NIMS NOW International

2009. May

Special Feature
Superconducting Materials

Nb_3Al reel-to-reel rapid-heating and quenching (RHQ) apparatus

Special Feature
Superconducting Materials

Where is Superconductivity Today?

Eiji Muromachi
NIMS Fellow and Group Leader of New Materials Group
Superconducting Materials Center

Superconductivity was first reported by the Dutch physicist Heike Kamerlingh Onnes in 1911. Onnes measured the electrical resistance of mercury at extremely low temperatures and discovered that electrical resistance dropped abruptly and completely disappeared at temperatures of 4.2 kelvin (K) and below. He called this phenomenon "superconductivity" (Fig. 1). Today, superconductivity is acknowledged to exist only at very low temperatures. In addition to having no electrical resistance, a unique attribute of superconductivity is its perfect diamagnetism. The temperature at which a material enters a superconductivity state is called the critical temperature (T_c). The Meissner effect, in which a magnetic field is excluded from a superconductor, occurs when a material in a normal conducting state at a temperature higher than the T_c is placed in a magnetic field and subsequently cooled so as to enter a superconducting state (Fig. 2). Owing to this magnetic effect, the superconducting material will float above a magnet.

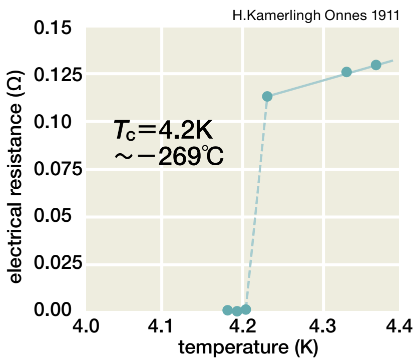


Fig. 1 At 4.2 K the resistance of mercury drops abruptly and disappears, as stated in Onnes' article of 1911

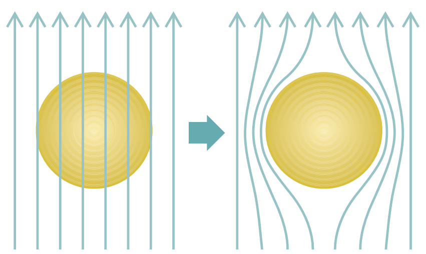


Fig. 2 The Meissner effect

Mechanism and Properties of Superconductivity

In 1961, about fifty years after the discovery of superconductivity, three physicists developed a model called the BCS theory (named after the initials of their surnames) to elucidate the basic mechanism of superconductivity. Electrical resistance in a conductor is thought to be the result of scattering of electrons by imperfections of the crystal lattice; namely, impurity atoms, structural distortion, and lattic vibrations (phonons). However, the BCS theory asserts that conduction electrons pair up under certain conditions, preventing the electrons from being scattered and thus, resulting in zero electrical resistance. While the fundamental part of the BCS theory can be applied to all superconductors currently known to exist, much of the details have yet to be explained. For example, we still know very little about the mechanism of high-temperature superconductivity described later.

The superconducting state of a material is lost when the magnetic field applied to the superconductor is increased above a certain strength referred to as the critical magnetic field (H_c).

Another important property of a superconducting material is its critical current density (J_c). Despite having no electrical resistance, superconductors have a limit to the amount of current they can conduct. In the graph shown in Fig. 3, superconducting material can only be used in the region inside the critical surface for temperature, magnetic field, and current density. Among these three critical values, T_c is an inherent property of the material, and significant improvement in H_c is unlikely. However, J_c is highly dependent on the process used to form the superconducting wires or other material. Hence, achieving a high J_c is effectively the primary objective for material processing.

Widespread Applications for Superconductivity

Applications for superconductors have emerged in diverse areas of science and technology, including energy, transportation, medical care, and the environment, owing to their ability to conduct an electric current at a density of ten thousand to one million times that of copper with no loss. Using this property, superconductors can handle high currents in power applications. A typical application is a system employing a powerful magnetic field generated by a superconducting magnet having a superconducting wire as the winding; for example, magnetic resonance imaging (MRI) equipment used in hospitals, a superconducting magnetic levitation (maglev) train, and a nuclear magnetic resonance (NMR) spectrometer used for analyses, such as the analysis of protein structures.

Superconductors are also finding important applications in electronics, including filters, antennas, resonators, magnetometers (SQUID), voltage standards, arithmetic circuits, and memory circuits. SQUID in particular is capable of detecting extremely weak magnetic fields and, thus, is used for studying magnetic properties of materials and for observing weak magnetic fields emitted by heart or brain.

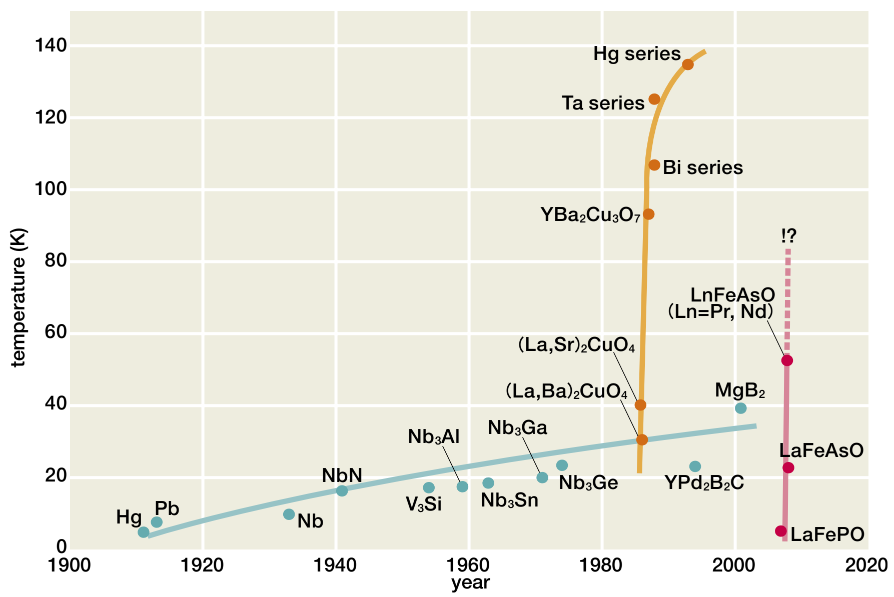


Fig. 4 As researchers pursue room-temperature superconductivity, superconductors with high critical temperatures are discovered every year

Varieties of Superconducting Materials

The superconductor most commonly used today is the niobium-titanium alloy Nb-Ti. Although its T_c of 9.8 K is low and its upper critical magnet field (H_{c2}) is not particularly high, this material is used extensively in applications having relatively low external magnetic fields of 10 T or less, because the plasticity of the alloy makes it easy to process. Nb_3Sn (T_c=18.2 K), which is an intermetallic compound of niobium and tin, is generally used in stronger magnetic fields exceeding 10 T. Since the compound Nb_3Sn is hard and brittle, the individual components must be drawn into wires and coiled at the raw material stage before reacting the Sn with the Nb. What stands in the way of these metallic superconductors being used more extensively is their low T_c, which necessitates cooling with expensive liquid helium.

