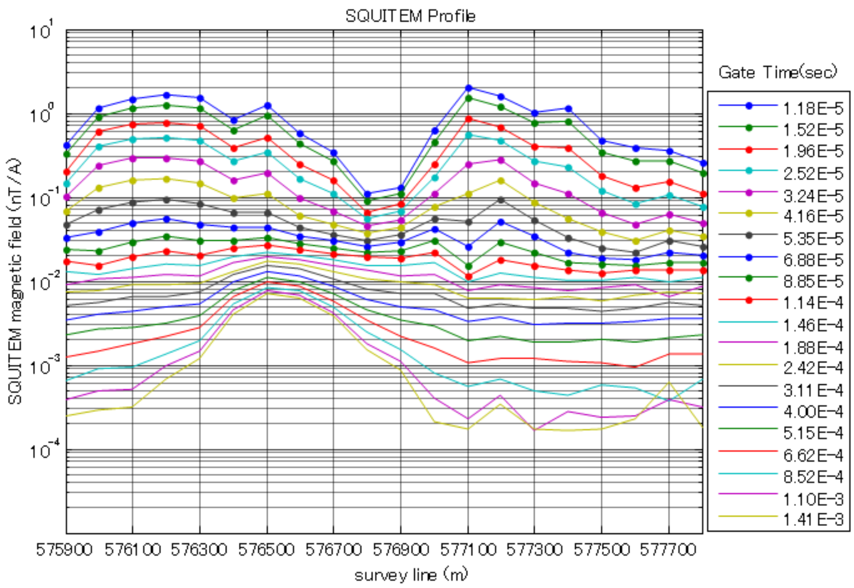

Fig. 2 Data profile curves from SQUITEM unit 2 (nickel exploration in Botswana)

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Figure 3 shows the outcomes of 1D-inversion result relative to the ground resistivity from the acquired data by SQUITEM unit 2 (resistivity cross sectional of the ground), whose computation consists of forward modelling, nonlinear least squares method and regularization theory (e.g. Hansen, 1998). Specifically, 1D-inversion was undertaken at each and every receiver point to obtain the horizontal resistivity distribution below each point. Connecting each horizontal resistivity layer at each receiver point provided a 2D cross-section of the ground resistivity distribution. For the 1D-inversion computation, the ground to be inverted was divided into 45 layers up to 700m, with the layer thickness enlarged according to depth. An iterative process of amending resistivity in each horizontal layer was undertaken by using the nonlinear least squared method with regularization theory until the difference between the actual measured values and the theoretical values became negligible.

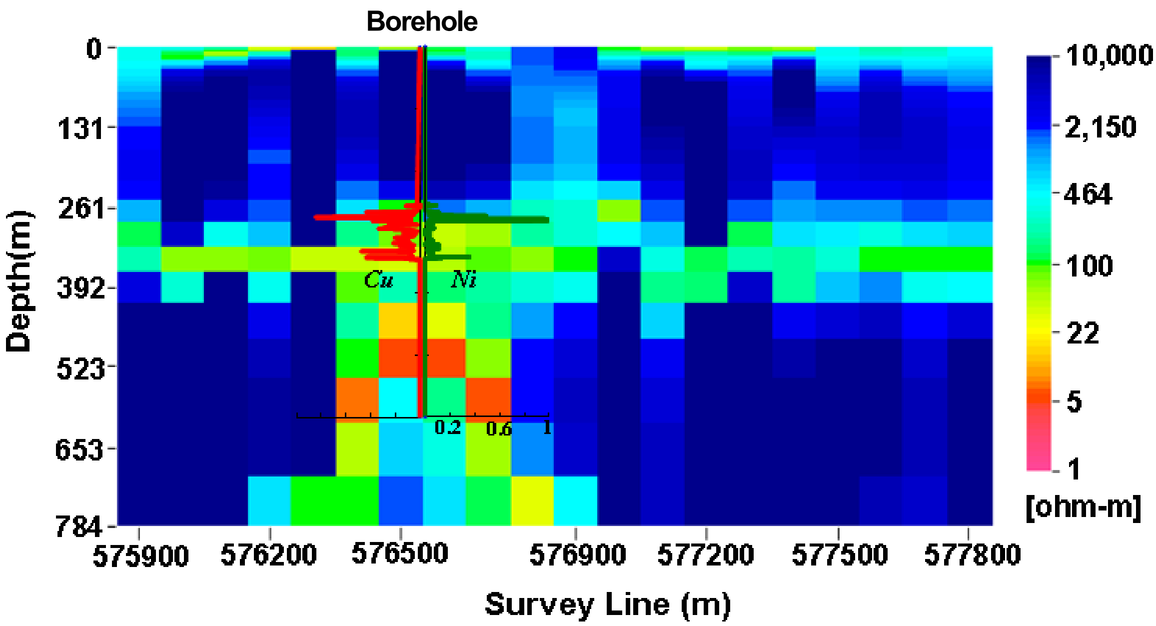

Fig. 3 Results from 1D inversion of the ground resistivity (resistivity cross sectional in the ground) computed from the acquired data by SQUITEM unit 2 (shown in Figure 2). The curves show the assay results (%) of copper (left) and nickel (right)

Figure 3 shows the analysis of the Archean basement (granite gneiss, ultramafic rock) as having a high resistivity of around 1000 Ωm. The horizontal layer has a resistivity of around 100 Ωm at a depth of 300~350 m and is considered to reflect the aquifer with high salinity. Additionally, since a low resistivity zone extending to the vertical direction below the prior-mentioned horizontal layer was inverted at 576400mE~576700mE, from its shape was understood to reflect the metal deposits. Therefore a drillhole was conducted by targeting this low resistivity zone, as shown in the figure, resulting in intersecting more than 20 % grade-level of metallic sulphide at a visual observation level from a depth of 254.56 m to 344 m. However, the drilling resulted in an inconsistency between the depth at which metal sulphide was intersected and the depth of 400m to 600m at which the low resistivity zone was inverted. The discrepancy was attributed to intrinsic 1D inversion error for the 3D geology.

4. Advancement of SQUITEM unit 3

As mentioned above, JOGMEC has been utilizing SQUITEM 2 for metals exploration, the results of which

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are currently emerging. Since the value of the measured data is proportional to the current in the transmitter loop, the greater the current induced in the transmission loop enables the acquisition of a larger S/N ratio data set. However, for example, unit 2 has been unable to transmit sufficient current to the transmitter loop due to the limitations in its slew rate, which means the benefits offered using SQUIDs in exploration depth have not been fully exploited. It is with this in mind that unit 3 has been undergoing development in a three-year project that started in 2009. Figure 4 shows the proto-type of unit 3, comprising a SQUID magnetometer and receiver system. The development of SQUID magnetometer and receiver system have been consigned to ISTEC and Mitsui Mineral Development Engineering Co., Ltd, respectively.

Fig. 4 SQUITEM unit 3 under development. SQUID magnetometer in the left corner, with the receiver system shown on the right, and a GPS synchronous clock in the forefront

Unit 3 consists of a SQUID magnetometer, controller (built-in battery), notebook PC used for measurement control, connection cable between the controller and SQUID magnetometer, transmission cable for synchronous signal and a GPS clock to synchronize the controller and transmitter. The weight and size of unit 3 is reduced by 1/3 that of unit 2, resulting in a remarkable improvement in portability and operability.

The SQUID device is based upon a direct-coupled type, resulting in a reduced noise level of approximately 30 fT/√Hz, which is 1/3 that of unit 2. In order to achieve a set developmental target of less than 20 fT/√Hz, research and development efforts have advanced by focusing on further improving the sensitivity of the direct-coupled type SQUID device as well as methods to introduce multilayered devices.

A slew rate field test was undertaken at oil fields in Akita prefecture, at the end of May 2011. Comparative performance evaluations between units 2 and 3 were undertaken by utilizing both units at the centre of the transmitter loop (50 m each side). The findings revealed that unit 2 became unstable when supplied with 1A currents whereas unit 3 remained stable up to 15A, which was the limit of the transmitter. Consequently, slew rates continuously calculated from the data measured by unit 3 revealed it to be 15 times greater than compared to unit 2, achieving 9.2 mT/sec, exceeding the developmental targeted value of 8 mT/sec. The present goal is to complete unit 3 by the end of this year. The development of SQUIDs with higher sensitivities are aimed, with finishing touches being given to the measurement control programme that automatically regulates the functionality of the SQUID.

5. Conclusions

JOGMEC has been progressing their metals exploration utilizing SQUITEM unit 2 as a substitute to a conventional TEM system. Moreover, in order to further improve the exploration depth of unit 2 as well as its portability and operability, the development of unit 3 has been undertaken. It is planned that this development will be completed by the end of this year. As mentioned earlier, the exploration for metal ore continues at even greater depths. Therefore, the developments of an electromagnetic exploration system that can be utilized in areas with low resistivity are highly desired. The SQUITEM system offers this realization in the not too distant future. The completion of unit 3 is expected to herald further improvements in efficiencies and success rates of mineral exploration.

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Feature Articles: Superconducting Digital Device
- Trends of Superconducting Digital Device Technology

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Nagoya University

Logic circuits or integrated circuits that exploit Josephson Junctions for superconducting digital applications have a 40-year history. The events marking the historical evolution seem to occur every 20-years, with the present time representing the transition period from the second to the third generation. The first-generation encompassed latching logic circuits, which evolved to a second-generation single flux quantum logic circuit (RSFQ circuit). The present third-generation involves a low-energy consumption SFQ circuit.

Figure 1 represents the evolutionary relationship between the bit-energy and the clock period for relatively large-scale integrated circuits such as the microprocessor fabricated up to now. Here, the bit-energy is defined as the power consumed per clock period divided by the number of active devices like Josephson junctions. The clock period and bit-energy for both the semiconductor CMOS device and the first-generation latching circuits are already at similar values. However, considering the additional costs associated with cryocooling made the CMOS circuit far more attractive than the latching circuit.

It was the RSFQ circuit design that significantly changed this state of affairs. Employing the same fabrication process, the clock period and bit-energy were reduced by more than one order of magnitude. Furthermore, the advanced process (ADP) developed at ISTEC demonstrated the possibility of circuits exceeding 100GHz operational frequency. This has reduced the bit-energy by one further order. Figure 2 is a complex co-processor prototype fabricated with the ADP, designed specially for scientific computation. The circuit consisting of a total of 11458 Josephson Junctions operated at 45GHz, with a power consumption of 3.4mW. The products of the operating frequency and the

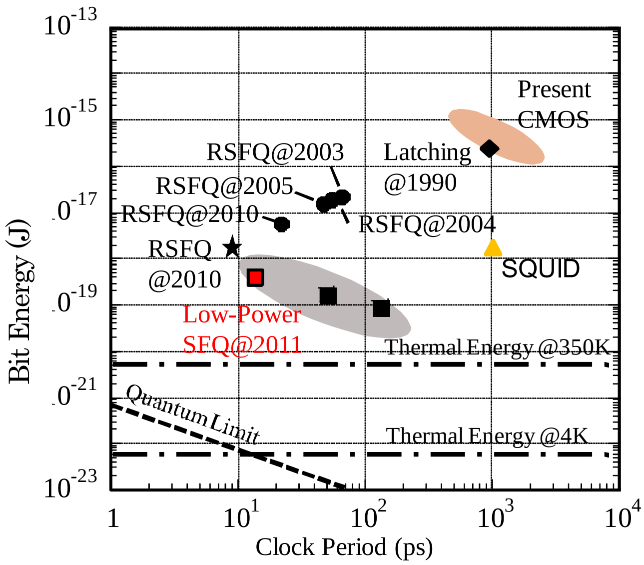

Fig. 1 Evolutionary relationship between the bit energy and clock period for each type of integrated circuit

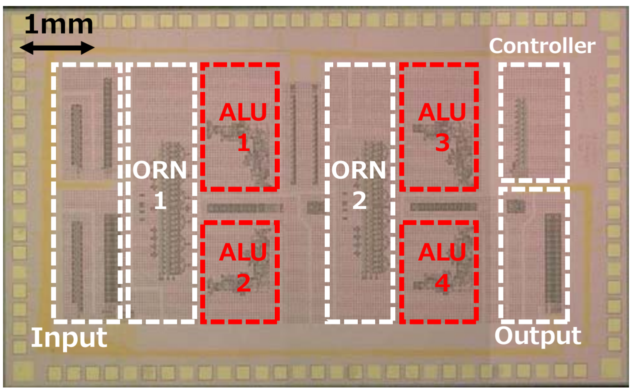

Fig. 2 A micrograph of a co-processor prototype fabricated with the ADP, designed specially for scientific computation

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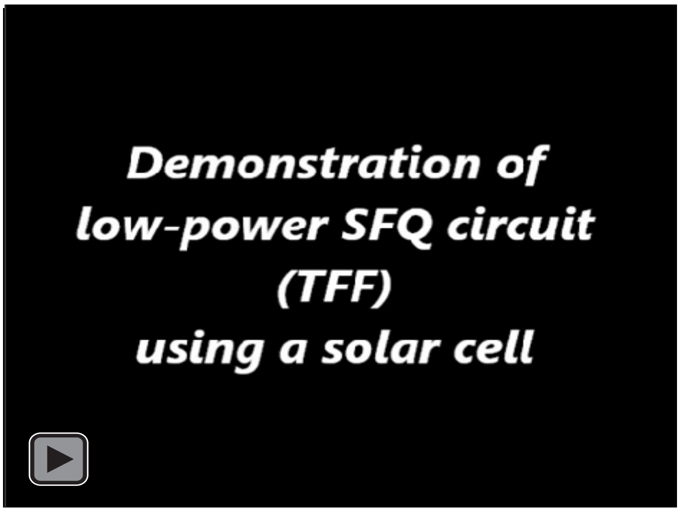
bit-energy of current RSFQ circuits have an overall 4 orders of magnitude less than those of the semiconductor CMOS counterparts, offering superior performance even taking into account the additional costs associated with cryocooling. The movie demonstrates a toggle flip-flop (TFF) using a solar cell and clearly shows the superiority of the SFQ circuit fabricated with ADP. The system operates up to 288GHz and consumes less than 15μW of power. Apart from future IT equipment-related applications, the development of this SFQ circuit has been proactively advancing for superconducting detector system applications. The system operates by detecting the power output from a multi-element detector, which after signal processing is multiplexed to room-temperature electronics. In Japan, the developments in a single photon detector, neutron detector and a mass spectrometer have been undertaken.



The demonstration of a low-power SFQ circuit (toggle flip-flop (TFF)) using a solar cell (Movie)

Nevertheless the limit is in sight, and performance enhancements of semiconductors have continued. Considering this present situation, a performance improvement of more than one order is desired in order to assure the superiority for the future of superconducting digital circuits. Conventional RSFQ circuits consume 90% of their energy at the current-limiting resistors. Therefore, the proposal is to reduce the power consumption at these current-limiting resistors. Current limiting resistors are placed between the voltage source and the Josephson junction to determine the current flowing into the Josephson junction. A relatively large resistance is required for driving Josephson junctions in a constant-current mode, resulting in increased power consumption. In the USA, methods specifically designed to reduce power consumption have been explored, and include reducing the AC-driven current by adjusting the ratio of the transformer windings and replacing the current-limiting resistor with an inductor and a Josephson junction. In Japan, at the Yokohama National University and Nagoya University, the current-limiting resistance value has been reduced to around 1/10 the original value by adopting an LR-biasing technique of placing the inductance in series with the resistance.

Recent attempts have been made to reduce the power consumption of Josephson junctions. The basic idea is to suppress voltage generation by delaying the switching time of the Josephson Junctions. nSQUID, developed by Stony Brook University, adiabatic-type QFT developed by Yokohama National University, and the low-voltage RSFQ developed by Nagoya University are examples of this idea. Further to the relationship between the bit-energy and clock period, the experimental values obtained are plotted as

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Low-Power SFQ in Figure 1. It shows that although the operating speed is slower, the bit-energy is significantly reduced with the product of the bit-energy and the clock period being more than five orders of magnitude superior to an semiconductor circuit counterpart. The energy consumption of Josephson junctions itself has already become less than conventional SQUIDs. nSQUID and adiabatic-type QFP are considered possible to reduce bit-energies up to both the thermodynamic and quantum mechanical limitations. Future development is highly expected.

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Feature Articles: Superconducting Digital Device
- An issue for the fabrication of small-size tunnel-type Josephson Junctions

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SRL/ISTEC

Josephson Junctions (JJ) are fundamental elements necessary in drawing out the macroscopic quantum effects of superconductors. The Superconductivity Research Laboratory (SRL) has fabricated JJs with a minimum size of 1 μm^2 aimed at superconducting Single Flux Quantum (SFQ) circuits. In order for JJs to be realized as quantum bits in a quantum computer, the size has to be reduced r to less than 0.1 μm^2. Furthermore, smaller JJs are also desired in order to reduce the power consumption of SFQ circuits. SRL has therefore been actively undertaking research activities towards establishing a process for the small-size JJ fabrication. Although leading-edge lithography processes and etching technology are required for the small JJ fabrication, this article does not address these issues as these can be found elsewhere, but instead we address the modified interconnections of JJs and the upper wiring which need to be solved in order to fabricate actual small JJs.

Figure 1 shows the schematic cross-sectional view of a tunnel-type JJ commonly utilized in superconducting circuits. The multilayered structure has superconducting upper and bottom electrodes composed of either Nb or Al, sandwiching a thin film tunnel barrier. The interconnecting area of the upper electrode with the tunnel barrier defines the JJ area. A small JJ is therefore defined as a JJ having a small upper electrode, which is connected to the superconducting upper wiring via a contact-hole made to the inter-layer insulating film and electrically connected to the outside.

Further to Figure 1, the contact-hole protruding from the upper electrode is a cause of current leaks and therefore it is necessary to place the contact-hole within the upper electrode area. Considering the alignment margin of exposure , the diameter of contact-hole has to be reduced by around 0.5 μm compared to a JJ. Therefore, further to JJ miniaturization, to reduce the size up to the limits offered by current lithographic and etching techniques, it is still not possible to connect the JJ to the upper wiring by employing the same contact-hole used in conventional JJ circuits.