However, there is another group of superconductors having a remarkably higher T_c than metallic superconductors. Materials in this group are all oxides containing copper and are called high-temperature (high-T_c) superconductors or copper oxide superconductors. Some representative high-T_c superconductors and their T_c values are $YBa_2Cu_3O_7$ (T_c=90 K), $Bi_2Sr_2Ca_2Cu_3O_y$ (Bismuth system; T_c=110 K), and $HgBa_2Ca_2Cu_3O_y$ (Mercury system; T_c=135 K). The last compound containing mercury in the above examples has the highest T_c value of all superconductors known today. High-T_c superconductors are advantageous in that they have dramatically higher T_c and H_c values than conventional superconductors and can be cooled with inexpensive liquid nitrogen (77 K). However, copper oxides are ceramics, which are difficult to form into wires or other useful shapes, and efforts aimed at developing methods to form such materials are ongoing. Recently, iron-based compounds, a new group of superconductors are discovered.

Room-temperature Superconductivity is the Ideal

All superconductivity researchers dream of discovering a room-temperature superconductor that can be used without cooling because the discovery of such a superconductor could lead to innovations that would fundamentally alter society. No one knows whether such a superconductor truly exists, but there is also no dispute that there remain numerous superconductors that have yet to be discovered. Fig. 4 shows how the critical temperatures of known superconductors have risen over the years. Somewhat like a tortoise, the T_c values for conventional metallic superconductors, shown in blue, have climbed slowly but steadily over the years. The last of these, MgB_2, is a new superconductor first reported in 2001 and has been drawing attention in both basic and applied research due to its T_c of 39 K, which is surprisingly high for a conventional superconductor. The T_c values for high-T_c superconductors, indicated in yellow, rose about 100 K in just a few years, but have subsequently been stagnate. The newest superconductor series to be discovered includes the iron-based compounds with arsenide and so on indicated in red. So far, the T_c values in this series have risen 55 K, generating much interest in the potential of these materials.

At this stage, we cannot know the peak T_c value of superconductors, meaning there is still a possibility for discovering room-temperature superconductivity. Much research aimed at that discovery is being conducted throughout the world.

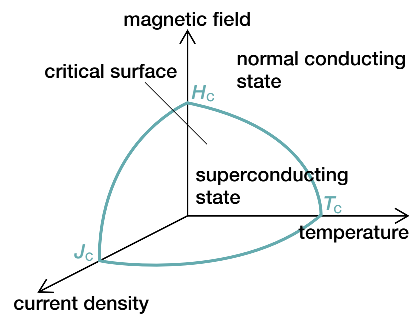


Fig. 3 Critical surface of a superconductor

Major Superconducting Materials and Their Applications

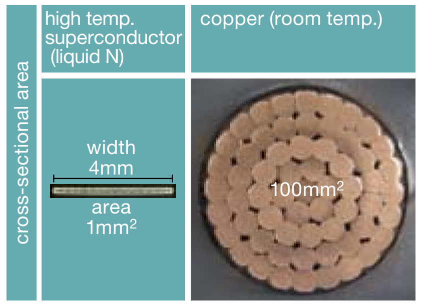
Part 1

Bismuth Oxide Superconducting Wire

Pursuing a Technological Dream for Energy and the Environment

Hitoshi Kitaguchi
Group Leader of High-T_c Superconducting Wires Group
Superconducting Materials Center

More than twenty years has passed since the discovery of the first high-T_c oxide superconductor, which can easily be cooled by liquid nitrogen to achieve superconductivity. Some readers may remember the great excitement generated by this discovery. Although the excitement subsided shortly thereafter, our efforts to develop superconducting materials have not abated. We believe that high-T_c superconductors have the potential to revolutionize energy conservation aimed at addressing in part global environment issues. Accordingly, we continue to pursue our research while looking forward to the day that these superconductors are actually put into use.



Cross-sectional area of conductors required for each 100 A of transmission current, assuming that the bismuth oxide high-T_c superconductor tape wire is operated at 50% of its critical current (about 200 A at the temperature of liquid nitrogen)

Power Cables formed of High-T_c Superconducting Material

Let's consider the example of using high-T_c superconducting material to form power cables. Although it is completely unnecessary for power lines formed of copper or aluminum, cables formed of superconducting material must be cooled to be effective. The expense for cooling superconductors used in power distribution was previously thought unrealistic when the only known superconductors were formed of Nb-Ti or other metallic material, which had to be cooled with liquid helium. However, after the development of high-T_c superconductors that can be cooled with inexpensive and readily available liquid nitrogen, superconductor power distribution became economically feasible, even when accounting for cooling costs. Nations throughout the world are pursuing the development of high-T_c superconductor power cables and are beginning to test some of these cables in actual power systems (systems that actually supply power to ordinary residences and businesses). The accompanying figure shows a comparison of power conductor using high-T_c superconducting cables and conventional copper cables. With high-power copper cables, the allowable current is generally about 1 A per 1 mm^2. Using a bismuth oxide high-T_c superconducting tape wire, the critical current (maximum current that can flow through the superconductor) reached 200 A per 1 mm^2 when cooled to the temperature of liquid nitrogen and when no external magnetic field was present. Even if the system were operated at half the maximum performance to provide a safety margin, the high-T_c superconductor cables have the potential to supply electricity at a current density greater than that possible with copper cables by double figures.