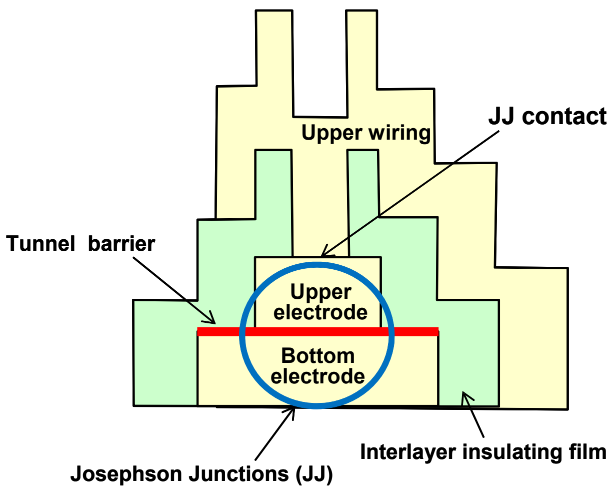

Figure 1 Schematic cross-sectional view of JJ utilizing a contact-hole

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At SRL, a Chemical Mechanical Polishing (CMP) method to connect the small JJ with the upper wiring has been developed[1]. Figure 2 shows the schematic cross-sectional diagram of a JJ fabricated by this method. In this method, after deposition of interface-layer insulating film on the JJ, CMP is employed to planarize the surface until the surface of upper electrode is exposed. Since CMP has a greater planarizing rate for uneven areas rather than smooth areas, the surface roughness prepared by CMP is improved. By depositing the upper wiring above the exposed upper electrode allows contact to be made between the JJ and the upper wiring. The difficulty associated with this method is CMP end-point detection. It is difficult to directly observe when the small upper electrode is exposed, and thus have adopted a method that assumes the exposition of upper electrode by utilizing interference spectroscopy to optically measure the thickness of the planarized insulating layer. By using this technique the JJ contact with the upper wiring has been successfully made and paves the way for the future development and fabrication of the small JJs.

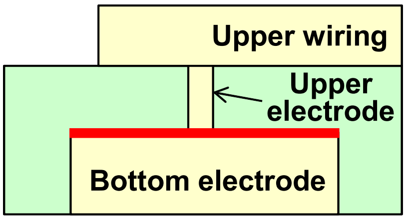

Fig.2 Schematic cross-sectional view of small JJ utilizing CMP planarization

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Feature Articles: Superconducting Digital Device
- The Fabrication Process of Integrated Cryogenic Current Comparators

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SRL/ISTEC

We have been developing fabrication process of integrated circuits (IC) including Nb/AlO_x/Nb Josephson Junctions. A large number of prototype ICs have been developed such as, Josephson memory and Single Flux Quantum (SFQ) ICs. As many more grandplanes and wiring layers are recently required within SFQ circuits, the fabrication technology of a 9-10 multilayer SFQ IC has been developed using Chemical Mechanical Polishing (CMP) and prototype circuits have been fabricated reproducibly. This article highlights the application of the process technology, which was originally developed for fabricating multi-layer SFQ ICs, to a device fabrication that is slightly different in structure and functionality.

A cryogenic current comparator (CCC) is a device that provides a ratio of two currents with the highest accuracy. It consists of more than two coils with a defined number of turns, a superconducting shield surrounding these coils and a Superconducting Quantum Interference Device (SQUID) magnetometer with a pick up coil to detect a magnetic field generated by the current flowing through the shield.

Here we assume that the two coils have an equal number of turns and an equivalent current flows through these coils in opposite directions. A shielding current is generated in the superconducting shield since the magnetic flux generated by those coil currents are excluded from the superconducting shield due to the Meissner effect. When the superconducting shield is thick enough to completely shield the magnetic field, then the magnitude of the shielding current is equal to the difference between these two coil currents. If the difference between the two coil currents is zero, then the shielding current becomes zero. This situation is independent of the geometrical size and arrangement of the coils and the shield. Hence, if this magnetic field generated by the shielding current (or the current difference) is adjusted to zero by measuring the magnetic field with the SQUID, an accurate ratio of the two currents can be determined. Also, by changing the turning ratio of the coils, we can determine other current ratios than 1:1.

A conventional use for CCC is in resistance standard measurements required for thermometer calibration. It is also used for a precise multiplication of a small current.

A conventional CCC employs a toroidal-shaped tube composed of lead foils as the superconducting shield. Thus, the CCCs are bulk devices more than several cms in size. It requires trained skill to fabricate a conventional CCC, in addition, we only use liquid helium as a coolant.

We collaborate with the National Institute of Advanced Industrial Science and Technology and Tokyo City University, and we have developed an integrated CCC (ICCC), integrating all the CCC components on one substrate[1)]. This is manufactured using well-established IC process technology allowing highly-reproducible fabrication. The ICCCs allow us to use a simple and compact cryocooler. The integration of all CCC components on a Si wafer is expected to contribute to greater mechanical durability. We have been responsible for the fabrication process development of the ICCC based on the fabrication process of robust Nb-based multilayered SFQ ICs. Thus far, major process modification has not been made, and we have succeeded in the reliable fabrication of ICCCs composed of five Nb layers and the confirmation of basic operation of ICCCs. Figure 1 shows a microscopy image of the ICCC. Figure 2 is a SEM cross-sectional image showing the structure of the CCC coils and the double superconducting shield layers surrounding the coils.

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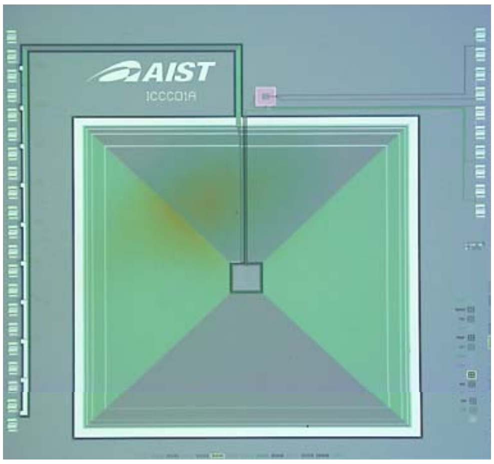

Fig. 1 A microscopy image of the prototype ICCC. The chip size measures 5 mm^2.

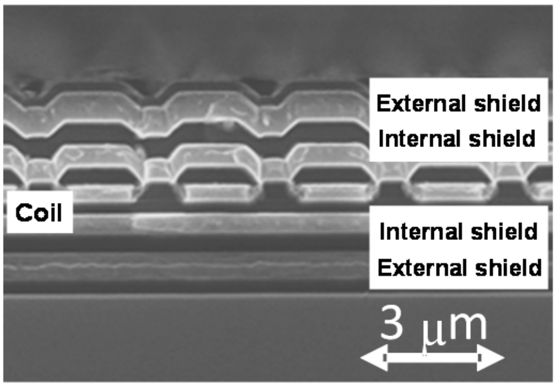

Fig. 2 Cross-sectional SEM image of ICCC

In the future process development, we will investigate fabrication process of CCC elements such as CCC coils having an entire length of several meters, and superconducting shield layers having a thickness of several μm offering an adequate amount of shielding characteristics.

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Feature Articles: Superconducting Digital Device
- Adiabatic-Type QFP Circuits with an Extremely Low Power Consumption

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In order to realize an exascale computer having more than 100-times the operating performance compared to a current supercomputer requires highly energy efficient logic devices. The most important evaluation benchmark when considering the energy efficiency of a logic device is the switching energy per bit.

The Single Flux Quantum (SFQ) circuit is highly regarded technology to drastically reduce the consumption energy of a computer system. With the critical current I_c of Josephson Junctions and Φ_0 as the single flux quantum, $I_c\Phi_0$ defines the dynamic switching energy of SFQ logic gates, which is extremely small. However, currently the static energy corresponds to more than 10-times the dynamic switching energy and is consumed in on-chip resistance for the bias current supply. Considering the cooling power requirements, this significantly affects the energy efficiency. In recent years, worldwide research and development into LR-bias SFQ circuits[1)], reciprocal quantum logic (RQL)[2)], eSFQ[3)] have been undertaken, all aiming to reduce the static energy consumption. Nevertheless, the aims of those research activities are to reduce the static energy consumption, whereas the dynamic energy consumption $I_c\Phi_0$, is essential for switching and thus cannot be reduced. As an alternative, a research activity has been proposed that is aimed at reducing the dynamic energy consumption of superconducting logic gates using nSQUIDS, where the reversible superconducting circuit takes advantage of a negative inductance[4)].

In parallel, we propose that by operating the logic gate slowly and adiabatically can reduce the dynamic energy consumption of the superconducting logic circuit. This time a Quantum Flux Parametron (QFP) was operated adiabatically and demonstrated the ability to reduce the dynamic energy consumption as well as clarifying the parameters required for the adiabatic operation of QFP [5)]. A prototype adiabatic QFP gate was fabricated and its stable operation confirmed by experiment. Figure 1 shows a photo of the circuit chip consisting of 3-stage adiabatic-type NOT gates fabricated utilizing the ISTEC standard process (STP2). The stable operation of this circuit was confirmed at low speeds. Circuit simulations showed that when STP2 was used the energy consumption of the adiabatic-type QFP gate was around 140 k_BT = 0.006 aJ at the operation speed of 4 GHz. This value is more than five orders smaller than the latest CMOS logic circuits. This research has indicated that the adiabatic-mode superconducting logic circuit is an extremely effective technology to reduce the energy consumption of a computer system.

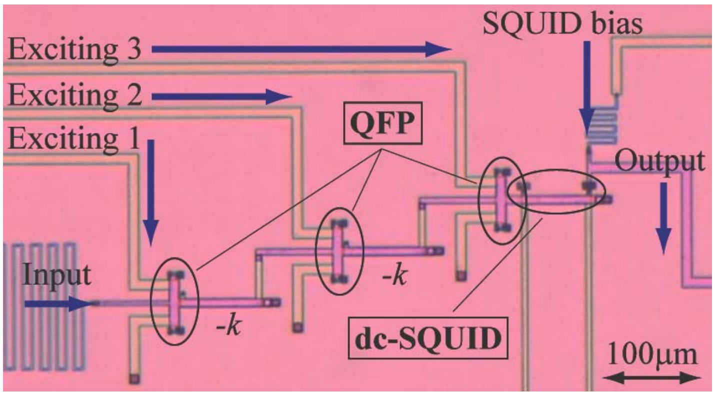

Fig. 1 The microscopic photo of a circuit consisting of 3-stage adiabatic-type QFP NOT gates. The dc-SQUID for the detection of the output signal is connected at the final stage of the QFP.

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Feature Articles: Superconducting Digital Device
- Readout Electronics Using Single-Flux-Quantum Circuit Technology for Multipixel Superconducting Single-Photon Detector Array

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National Institution of Information and Communication Technology

Superconducting Nanowire Single Photon Detectors (SNSPD) have attractive features such as high-count rate, high detection efficiency, low dark-count rate, and low-timing jitter, and wide range of detectable wavelength. The SNSPD has been developed for the application to quantum information and communications field, including quantum key distribution (QKD) systems[1)]. The intrinsic response time of an SNSPD is determined by the quasiparticle relaxation time of a hotspot generated by an incident photon. However, the actual response time is limited by the time constant, L_k/R, which is determined by the detection area (10~15 μm^2). Here, L_k represents the kinetic inductance and R represents the load resistance for the nanowire. Reduction of the detection area allows reduction of L_k, which gives higher count rate. However, it will be difficult to reduce the detection area without reduction of the coupling efficiency with an optical fibre. One of the methods to overcome this problem is to make SNSPD array consisting of multiple pixels. The SNSPD array enables reduction of L_k of each pixel, while keeping the total detection area constant and hence a nearly 100 % coupling efficiency with an optical fibre. The resulting count rate will be improved from current 100 MHz up to the GHz range. In addition, the SNSPD array enables photon number resolution, which was not achievable by the single-pixel SNSPD. Multi-pixel SNSPDs make a single photon imaging with wide detectable wavelength as well as high-frame rate possible, which could lead to a wide range of applications other than quantum information and communications field such as semiconductor diagnostic, biotechnology and mass spectrometry and further advanced technology research, possibly leading to the creation of a new industrial field.

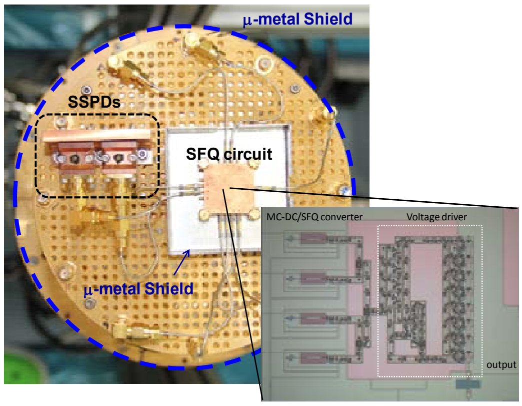

Fig. 1 The inside view of the cryocooler for the connection tests of SNSPD-SFQ readout circuits

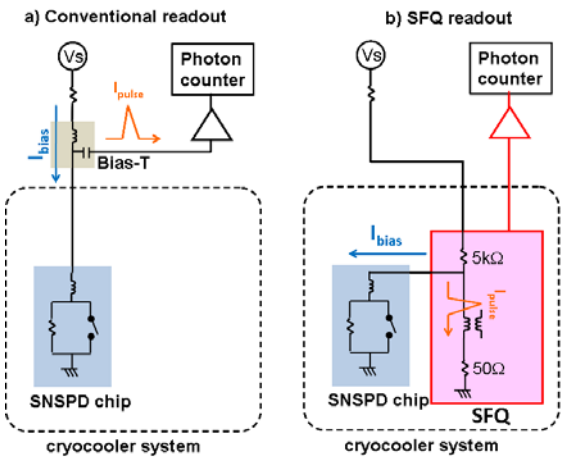

Fig. 2 The demonstration set up of the photon detection efficiency measurements

One of the critical issues involved in realizing a multi-pixel SNSPD array is the development of its readout electronics. In these arrays, the multi-pixel readout uses a large number of RF cables and causes a significant heat load to the refrigerator. The implementation in a small size GM cryocooler with 0.1 W cooling power that is able to operate at 100 V

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power line, which is currently employed in the SNSPD system, will be difficult. It is necessary to reduce the numbers of readout cables by employing signal processing in the cryocooler. We proposed and developed cryogenic readout system using single-flux-quantum (SFQ) circuits[2). The SFQ circuit has high speed at a clock frequency ~100 GHz, and consumes only several mW per 10,000 Josephson Junctions. The SFQ circuits are therefore suitable for the signal processing of SNSPD operated under the cryogenic environment.

We developed an interface circuit able to generate SFQ pulses from weak signals, approximately 1 mV, from SNSPD. We have already demonstrated the correct operation of this interface circuit by using actual output signals from the SNSPD[3)], where SNSPD and SFQ circuits were cooled individually, each connected by a 3-m long RF cable. This time, both the SNSPD and SFQ circuits were cooled in the same refrigerator and tested its operation[4)]. Figure 1 shows the photograph of SNSPDs and SFQ circuit implemented on the workspace in a 0.1 W GM cryocooler. The SFQ readout circuit is connected to the SNSPD via 10-cm long RF cable without bias tees. Figure 2 shows the demonstration set-up and Figure 3 shows the bias current dependence of detection efficiency of the SNSPD. Even though the SFQ readout circuit was directly connected to the SNSPD without a bias tee, the detection efficiency curve well agrees with that in a conventional signal readout using a bias tee and a room temperature amplifier. The jitter timing measured with the SFQ readout circuit was as large as 50 ps, which is small enough for the QKD application. We also confirmed that the SFQ readout circuit connected to two SNSPDs successfully gives the sum of the output pulses from each of the SNSPDs (Refer to the movie).

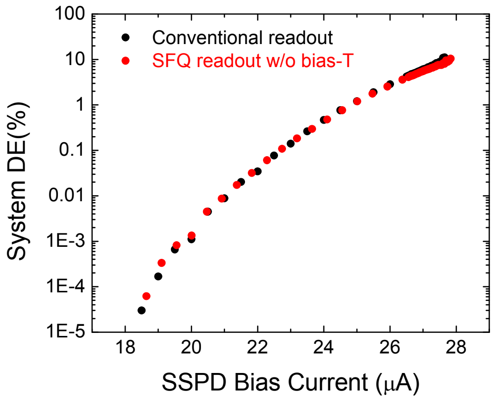
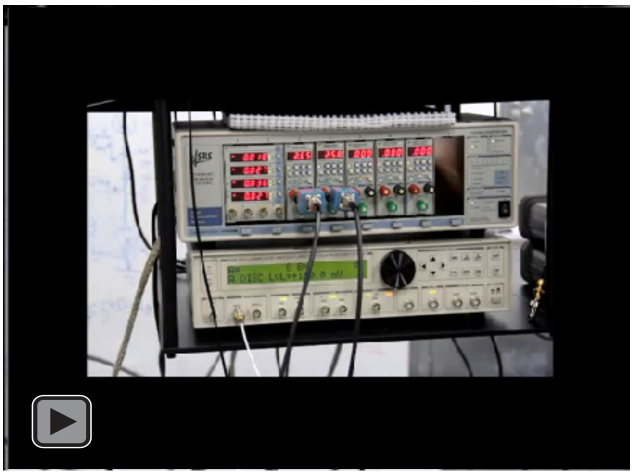


Fig. 3 The dependency of the Bias current with photon detection efficiency



View of 2-channel SNSPD+SFQ readout circuit connection tests (Movie)

These results indicate that the SFQ readout circuits can be connected to the SNSPDs without bias tees, which is an important step to the future multi-pixel SNSPD arrays. Further research and development are ongoing, including the fabrication of SNSPD and SFQ readout circuits onto the same substrate.

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Feature Articles: Superconducting Digital Device
- Future Possibilities Cultivated by the Superconducting Quantum Circuit

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Green Innovation Research Laboratories
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Researching macroscopic quantum coherence phenomena can result in an endless array of innovative possibilities for micro Josephson Junctions circuits. Amongst a series of related research activities for quantum computer utilizing qubits, this report introduces studies undertaken into quantum optics for quantum computing applications that utilize recently advancing superconducting artificial atoms.

Quantum optics is the basis of lasers and time standards, which play a large role in modern society. Over the past 100 years quantum optics was limited to the natural atom. On the other hand, qubits have quantum energy levels and can be regarded as being artificial atoms. An artificial atom has superior degrees of freedom in design, controllability and integration, which a natural atom does not. Additionally, the coupling of an artificial atom to a photon is remarkably stronger than the coupling of a natural atom to a photon, easily resulting in the realization of a "strong coupling" condition with strong quantum characteristics. The research activities mentioned below demonstrate the realization of strong coupling of a single artificial atom. The research outcomes imply an infinite array of possibilities and new directions for future quantum optics with the potential to create new arrays of quantum optic devices.