Satisfying Power Needs with Compact Cables

In addition to their ability to maintain low transmission loss, high-T_c superconductor power cables are expected to help conserve space due to their compact size. Simply replacing conventional copper cables with high-T_c superconductor power cables having the same cross-sectional area can increase the power transmission capacity of the system. It is anticipated that high-T_c superconductor cables can be used in city centers to meet the ever-increasing demand for power, while minimizing the environmental impact generated when building new underground cable tunnels and installing pipes to protect the power cables. Our goal is to increase the critical current of the bismuth high-T_c superconductor cable material from the current 200 A per 1 mm^2 to 300 A within a few years, and eventually to 400 A.

The most important property of superconducting materials, the critical current, is greatly influenced by a variety of material technologies and the materials science forming their foundation. These technologies, which are focused on overall micro-to-macro control of the material composition, include synthesis of powdered raw material, wire drawing and heat treatment processes, and wire composition design based on electromagnetic properties. We are confident that one day we will see great strides in the development of superconducting material technology based on the material research at NIMS and that equipment employing superconductors will permeate society in such fields as energy and the environment.

A practical use of superconducting wire — Challenges in the industry

Bismuth-based superconducting wire with the length of 2000m class

Ken'ichi Sato
Fellow, Chief Engineer in charge of Superconductor
Sumitomo Electric Industries, Ltd. Material and Process Technology R&D Unit

I am engaging in R&D of a bismuth-based superconducting material discovered by Dr. Hiroshi Maeda of NIMS. We already succeeded in making superconducting seamless wire longer than 2000m. Since a bismuth-based material comes to superconductor at 110K, being cooled with liquid nitrogen (77K) is enough to give full scope to its ability. Comparing with yttrium series, a bismuth-based material is easy to form into long wire using the same technique as to form copper wire. Development of the wire is already in practical level and we are looking forward to applying a bismuth-based superconducting wire to power cable. Wider application is to be expected. Last year, we tested and released the world-first electric automobile loaded with a small-sized superconducting motor. Not only an automobile, but a superconducting ship and other challenges would have a possibility. I should say that superconductor will be an ultimate resolution for energy and the environment issue.

Part 2

Niobium-Aluminum Superconducting Wires Developed for Nuclear Fusion

Takao Takeuchi
Group Leader of High Field Superconducting Wires Group
Superconducting Materials Center

Power generation by nuclear fusion is widely anticipated to be the eventual solution to energy problems in a low-carbon society. Superconducting magnets are essential in such a power generation system for the magnetic confinement of plasma. When attempting to produce a high magnetic field in a large space using water-cooled electromagnets formed with copper conductors, the power required to generate sufficient magnetic force exceeds the generated output of the system. Therefore, superconducting magnets are essential to overcome this problem.

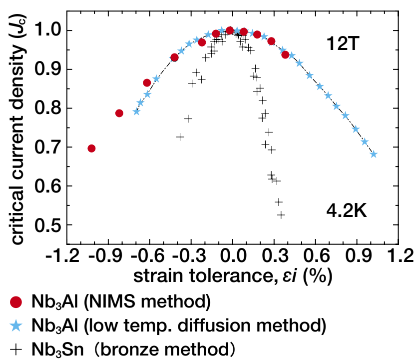


Fig. 1 Comparison of strain tolerance in superconducting wires developed for a fusion reactor

Superconducting Magnets Designed for ITER

Superconducting magnets for fusion reactors are expected to have significantly greater electromagnetic force and stored energy than normal superconducting magnets. To address safety concerns, we have increased the current capacity of the conductor while reducing the number of turns in the winding in order to maintain a low coil inductance.

We have developed conductors with a current capacity exceeding tens of kA, called cable-in-conduit (CIC) conductors, for use in ITER (maximum field of 13 T) scheduled to begin operations in 2016. The conductors, which consist of multiple niobium-tin (Nb_3Sn) superconducting wires twisted together, are encased in a strong stainless steel conduit serving both to encapsulate coolant and to provide electromagnetic support. In ITER, a maximum electromagnetic force of about $8{\times}10^5$ newtons (80 tons) is exerted per meter length of the conductor. Consequently, superconducting wires in the conduit incur a bending strain and a large lateral compressive load at points of contact between adjacent wires. The lateral load and strain lower the maximum current density (critical current density J_c) that can flow through the Nb_3Sn wires while sustaining a superconducting state. The lateral load and strain increase in response to increases in the operating magnetic field and operating current.

A prototype reactor aimed at achieving actual power generation by nuclear fusion and planned as the next step after ITER is expected to achieve an operating magnetic field of 16–20 T, considerably higher than ITER, and an operating current exceeding 80 kA. Consequently, a greater electromagnetic force will be exerted on the superconducting wires, under which force the critical current density J_c will drop dramatically, indicating that Nb_3Sn wires are no longer suitable.

Development of Materials for the Demonstration Reactor

Therefore, at NIMS we have been developing rapid heating, quenching, and transformation processed niobium-aluminum (Nb_3Al) superconducting wires. These wires not only demonstrate significantly less deterioration in J_c than

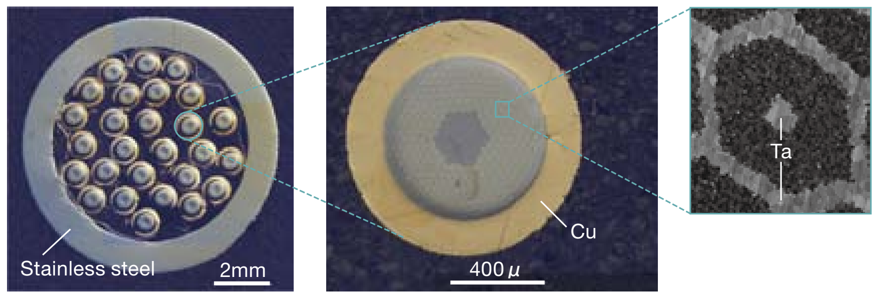


Fig. 2 Cross section of a prototype Nb_3Al-based CIC conductor

ITER	prototype reactor	commercial plants
collaboration (Japan, EU Russia, U. S. China, S.Korea India)	Japan EU, U.S. (under investigation)	introduction onto the market
2016–2035	2030~	after 2050

Fig. 3 Pursuing practical power generation by nuclear fusion

Nb_3Sn wires when strain is applied (Fig. 1), but also maintain a high J_c under high magnetic fields in a strain-free state. Accordingly, Nb_3Al superconducting wire is a promising candidate for conductors used in the demonstration reactor. Fig. 2 shows a model CIC conductor for a fusion reactor experimentally manufactured by encasing the third stage cable of Nb_3Al (3 ×3×3 strands) in a stainless steel conduit, where Nb_3Al are coated with a Cu stabilizer using an ion plating and electroplating techniques, after quenching. Since most Nb_3Al superconducting wires to date have been developed for use in NMR magnets that must operate in a permanent current mode, an Nb matrix is used for facilitating the superconducting joint. However, the matrix material has been changed to tantalum for use in fusion reactors, so as to improve a low magnetic-field stability as well as to suppress an electric coupling between filaments in time-varying field.