A few years ago, we successfully demonstrated laser emission from a single artificial atom by coupling a superconducting qubit (an artificial atom) to a microwave resonator, (Nature, 449, 588, 2007). An extension to this study led to the trapping a flux qubit (artificial atom) in a 1D transmission line (Science, 327, 840, 2020). A natural atom in open space can be detected by resonant scattering. This is the fundamental phenomenon of quantum optics called resonance fluorescence. Likewise, a single artificial atom resulted in the scatter of electromagnetic waves. The behaviour of an artificial atom quantitatively agrees with the predictions of quantum optics for a point like scatterer interacting with an electromagnetic field in 1D open space. Such phenomena are referred to as macroscopic quantum scattering. Under resonance conditions, a high degree of extinction of the propagating electromagnetic waves (vanishing of the transmitted electromagnetic waves) was

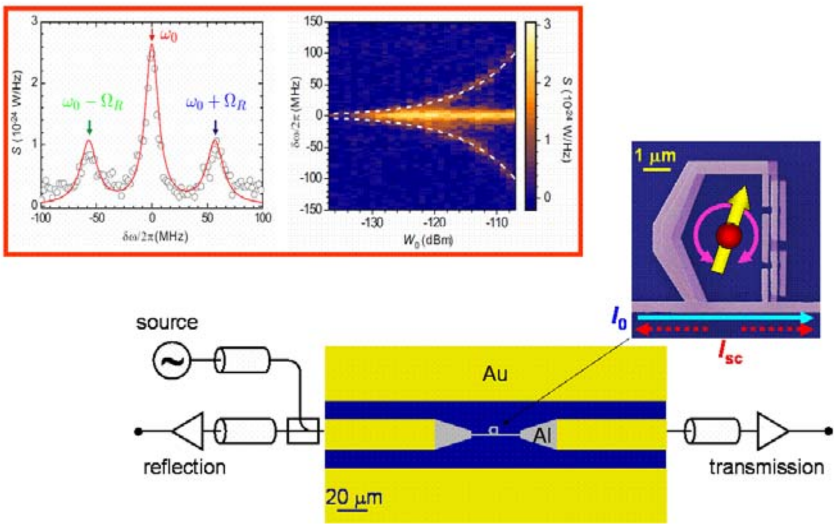

Fig. 1 An artificial atom (flux qubit) was positioned in a transmission line (1D open space), Inset (Red frame): As an example of macroscopic quantum scattering, result of inelastic scattering (resonance fluorescence) allowing a clear observation of the Mollow triplet.

observed. This strong atom-field interaction is expected to allow future applications of controllable artificial atoms in quantum optics and photonics.

A wave with a weak incident power interacting with the lowest two energy levels, scatters elastically with nearly perfect (94 %) reflection of the incident wave. Increasing the incident power of the wave leads to inelastic scattering (resonance fluorescence), allowing observation of the Mollow triplet.

Utilizing three energy levels, electromagnetically induced transparency (EIT) was observed when biased at the degeneracy point where the |0> ⇔ |2> transition is prohibited, allowing a clear observation of the Autler-Townes doublet (Physical Review Letters, 104, 19361, 2010). Biasing away from the degeneracy point so that |0> ⇔ |2> transition is allowed, realized optical pumping required for generating population inversion, leading to the amplification of stimulated emission (Physical Review Letters, 104, 183603, 2010). We have also undertaken time domain experiments on the same system. We demonstrated by just applying photons and measuring the transmitted waves, we are able to control and evaluate the dynamics of the quantum states, allowing us to fully characterize the artificial atom. (Physical Review Letters, 107, 043604, 2011).

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Feature Articles: Development of Superconducting Power Device Technology
- Trends in the Development of Superconducting Power Devices

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In Japan, the research and development of superconducting power devices has been undertaken mainly by projects supported by the Ministry of Economy, Trade and Industry and New Energy and Industrial Technology Development Organization (NEDO). At present, the projects involve the "Technological Development of Y-based Superconducting Power Equipment (M-PACC : Material & Power Applications of Coated Conductors)" project (FY2008 to FY2012) and the "High-Temperature Superconductor Cable Verification Project" (FY2007 to FY2012) utilizing Bi-based superconducting wires.

The core aims of the M-PACC project are to develop the process technology required to fabricate Y-based superconducting wires. The aspirations for Y-based superconducting wires include, the technology development to achieve the realization of superconducting magnetic energy storage (SMES), transmission power cables and transformer applications, with ultimately aim for a stable supplying cities with large amounts of electricity using superconducting power devices. An interim evaluation carried out by NEDO in the first three months of the research projects in 2010, deemed the research outcomes as being very positive.

In the "High-Temperature-Superconductor Cable Verification Project", the construction of not only a cable itself but also a cable system that integrates technologies from both Bi-based superconducting wires and refrigeration is aimed. A verification test utilizing an actual 66 kV power grid network is planned to comprehensively verify the integral reliability of the entire superconducting power cable system operation, including operation and maintenance. Local infrastructure construction began in 2010, with the facilities, including superconducting cables and the refrigeration system, being installed in 2011. The preparation for a number of verification and demonstration tests has been made.

The research and development of superconducting power devices overseas has continued, with the USA, as part of the ARPA-E project, last year launching a 3-year plan aimed at the development of a 3.4 MJ-class SMES utilizing Y-based superconducting wires. In Korea, the development of a 2.5 MJ-class SMES has been progressed.

The development of a superconducting cable is planned at the Tres Amigas SuperStation in the USA (the installation is planned in the state of New Mexico), which aims to connect three major power grids by a 5 GW-class DC cable utilizing Y-based superconducting wires. The Hydra project is progressing to develop a 13.8 kV-class superconducting cable equipped with a fault current limiting function, by 2012. The LS Cable Company based in Korea, is planning to install a superconducting cable to the power grid network of Korea Electric Power Corporation (2012-2013). In the Netherlands, the development of a three-phase cable equipped with a fault current limiting function has been advanced with objectives for commercialization by 2015. Furthermore, the development of a high-voltage class cable is intended, such as a 150 kV-class single-phase cable. At a transformer substation in Moscow, Russia, demonstration tests of a 200 m long 20 kV-class cable composed of Bi-based superconducting wires have been undertaken. The application of a 360 m long 10 kA-class DC cable is planned at a factory located in Henan Provence, China.

The development of a superconducting transformer utilizing Y-based superconducting wires has been promoted in the USA, under a project aimed for a 705kV/12.4kV-28MVA-class superconducting

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transformer equipped with fault current limiter function.

The development project of an inductive shield-type superconducting fault current limiter that utilizes Y-based superconducting wires has been advancing in Germany since 2010. The first two years of the project has seen the development and fabrication of a full-scale three-phase fault current limiter. After a number of verification tests, demonstrations at actual power grid network are planned. In the ECCOFLOW project, a four-year design development phase of a superconducting fault current limiter utilizing Y-based superconducting wires has just completed. Actual fabrication of the equipment needed has begun at the Nexans factory, and long-term demonstration tests at a transformer substation are planned after the completion of a number of evaluation tests at the substation in Spain.

The Converteam HYDROGENIE project in Europe has led to the development of a 1.7 MW-class high-temperature superconducting power generator. The fabrication of a power generator is currently under way utilizing a HTS coil provided by Zenergy Power. This project is being conducted as part of a EU-funded project and plans to install the power generator at a hydroelectric power plant in Germany, aiming to begin operations in the latter half of this year.

As mentioned-above, an outline of the recent trends in the development of superconducting power devices in both Japan and abroad was reported. The developmental status for each superconducting power device in the M-PACC project is reported as follows.

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Feature Articles: Development of Superconducting Power Equipment Technology
- Current Status in the Development of Large Current Superconducting Power Cable Technology

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In Japan, the replacement of old, large-capacity pipe-type oil-filled (POF) cables is planned for around 2020. Replacing these with low-capacity cross-linked polyethylene vinyl sheath (CV) cables however requires additional circuits, which is impractical due to the difficulties in constructing new cable tunnels in urban areas. Because high-temperature superconducting (HTS) cables fit within the large-capacity, low-loss power transmission network using compact conduits, HTS cables are expected to offer an innovative solution to these technical bottlenecks. Therefore, HTS cables have been identified as one of the key technologies for the development of next-generation power transmission grids.

Sumitomo Electric Industries (SEI) has taken part in NEDO's Technological Development of Yttrium-based Superconducting Power Equipment project that began in 2008, and has been responsible for the development of the 66 kV/5 kA-class HTS cables using REBCO wires (see Fig.1) to be used for future transmission grids. The targets of this project are as follows:

- AC loss reduction: less than 2 W/m/phase@5 kA.
- Maximum fault current: 31.5 kA, 2 sec.
- Compactness: installed in 150 mmφ conduits.

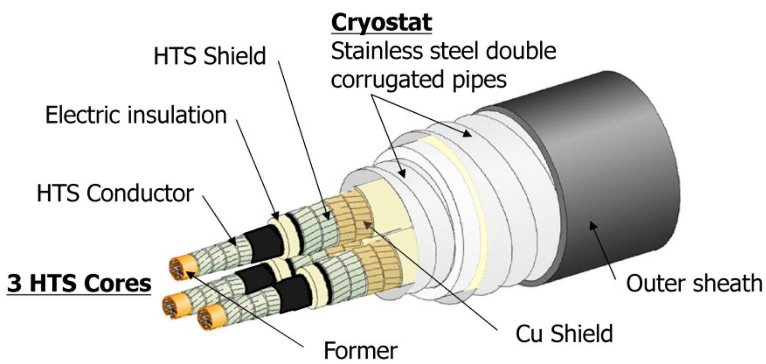

Fig.1 3-in-One High Temperature Superconducting Cable

During the first three years (2008-2010), we developed the elemental technologies for the HTS cable in collaboration with, ISTEC, Kyoto University and Waseda University, and all the targets were achieved on schedule.

The key technologies for the AC loss reduction were the development of a low-magnetic textured substrate and the slitting of a wide REBCO wire into narrow strips. SEI has developed a new type of textured metal substrate referred to a clad-type substrate. The magnetization loss in the clad-type substrate is one twenty-fifth that in a conventional Ni-alloy substrate. The developed REBCO wire is composed of a 120-μm-thick clad-type textured metal substrate, CeO_2/YSZ/CeO_2 buffer layers, a $GdBa_2Cu_3Cu_x$ (GdBCO) superconducting layer, and a stabilizing Ag layer. A 30-mm-wide wire was slit into 4-mm-wide strips, and each strip was coated by electroplating with 20-μm-thick copper. A cable core with 4-layer conductor and 2-layer shield was manufactured using these 4-mm-wide strips, and the AC loss characteristics were evaluated. The measured AC loss was 1.8 W/m/phase@5kA, thus achieved the AC loss goal (see Fig. 2). In this figure, the solid line shows the numerically simulated AC loss for the cable at Kyoto University. The measured loss was almost the same as the simulated loss.

The cable has to survive during fault accidents, so it is necessary to limit the temperature rise from a fault current to a small enough value to avoid the degradation of the HTS cable. A simulation study was performed at Waseda University to optimize the design of the copper protective layers, taking into account the required size restriction. Based on the simulation findings, a copper stranded former was adopted for the HTS conductor, and a copper shielding layer was added for the HTS shield. Using this design, test samples were prepared to conduct fault current tests (max. 31.5 kA, 2 sec). The measured temperature rise was within the expected range from the numerically simulated results. Furthermore, no deterioration in the critical current characteristics was observed in the test samples after the fault-current tests. These results confirmed that the designed HTS cable has the required fault current withstanding characteristics.

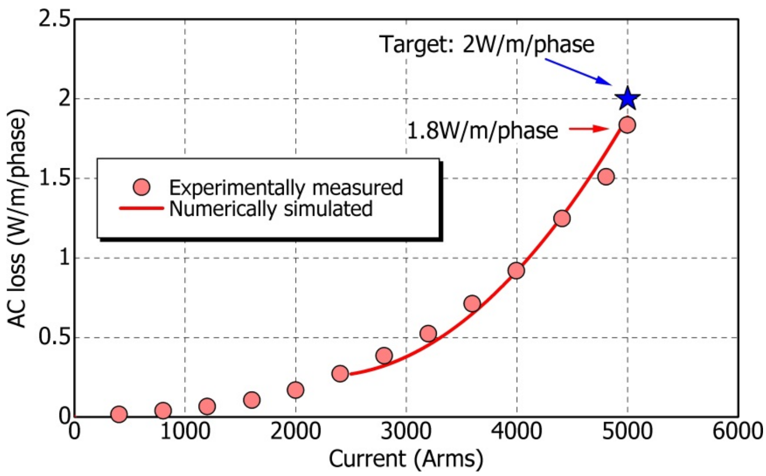

Fig. 2 Measured and Simulated AC Loss of the HTS Cable

Today, the design studies and elemental tests have been completed for each component of the HTS cable system. In the next two years (2011-2012), a 15 m-long cable system will be built for testing. The 15 m-long demonstration system will be cooled and subjected to various tests, including those for electrical, thermo-mechanical, and heat-loss measurement. After the confirmation of the nominal current and voltage performance, a long-term operational test will be performed to verify whether the HTS cable system is capable of handling the rated current and voltage for thirty years.

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Features Articles: Development of Superconducting Power Device Technology

- Development of 275 kV Very-High Voltage Superconducting Cable

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Superconducting Engineering Dep., Power & System Laboratories
Furukawa Electric Co., Ltd.

Presently, the development of a 275 kV 3 kA-class high temperature superconducting cable utilizing YBCO tapes is progressing in our research group. The development, launched in 2008, was aimed at enhancing cable characteristics with set developmental targets such as, power transmission capacity 1.5 GW (275 kV-3 kA), a transmission loss of 0.8 W/m, a short circuit tolerance of 63 kA for 0.6s and an external cable diameter less than 150 mm. The superconducting cable is aimed towards Japan's main-network applications.

Furukawa Electric Co., Ltd is currently developing a 275 kV cable that utilizes liquid nitrogen (insulation pipe or cryostat pipe), housing a superconducting cable core. Showa Cable Systems Co., Ltd initially fabricated a REBCO tape by depositing the YBCO layer on the Fujikura-made IBAD substrate by a TFA-MOD method. Furukawa Electric provided copper plating for stability.

Heat generated by the conductor led to large AC losses in the 275 kV superconducting cable, which risk the increase of AC loss and degrading the performance characteristics of electric insulation. Low AC loss is therefore an important issue that requires further development. In an attempt to decrease AC loss, both ends of the 5 mm-wide REBCO tape were cut to a 3 mm width. Results from this tape showed an improvement in the critical current homogeneity distribution across the width of the wire. Furthermore, AC losses are significantly reduced when the wire cross sections are cylindrical. The tests confirmed cryocooling the conductor to 73.7 K and an I_C=9020 A, low AC losses of 0.124 W/m at 3 kArms were achieved (Figure 1); this is half the AC loss measured one year ago.

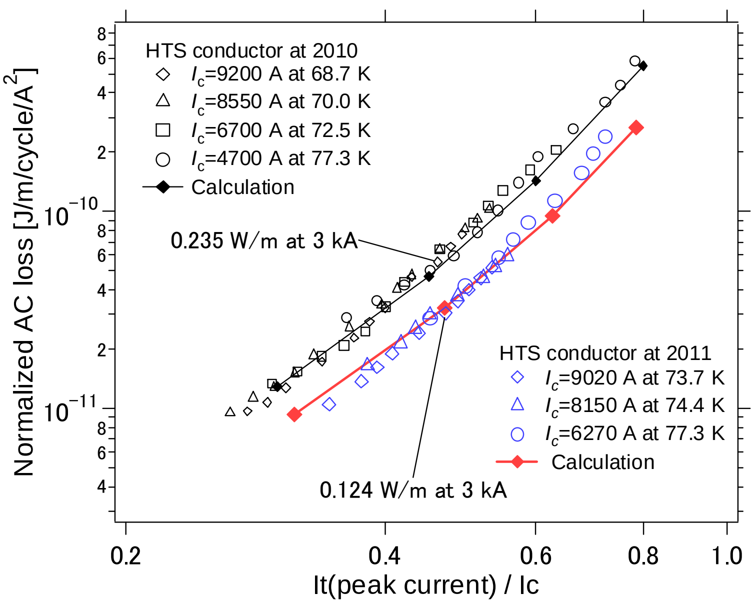

Fig.1 The measured AC loss results of a 3 kA Yttrium-based superconducting conductor

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The voltage capability of the insulation used in the 275 kV cable is four-times that of a superconducting cable developed in Japan so far. Whilst abroad, Nexans is aiming to achieve a high voltage of 138 kV - twice that of a Japanese superconducting cable. Liquid nitrogen-impregnated tape insulation has been employed for electrical insulation development. The required thickness of a polypropylene laminate (PPL) insulation layer has been determined from various tests such as, AC withstand voltage test and impulse withstand voltage test, Partial Discharge Inception Electric Field Strength (PDIE) test, life test (V-t) and dielectric loss measurements. In particular, an accident at transmission power grid has a large social impact and therefore, in order to achieve a high reliability of insulation, each measured data was analyzed using a Weibull distribution function, resulting in an electric field design with 0.1 % probability. Furthermore, a V-t test, simulated running over 30 years was used to determine a partial discharge-free design. The results proved remarkable, achieving a dielectric loss of 0.6 W/m and a total cable loss of 0.8 W/m for the 275 kV cable. Thus, a cable with the required electric characteristics was successfully realized. To confirm the design insulations, a model 275 kV cable was fabricated. Voltage load tests based on the Japanese and international electrical standards JEC and IEC standards, respectively, confirmed the characteristics of the cable (Figure 2). Measures to protect against potential short-circuit incidents involved bypassing the short circuit current to the cable former and shield protection layer. A short-circuit test of the model cable revealed that it was tolerant to a 63 kA current for a 0.2s duration.

Fig. 2 The 275 kV superconducting cable model and the outdoor termination.

During the next two years of the project, a prototype, 30m-long cable will be fabricated for complete system evaluation involving each section of the cable development; outdoor terminations, an intermediate cable joint. Electrical current tests, lasting over a month, are planned from July next year. For these tests, wire fabrication and systems design are currently ongoing.

This research was commissioned by New Energy and Industrial Technology Development Organization (NEDO).