The Development of MgB_2 Wire for Commercial Application

Hiroaki Kumakura
Group Leader of Advanced Superconducting Wires Group
Superconducting Materials Center

Magnesium diboride (MgB_2) is a compound that was already well-known in the 1950s and it has been sold as a powder reagent. However in 2001, Japanese researchers found that this metallic compound has a very high critical temperature (T_c) of around 40 K. Since then, it has been the focus of extensive basic and applied research.

The Many Advantages of MgB_2

Superconductors must be formed into wire for applications such as superconducting magnets and transmission cables, and here, MgB_2 offers many advantages. The high critical temperature is its main merit. But besides this, other benefits include the fact that there is no need for grain orientation such as with high-temperature oxide superconductors where the crystal grains are aligned when a large supercurrent flows from one crystal grain to the next. The raw materials are abundant and relatively cheap, and MgB_2 is mechanically strong and lightweight. Therefore research into making MgB_2 wire has been pursued aggressively around the world since the superconductivity of this material was discovered.

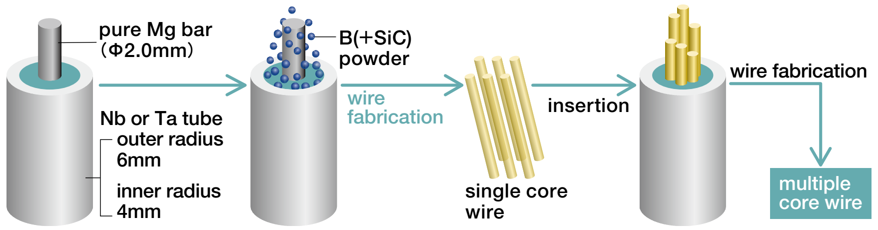
So how is MgB_2 formed into wire? The most common method is Powder-In-Tube (PIT) where the raw materials in powder form are packed into a metal tube and processed. However, in wire made with this method, the packing density of the MgB_2 core is not very high so that the connectivity between the MgB_2 crystal grains (the effective cross-section area for transporting current) is insufficient. As a result, the critical current density (J_c) required for practical applications has yet to be obtained.

Fabricating Good Wire with the Diffusion Method

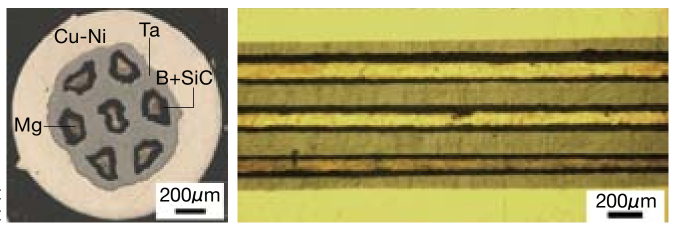
The connectivity between crystal grains depends significantly on the packing density of the MgB_2, and recently, the NIMS Superconducting Materials Center has developed a method for improving the packing density of MgB_2 in wire (Figure). This method is called the diffusion method since magnesium (Mg) is supplied from outside the boron (B) layer. Using this method, we have succeeded in obtaining wire with a higher J_c compared with wire made with the PIT method. First a pure magnesium rod is placed in the center of a metal tube, and the space between the magnesium rod and metal tube is filled as tightly as possible with amorphous boron powder. Then it is worked into a wire of about 1mm diameter by groove rolling or drawing. By bundling these wires together, inserting them in a metal tube, and processing them further, a wire with multiple cores can be fabricated. Magnesium is known as a hexagonal crystal with poor workability, but if it is handled in this way, it can be formed into wire without annealing. Finally, with heat treatment, the magnesium diffuses into the boron layer, forming MgB_2.

Look at the cross section photograph of the 7-core wire fabricated with the diffusion method. The MgB_2 layer obtained in this way has a higher packing density than an MgB_2 core obtained with the PIT method. And at 4.2 K in a magnetic field of 10 T, it achieves a J_c value of 10^5A/cm^2 or more, on a par with levels required for practical use. We intend to improve the diffusion method, conducting research towards fabricating long wires for practical applications.

Wire fabrication with the diffusion method



Cross section of 7-core wire fabricated with the diffusion method



FACE フェイス interview

As a front-line researcher in the development of superconducting wires, Managing Director Hiroaki Kumakura of Superconducting Materials Center has had a close-up view of the rapidly changing era that began with the fever caused by the discovery of high temperature superconductor, which created a sensation at the end of 1986, the difficult period that followed, and the recent discovery of iron-based superconductors. With his broad perspective, Dr. Kumakura discusses the fascination and difficulties of using the quantum phenomenon known as superconductivity in materials.

Hiroaki Kumakura
Managing Director, Superconducting Materials Center

The Past and Future of High Temperature Superconducting Materials

First, when did you become involved with superconducting materials?

After I joined the National Research Institute for Metals (NRIM: one of predecessors of NIMS) in 1978, my superior asked me if I wanted to work on superconductors, and I was attracted by the strokes in the character for "super." That's how I began working in this field.

At the time, the practical wire materials were limited to Nb-Ti (critical temperature, T_c = 10K), and Nb_3Sn (T_c = 18K). Nb_3Al was also known, but it was difficult to fabricate as a wire. However, because it maintains a high current density (J_c) in high magnetic fields, it was suitable to be used in high field magnets. Therefore, I took on the challenge of this material.

At first, this work went smoothly, but at the point when I had run into a wall, a high temperature superconductor of a lanthanum-based copper oxide with a T_c of 35K was reported by Bednorz and Mueller of IBM's Zurich Laboratory, and the Superconductivity was confirmed definitively by Prof. Shoji Tanaka's laboratory at the University of Tokyo. This was at the end of 1986. Over the several following years, there was a fever over superconductivity, and I, of course, and also the NRIM became deeply involved.

What was your first reaction on hearing this news?

It was a great shock to me, seemed to make our metal superconductors obsolete. Because copper oxide is a ceramic, I thought it might be quite difficult for a metallurgist to start working in this field until I got to know those materials could be produced easily.

In February of 1987, an yttrium-based high temperature superconductor was reported. The T_c of this material was over 90K, way over exceeding the boiling point of liquid nitrogen. Then, we started to research on wire fabrication using this material.

In January 1988, an NRIM group led by Dr. Hiroshi Maeda announced a bismuth-based copper oxide superconductor with a T_c of 110K. After that, we worked on developing a wire material from the high T_c bismuth-based material.

How did you proceed with the development of the bismuth-based material?

The J_c of the bismuth-based material decreases rapidly as the temperature increases in high field environments. Because this is an intrinsic problem which has its origin in the crystal structure of the material, it is difficult to apply to high field superconducting magnets that operate at the temperature of liquid nitrogen. However, if it were used at the temperature of liquid helium, we thought that the bismuth material would be more suitable than the conventional Nb_3Sn, because its critical field, or B_{c2}, is higher.

We proceeded with research to develop wires by aligning the crystal orientation and so on, and in 1995, we achieved a world's record of 23.4T when we introduced a bismuth-based superconducting magnet in the inner side of a metal-based superconducting magnet. One practical need is nuclear magnetic resonance, or NMR, because the resolution of NMR instruments increases as the magnetic field becomes more powerful. Last year, we succeeded in observation of an NMR signal with a magnet incorporating a compact bismuth-based magnet. This was a world's first with a high-T_c oxide material. Our goal is to exceed a frequency of 1GHz at 23.5T.

As another direction for bismuth-based superconductors, development of power transmission cable using liquid nitrogen cooling is progressing worldwide. In power transmission, there is virtually no magnetic field, and a temperature margin between the T_c and the boiling point of liquid nitrogen is large.

What about competition with other high temperature superconductors?

Development of yttrium-based oxide wire is also in progress, but I think mutual competition is important. In the 10-plus years since the fever over copper oxide superconductors, public and governmental enthusiasm cooled, and the times continued to be difficult. However, Prof. Jun Akimitsu at Aoyama Gakuin University discovered MgB_2 (T_c = 39K) in 2001. We are also engaged in wire development using this superconductor.

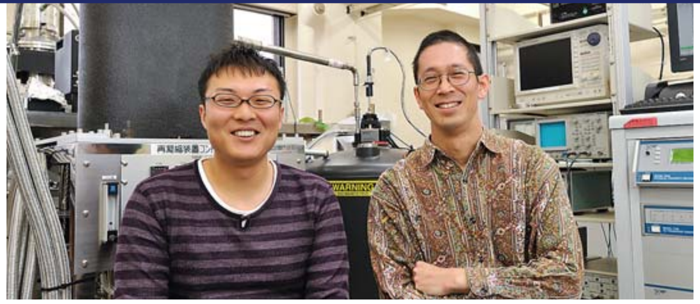
The conditions for a practical superconducting wire are high T_c, B_{c2}, and J_c, easy workability, mechanical strength, and low cost. Although there is still no material that completely satisfies all of these requirements, iron-based superconductors have already been discovered, and there may also be further discoveries.

Finally, do you have any words for young researchers?

Have a "research style" that's based on your own thinking. Go forward with an independent style and convictions -that's the only road.

Discovery of New Fe-based Superconductor $FeTe_{1-x}S_x$

Nano Frontier Materials Group,
Superconducting Materials Center



Yoshikazu Mizuguchi Group Leader Yoshihiko Takano

In February 2008, a group under Prof. Hideo Hosono at Tokyo Institute of Technology discovered that an Fe-As compound, LaFeAsO, displays a superconducting transition at an absolute temperature of 26K. In spite of the fact that the compound contains iron, which had been considered disadvantageous for superconductivity because it is magnetic, this material attracted worldwide attention due its relatively high superconducting transition temperature (T_c) and spurred a boom in research on Fe-based superconductor. Immediately after this discovery, it was found that SmFeAsO, in which La is replaced with Sm, displays an even higher T_c of 55K. As a result, high expectations have been placed on the Fe-based materials as new high temperature superconductors succeeding the copper oxide-based materials.

The crystal structures of the main Fe-based superconductors discovered to date are summarized in **Fig. 1**. Here, (a), (b), and (c) have a common FeAs layer (superconducting layer), and superconductivity occurs in this layer. The T_c of these three materials differs greatly, as the T_c of (a) is 55K, that of (b) is 38K, and that of (c) is 18K, showing that T_c is strongly dependent on the crystal structure between the FeAs layers.

The FeSe in **Fig. 1** (d) is a T_c = 13K superconducting material with a structure that resembles the FeAs layer. We focused on FeSe because it has the simplest crystal structure in Fe-based superconductor, but does not contain arsenic. When the lattice is compressed by applying pressure at approximately 40,000atm, we discovered that the T_c of FeSe increases to 37K, that is the highest class of T_c among the binary superconductors. In addition, our attention was also drawn to FeTe, which does not display a superconducting transition even though its crystal structure resembles that of FeSe. When we replaced the Te site with 20% S, which has a small ion radius, we made the new discovery that $FeTe_{0.8}S_{0.2}$ displays superconductivity when the lattice is slightly compressed.

One of the attractive features of Fe-based superconductor is the diversity of superconducting layers. In addition to the FeAs, FeP, and FeSe layers which were discovered previously, we found that the FeTe layer also shows superconductivity. In the future, it may be possible to realize even higher superconducting transition temperatures than those to date if superconducting layers with new structures and new combinations of elements can be discovered. Thus, research on Fe-based superconductor truly has great potential.