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Feature Articles: Development of Superconducting Power Equipment Technology

- Development of Superconducting Transformer Technology ~Steady Progress towards the Realization of Technology Applications~

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Power Storage Engineering Group Leader & Superconducting Transformer Sub-Leader,
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For a development project investigating superconducting transformer technology as part of the Yttrium-based superconducting power equipment technology development project (hitherto, Y-based project), Kyushu Electric Power Co. Inc. leads the consortium, with collaborations between Kyushu University, Iwate University, International Superconductivity Technology Centre (ISTEC), Fujikura, Showa Cable Systems Co., Ltd, Fuji Electric Co., Ltd, Taiyo Nippon Sanso Corporation and Japan Fine Ceramics Centre (JFCC). This project has undertaken developmental research into component and system technology for the periods for 2008-2012. This development has been progressed, focusing on: (1) wire development required for superconducting transformers, (2) wire winding technology development, (3) cryocooling system technology development, (4) technology development equipped with a current limiting function and, (5) demonstration of a 2MVA-class superconducting transformer model (for full details, please refer to the feature articles in this issue).

Having entered the final stage of the Y-based project, which concludes at the end of 2012, research results are appearing steadily and are achieving the set original targets as shown in Table 1. The current status of items (1) and (4) are introduced and summarized in this article.

Table 1 The Final Targets of Superconducting Transformer Technology Development Project

Technology Development Category	Final Aims of Y-based Project
1. Wire Development required for Superconducting Transformer	• Stable Manufacturing, Improvement of Process Technology (Yield Improvement)
2. Wire Winding Technology Development	• Establishment of 2kA-class wire winding technology • Low AC loss of wire windings ≦1/3(*cf.* wire fabricated without a thinning process)
3. Cryocooling System Technology Development	• Cooling capacity：2 kW@65 K • Cooling Efficiency (COP)：0.06@80 K
4. Technology Development equipped with Current Limiting Function	• Demonstration of operational function of several hundreds kVA class transformer equipped with current limiting function (Suppression of excess current less than three times rated)
5. Demonstration of 2 MVA Class Superconducting Transformer Model	• Demonstration of model 66/6.9kV-2MVA transformer with the application of an electric current

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1. Wire development required for superconducting transformer

Reducing AC losses are paramount in advancing the development of superconducting transformers. A wire thinning technology for Yttrium-based superconducting wires (hitherto Y-based wires) is therefore necessary. A process of laser-thinning long Y-based wires (5mm width wires, single length of 100-300m class) is currently in the mid-stage of development for this project. Figure 1 shows an example of a long Y-based wire with a length of 282m, maximum length as 3-scribed wires, with each wire filament having an almost similar I_C value. Furthermore, positive results were obtained as the hysteresis loss was reduced to less than 1/3 for the same wire after the thinning process (Figure 2).

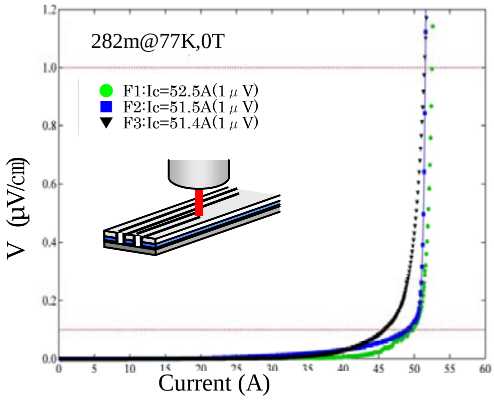

Fig. 1 The I_C results measured for each filament after the thinning process (Y-based wires 282m@77K, 0T)

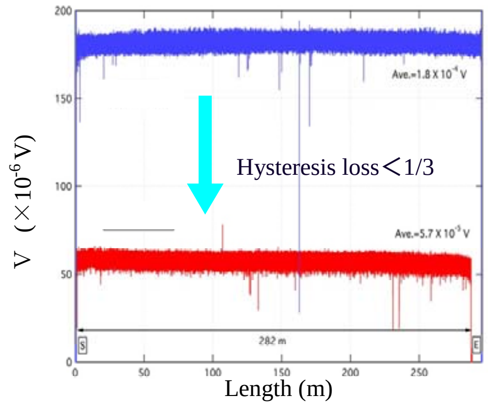

Fig. 2 The results of the hysteresis loss measured from the Y-based wires shown on the left

2. Technology development equipped with a current limiting function

A superconducting transformer equipped with a current limiting function as an added value new technology is in mid-development. A single-phase 10 kVA transformer model was used for demonstration tests to verify the current limiting function by mimicking the increase in resistance accompanied by the transition from a superconducting to a normal conducting state, (for further details, please refer to the 2010 October issue of Superconductivity Web21). Following on from this test, a single-phase 400 kVA-superconducting transformer equipped with a current limiting function and an optimized wire-winding configuration was fabricated for demonstration tests aimed at commercialization. The current limiting characteristics were confirmed with the same transformer.

The transformer wire windings are required to have a tolerance for short circuit current faults for certain durations of time. Using a set point value of 0.2s distribution wire protection, a simulated short circuit for 0.25s was tested to determine whether the current was suppressed to three times the current rating. Figure 3~5 shows the demonstration circuit used, a view of the equipment and the voltage and current waveforms results, respectively. With a simulated short circuit of 0.25 second duration, the test results showed that the excess current was limited to almost three times (174 A) the current rating (I_n : 58 A), down from 9.6-times the current rating current (559 A). Also the voltage-current characteristics before and after the test remained unchanged for the transformer wire windings, verifying the stability of the wire windings (short circuit strength).

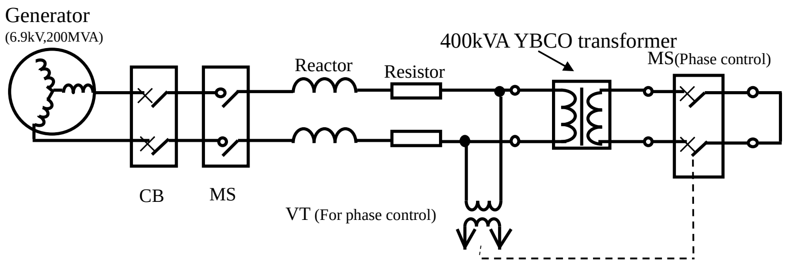

Fig. 3 The circuit used to demonstrate the current limiting characteristics of the 400 kVA transformer.

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Fig. 4 A view of the test equipment used to determine the current limiting characteristics of the 400 kVA transformer.

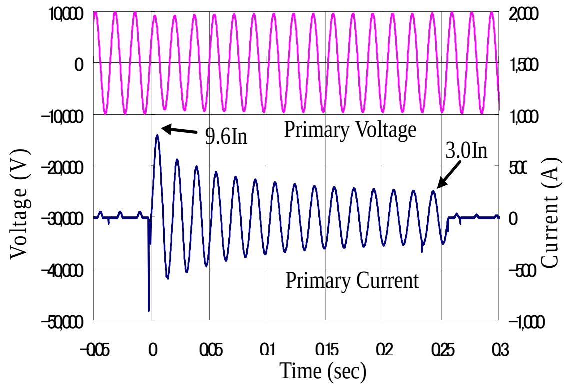

Fig. 5 The test results for the current limiting characteristics of the transformer

3. Future development

The development of wire winding technology having a large-current capacity and low-loss characteristics are continuing together with the required cryocooling system technology. The development and demonstration of a 2 MVA-class transformer model (Figure 6) is planned. Furthermore, depending upon the outcomes of the cryocooling system and the 2MVA transformer, further development is planned to improve the design accuracy, with the aim towards the commercialization of 20 MVA-class distribution transformer. Furthermore, investigations into potential applicable opportunities as well as the economic considerations are also planned.

This project has been progressed to the point where the future of a 2 MVA-class superconducting transformer can be realized for power distribution (Figure 7). Nevertheless, this technology can be applied to any type of superconducting transformer. As shown in Figure 8, its uses are not limited to only electrical power applications as there are an array of other applications such as industrial and transportation that are considered. It is therefore highly expected that the developmental outcomes of the Y-based project will significantly contribute to technological development for an array of superconducting transformers, leading to commercialization as early as possible.

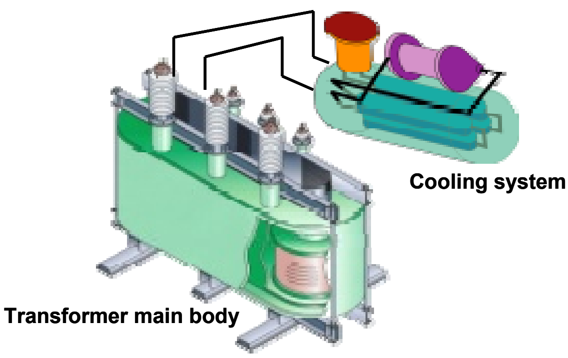

Fig. 6 2 MVA Transformer Model

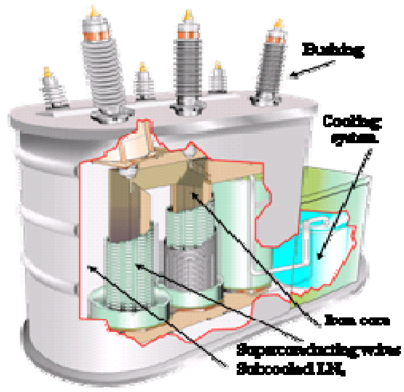

Fig. 7 Conceptual diagram of 20 MVA class superconducting transformer for practical use