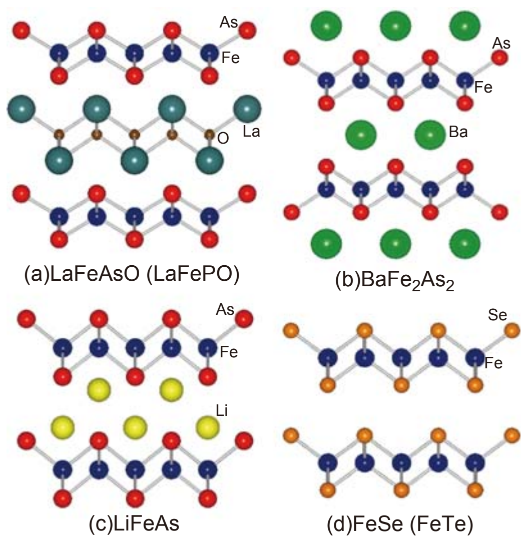


Fig.1 Crystal structures of various Fe-based superconductors. The respective T_c are (a) 55K, (b) 38K, and (c) 18K. The T_c of (d) FeSe is 13K, but this increases to 37K under pressure.

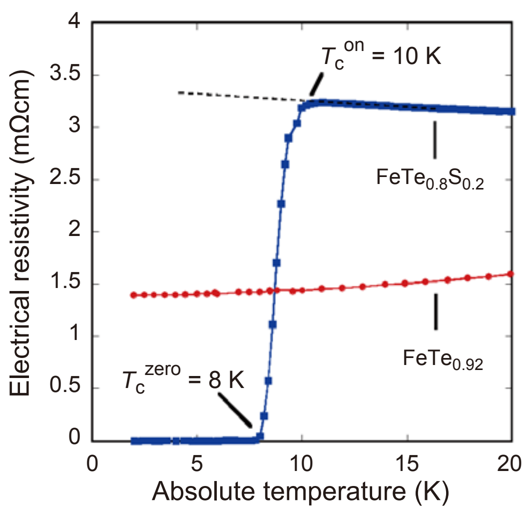


Fig.2 Temperature dependence of electrical resistivity in $FeTe_{0.8}S_{0.2}$. A zero resistance state was observed at temperatures of approximately 8K and below.

Research Highlights

NMR Measurements of Protein using a High T_c Superconducting Coil

Magnet Development Group,
Superconducting Materials Center
RIKEN,† Kobe Steel, Ltd.,†† JOEL, Ltd.†††

Group Leader
Tsukasa Kiyoshi, Hideaki Maeda,† Mamoru Hamada,†† Masami Hosono†††

An NMR (nuclear magnetic resonance) spectrometer is a powerful tool for analyzing the structures of organic compounds. NIMS improved the Nb_3Sn superconductors, leading to the development of 920MHz (21.6T) and 930MHz (21.8T) NMR magnets. Because the Nb_3Sn conductor is already being used near its critical magnet field, any large increase in the magnetic field would be difficult. As high T_c superconductors (HTS) exhibit large critical current even in fields exceeding 30T, we attempted to apply an HTS coil to an NMR magnet.

In conventional NMR magnets, conductors with a square or round profile are wound in an aligned manner without spacing (layer-winding), and the magnet is operated in the persistent current mode in order to maintain the spatial homogeneity and temporal stability of the magnetic field. In case of Bi-2223 conductors, layer-winding is difficult because of its tape shape. Furthermore, due to the resistance of the conductor itself and the joints between conductors, the magnetic field is greatly decreased in the persistent current mode, making high quality NMR measurement impossible.

We used bronze-reinforced Bi-2223 conductors. (**Fig. (a)**) This not only improves the mechanical strength of the conductor, but also increases the thickness of the conductor, enabling layer-winding. The wound coil was replaced with the Nb_3Sn innermost coil of a conventional NMR magnet, and was operated at 11.7T (corresponding to 500MHz) using a power supply with high stability 20 times greater than that of the conventional type. Even when the power supply with excellent stability was used, fluctuations occurred in the field due to noise and ambient temperature change. Furthermore, a phenomenon in which the central magnetic field gradually increased due to magnetization of the Bi-2223 coil was also observed. However, it was possible to solve these problems by detecting the changes in the magnetic field and applying compensation techniques. **Fig. (b)** shows a result obtained with the developed NMR spectrometer by the NOESY* technique of an aqueous solution sample of lysozyme. Although NOESY is the most important measurement for obtaining the 3-dimensional structure of proteins, good signals cannot be obtained if the field stability and homogeneity of the NMR spectrometer are poor. The result shown in the **figure** is comparable to the results obtained with NMR spectrometers operating in the persistent current mode using low T_c superconducting coils.

In this research, we successfully demonstrated the application of a bismuth-based superconducting material discovered at NIMS to an NMR magnet, which is considered to require the most difficult magnetic field conditions. We plan to develop an "above 1GHz" NMR spectrometer, which will be a first step toward ultra-high field NMR spectrometers and can demonstrate the usefulness of HTS. Applying the developed technology to MRI (magnetic resonance imaging) and other measurement instruments is also expected.

This research was supported by SENTAN, JST.