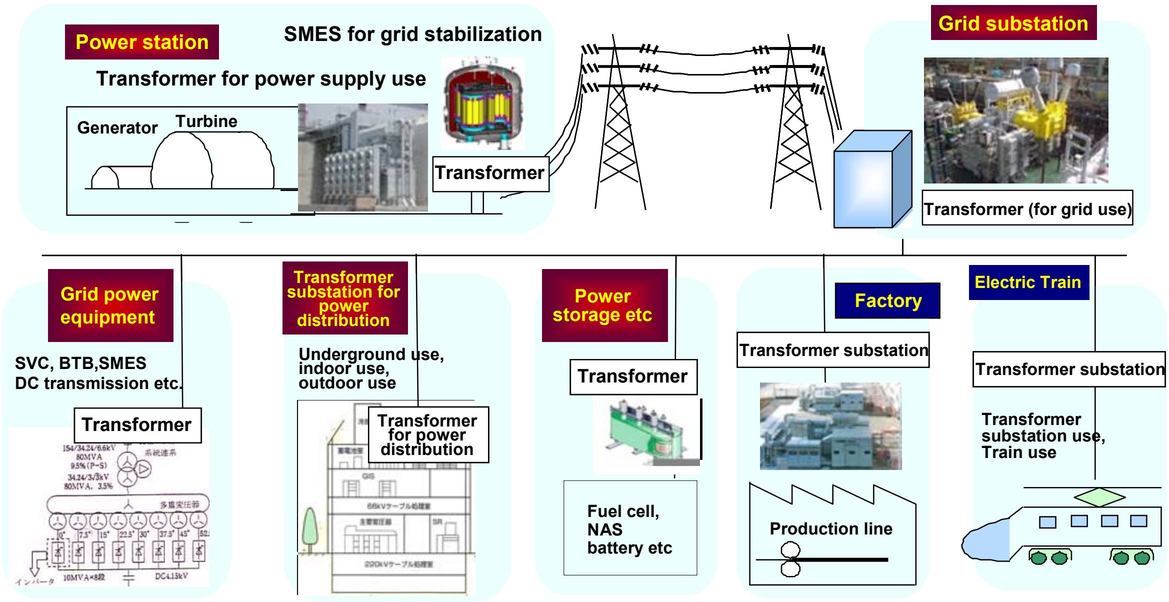

Fig. 8 Application example of superconducting transformer

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Standardization Activities

Topics in August 2011

- IEC/TC90 ad hoc 4th group* Meeting -

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The first IEC/TC90 ad hoc 4th group (superconducting sensors) meeting was held after the closing session of the first day (1 August) of the 14th International Workshop on Low Temperature Detectors, at 18:30-21:00. The following photo taken in the meeting room shows the six participants. The names of participants (from left to right) are as follows:

Roberto Cristiano, CNR, Italy (Committee Member)
Taiji Fukuda, AIST, Japan (Committee Member)
Masahiro Ukibe, AIST, Japan (Observer)
Masataka Okubo, AIST, Japan (Committee Member)
Chong Yonuk, KRISS, Korea (Committee Member)
Yong-Hamb Kim, KRISS, Korea (Committee Member)

Fig. 5 The participants at the 1st IEC/TC90 ad hoc 4group (superconducting sensors) meeting

In this meeting, I acted as the rapporteur and introduced the activities of the IEC/TC90 to those committee members. Using the documents for the ad hoc group proposals used at the TC90 meeting in 2010 (IEC General Meeting, Seattle), I explained the aim of the ad hoc group and the significance of the IEC.

* responsible for the IEC standardization of superconducting sensors.

The technical terminology for naming detectors was discussed especially. Although there are a number

of detectors mentioned below, it was evident that there is a confusion on the terminology (naming) for the superconducting sensors. This issue should be addressed as soon as possible, as it will eventually lead to a source of serious confusion.
In particular, the so-called SSPD could be critical.

1. The detector names based on the principle of operation
Superconducting Quantum Interference Device (SQUID) magnetometer
Transition Edge Sensor (TES)
Superconducting Phase Transition (SPT) sensor
Microwave Kinetic Inductance Detector (MKID)

2. The detector names based on the structure
Superconductor-Insulator-Superconductor (SIS)
Normal-Insulator-Superconductor (NIS)
Superconducting Tunnel Junction (STJ)
Superconducting Strip-Line Detector (SSLD)

3. The detector names based on both the operating principle and the structure
Metallic Magnetic Calorimeter (MMC)

4. The detector names based on the subjects to be measured
Superconducting Single Photon Detector (SSPD)

5. The detector names based on both the structure and the measurement content
Superconducting Nanowire Single Photon Detector (SNSPD)

All the committee members agreed that there were issues associated with the terminology for the superconducting sensors.

The main issues highlighted by the meeting are as follows:

- The word "Semiconductor sensor (detector)" is widely used in the semiconductor field. However, The word "superconducting sensor (detector)" is used in the superconductor field. As detectors are operational in the superconducting state, it is considered that "superconducting sensor (detector)" better describes the device. It is possible that the difference between "superconductor and superconducting" will be an issue in the IEC Advisory Committee meeting on vocabulary.
- Since TES is operated between the superconducting and the normal state, strictly speaking, it is not a superconducting sensor.
- Although *"TES detector"* terminology is sometimes used, an alternative would be "*Detector using Transition Edge Sensor"* rather than *"Transition Edge Sensor Detector."* The overlap of *"Sensor"* and *"Detector"* may be inappropriate.
- Although the detector names derived from the structures may be preferable, there are some names that cannot be changed, for example, *SQUID*, a name derived from the operating principle. SQUID is widely accepted by the community and cannot be changed.
- *"MKID"* is sometimes referred to as *"KID,"* skipping the letter *"M"*.
- The name *"SSPD"* is derived from the Single Photon Detector (SPD) that is used in the semiconductor

field. The term *"Superconducting"* was added to SPD in order to distinguish from conventional SPD. However, TES, STJ and MMC are also single photon detectors. There are many types of superconducting single photon detectors other than the so-called SSPD.

- Since the dimensions of SNSPD are a thickness of 10nm and a width of, 200 nm-1 µm, the word "nano-wire" may be inappropriate. Alternative name for SSPD is *"Superconducting NanoStrip Detector"* (SNSD) that would better represent the structure.
- Referring to the structures and measurement objects, it is proposed that possible names are "*Superconducting NanoStrip Photon Detector*" (SNSPD) and a "*Superconducting NanoStrip Molecule Detector*" (SNSMD).
- It is also possible that the detector names should be made up from the detector structures only, and the objects to be measured can be written in specification sections.
- We agreed with the IEC standardization for superconducting sensors. It was suggested to consider the EU Superconductor Roadmap, recently published by the European superconductor community. (Physica C 470 (2010) 209-2126).
- It was suggested that issues regarding naming can be shared with many researchers by announcing it in international conferences.
- Yonuk Chong's expertise is now SIS, Voltage standard.

The meeting was completed with the following agreements.

1. The detector names should basically be derived from the structures. However, this excludes those detectors where the name is widely accepted and commonly used.
2. Further deliberations need to be undertaken to determine whether the measurement objects are included in the detector names, or whether they should be part of the specifications.
3. Detector names used in scientific fields other than superconductivity as well as description in roadmaps on superconductivity should be considered in further discussion.
4. The establishment of a Working Group is expected.

The second and third IEC/TC90 ad hoc 4-group meetings are planned for the Superconducting Centennial Conference, which takes place in The Hague, Netherlands, and ISS2011, in Japan, respectively. At the IEC/TC90 General Meeting, China, 2012, we plan to propose a new Working Group.

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Standardization Activities

Topics in November 2011

- Toshiyuki Mito and Hirofumi Yamasaki Received IEC1906 Award 2011

Recipients of the IEC1906 Award
(Back row: Toshiyuki Mito third from left, Hirofumi Yamasaki seventh from left)

The Industrial Standardization Awards Ceremony 2011 was held at "Cosmos Hall," third-floor of the Toshi Center Hotel on the 17th October 2011. The IEC1906 Award took place at this event. Toshiyuki Mito, Director of Coordination Research Project at National Institute for Fusion Science, and Hirofumi Yamasaki, Group Leader of Superconductor Technology Group at National Institute of Advanced Industrial Science and Technology, both received awards.

Toshiyuki Mito was presented with the award for his significant contribution to standardization activities in the field of superconductivity, including activities of collating the opinions from Japan and abroad regarding international proposals of international standards, IEC61788-14 (Superconducting power devices — General requirements for characteristic tests of current leads designed for powering superconducting devices), as Convenor of IEC/TC90/WG12 (Superconductivity – Current Leads) and also as a chairperson of national committee of WG12, over the past five years since 2007.

Hirofumi Yamasaki was also presented with the award for his significant contribution to standardization activities in the field of superconductivity, including activities on international proposals with international standards IEC 61788-7 of superconducting thin film, as an expert (IEC's Expert from 2009 onwards) for IEC/TC90/WG8 (Superconductivity – Electronic characteristic measurements), over the past six years since 2006.

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The meeting informed that this year a Japanese would be the recipient of the IEC Thomas A. Edison Award. Kenichi Sato, Fellow, at Sumitomo Electric Industries, Ltd., who has been posted as Secretary at IEC/TC90 for the past 22 years, was unofficially accepted as the recipient. It was reported that the award ceremony would take place at the SMB meeting during the 2011 IEC General Meeting (Melbourne, Australia) on 24 October.

(Editor)

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