* NOESY: Nuclear Overhauser Effect Spectroscopy

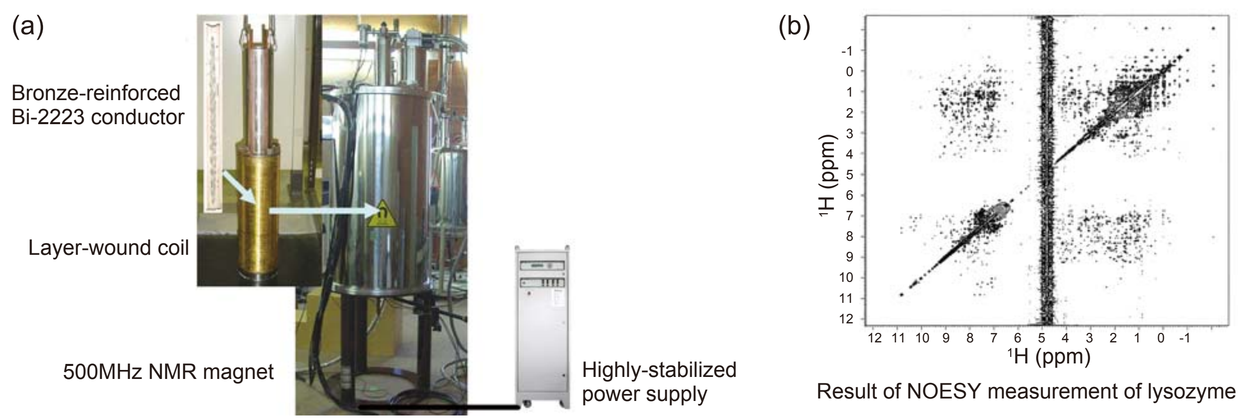
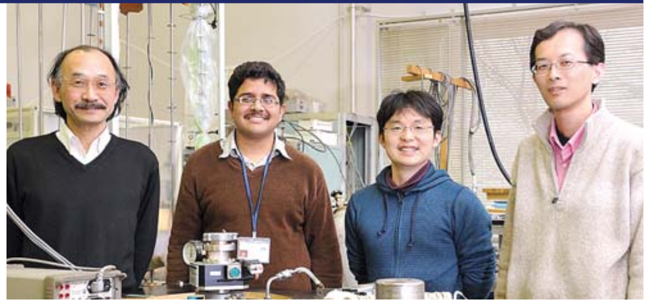


Fig. NMR magnet containing a high T_c superconducting coil and an example of NMR measurement.

Rectification Controlled by Vortex Dynamics Control

Physical Properties Group,
Superconducting Materials Center

Group Leader
Kazuto Hirata, Ajay Thakur, Shuuichi Ooi, Takashi Mochiku



Superconductors are classified as Type I or Type II. In the Type II superconductors, the magnetic field penetrates into the superconductor in a quantized form. The supercurrent flows around the quantized magnetic flux line in a vortex-like shape, and is termed a "vortex" based on this structure. The copper oxide-based high temperature superconductors first discovered by J. Georg Bednorz and K. Alex Mueller in 1986 include many types, and the majority of these, as shown in **Fig. 1**, form a crystal structure in which superconducting layers and non-superconducting layers are stacked in a layered manner. When a magnetic field is applied perpendicular to the superconducting layers, the vortex (line) separates in the perpendicular directions to the layers, and precisely resembles a stack of pancakes (**Fig. 1**, left). This is called a "pancake vortex." On the other hand, when the magnetic filed is applied parallel to the layers, vortices penetrate between the layers (**Fig. 1**, right). This is called as a "Josephson vortex." The Josephson vortices exist between the superconducting layers and move between the layers (left-right direction in the **Fig. 1**, right). These vortices can move at an extremely fast velocity, approaching the speed of light.

By the way, if hole-arrays with a nanoscale period are introduced in a superconductor by micro-processing (**Fig. 2**, photos), vortices are captured in the holes, or, stopped between the holes by the attraction that acts between the vortices and holes and the repulsion that acts between vortices (**Fig. 2**). This resembles the state in which the electrons in a crystal are attracted by atoms, while mutual repulsion acts between pairs of electrons. Today, rectification is one function in which semiconductors are used as electronic devices called "diodes." A function similar to this can also be imparted to vortices. Previously, rectification in one direction had been observed when a spatially asymmetrical hole-array was fabricated in a superconductor and the vortices were driven with an alternating current. However, it has also become possible to realize bidirectional rectification, even with symmetrical hole-arrays (**Fig. 2**, photos), by applying a time-asymmetrical alternating current (**Fig. 3(a)**). Furthermore, with the copper oxide-based high temperature superconductor shown in **Fig. 3**, pancake vortices and Josephson vortices can be made to coexist, and a large rectified voltage (**Fig. 3(b)**) could be obtained by using a multilayered structure. Because the Josephson vortices can move at an extremely high speed, it is expected to be possible to realize electronic devices that combine extremely high speed and energy saving performance in comparison with the conventional electronic devices if the movement of the Josephson vortices is controlled utilizing nano-processing techniques.

Dr. K. Hirata was awarded the 2008 "Superconductivity Science and Technology Prize" of the Society of Non-Traditional Technology (SNTT) for his achievements, including this research.

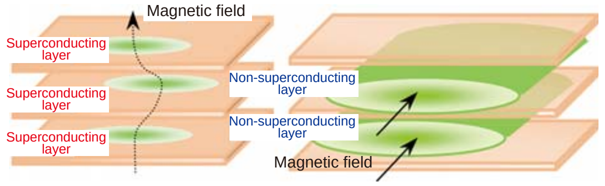


Fig.1 Schematic diagram of the vortices in an oxide high temperature superconductor, showing the case where the magnetic field is perpendicular to the superconducting layer (left) and parallel to the superconducting layer (right).

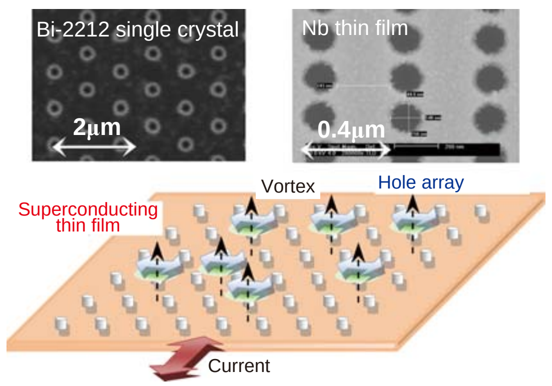


Fig.2 Vortices move in a hole array in superconductor thin films (see photos) when driven by an electrical current.

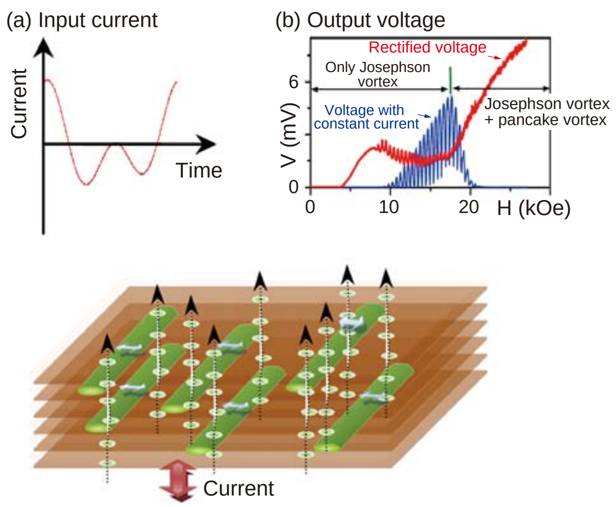


Fig.3 Coexistence of pancake vortices and Josephson vortices. (a) shows a time-asymmetrical input current, and (b) is the rectified output voltage.

New Auditor

Kenji Haga

Doctor of engineering, Graduate School of Science & Engineering, Waseda University (1974).

Joined Nihon Oil Seal K.K. (1971, Now: NOK Corporation), named Auditor (2004), is an Adviser since June 2008.

Appointed Auditor (part-time) of NIMS in April 2009.

Comments on Appointment

After 30 years of involvement in R&D and technology for the creation of new businesses, I had worked as a full-time Auditor for 4 years at NOK Corporation. I was appointed part-time Auditor of NIMS in April 2009. NIMS is expected to create unprecedented new materials and contribute to human progress through new products which are useful in society. As an Auditor, I would like to devote my efforts utilizing my experience, so that NIMS can carry out its research activities more effectively and efficiently toward realizing practical applications with true value.

New Fellows

Eiji Muromachi

Doctor of Science. Completed Master course of the Graduate School of Engineering, Tohoku University.

Joined NIRIM* in 1977. Senior Research Officer of No. 11 Research Group, then Supervising Reseacher, Director General of the Advanced Materials Laboratory, and Deputy Director-General, MANA(2007), Group Leader, Principal Investigator at MANA (2008). Named NIMS Fellow in April 2009.

Comments on Appointment

Since I became a researcher, I have consistently been engaged in the search for and development of new materials. In particular, the report by Bednorz and Mueller in 1986 led to my involvement in research on high temperature superconductors. Fortunately, I was able to find many new high temperature superconductors which are stable only under high pressures thanks to the high pressure synthesis techniques at NIMS (and NIRIM). Recently, iron-based superconductors became a hot topic of scientific community worldwide. As a Fellow, I hope to produce results, including this new field.

Takayoshi Sasaki

Doctor of Science. Completed Master course of the Graduate School of Science, University of Tokyo.

Joined NIRIM* in 1980, Senior Researcher of the 7th Research Group, Director of the Soft Chemistry Group, then Managing Director of the Nanoscale Materials Center. Coordinator of the Nanomaterials Field, MANA (2008). Named NIMS Fellow in April 2009.

Comments on Appointment

Since I started research at NIRIM, I have always been involved in topics related to layered materials. In steady effort involving the synthesis of various kinds of layered materials and exploration of their structures and properties, I encountered unexpected developments such as exfoliation reactions, nanosheets, and others. Encouraged by being named a NIMS Fellow, I hope to further develop my research, take on challenge of discovering unknown phenomena and new functions, and pursue the possibility of applications and practical applications of materials.

*NIRIM: National Institute for Research in Inorganic Materials, one of NIMS's predecessor organizations

NIMS Receives a Certificate of Appreciation from JAXA

(March 19, 2009) NIMS recently received a Certificate of Appreciation from the Japan Aerospace Exploration Agency (JAXA) in recognition of the significant contribution of NIMS's research achievements to the improvement of the reliability of JAXA's H-IIA and the development of its H-IIB launch vehicle.

Representatives of NIMS and JAXA

In the past, JAXA had used the literatures and foreign databases for materials data for the design of its launch vehicles. JAXA was able to modify its design standards and improve the properties of its materials by using NIMS' evaluation data of the actual materials to be used in its liquid hydrogen-fueled engines, resulting in greatly improved reliability in the H-IIA engines, and successfully reduced the number of engine test-firings by estimating the remaining life of the structural materials after tests.

Since the year 2000, NIMS and JAXA have collected and evaluated data on the strength, toughness, and fatigue properties of the metal materials for liquid-fueled engines under environments ranging from cryogenic to high temperatures, and have published 11 datasheets and two photo collections of facture surfaces which are available to the general public. These efforts are also contributing to maintaining quality targets of the engine materials and manufacturers of the engines. In the future, evaluation of materials for a next-generation liquid-fueled engine (the LE-X engine) is also scheduled.

President Kishi receives the Nishiyama Medal from ISIJ

(March 28, 2009) President Prof. Teruo Kishi recently received the Academic Prize (Nishiyama Medal) of the Iron and Steel Institute of Japan (ISIJ). The Award Ceremony and a Memorial Address were held on March 28.

The Nishiyama Medal is given to persons with distinguished accomplishments in scientific and technical research related to iron and steel. President Prof. Kishi received this award in recognition of his long record of research achievements in connection with destructive and nondestructive evaluation of iron and steel materials.

At the awarding ceremony

Hello from NIMS

From my very boyhood, Japan was known to me as the country of sunrise. I came to Osaka University as a Monbusho student in 1994. During my four year stay in Osaka, I had chances to experience different seasonal festivals like Hana-mi (flower-viewing), Hanabi (fireworks) and Oshogatsu (New Year's holidays), and I also visited many memorial and sightseeing places, especially Kyoto, Nara, Mie, Hokkaido, Hiroshima and Nagasaki. Before I came to NIMS, I spent four years at the National Institute of Advanced Industrial Science and Technology (AIST), Tsukuba and then seven years at Sharp Corporation, Nara where I enjoyed Japan's modern technologies through my research on Photovoltaic Technology. Now, I am enjoying both research and the international atmosphere of NIMS. During my long stay in Japan I was moved by the warmth of Japanese culture and helpfulness of the Japanese people more than the fact that we find Japan a very safe place to live. That is the reason we decided to stay in Japan and raise our two boys, Wasif and Tausif, here. I like traveling and fishing. In summer, I usually go camping with my family and enjoy fishing and BBQ.

Ashrafu Islam (Bangladesh)
Dye Sensitized Solar Cell Group,
Advanced Photovoltaics Center
September 2008 - present

[At Universal Studios Japan]

[My sons with friend at Undokai (school sport festival)]

NIMS NOW International 2009.Vol.7 No.4
National Institute for Materials Science
http://www.nims.go.jp/eng/news/nimsnow/

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