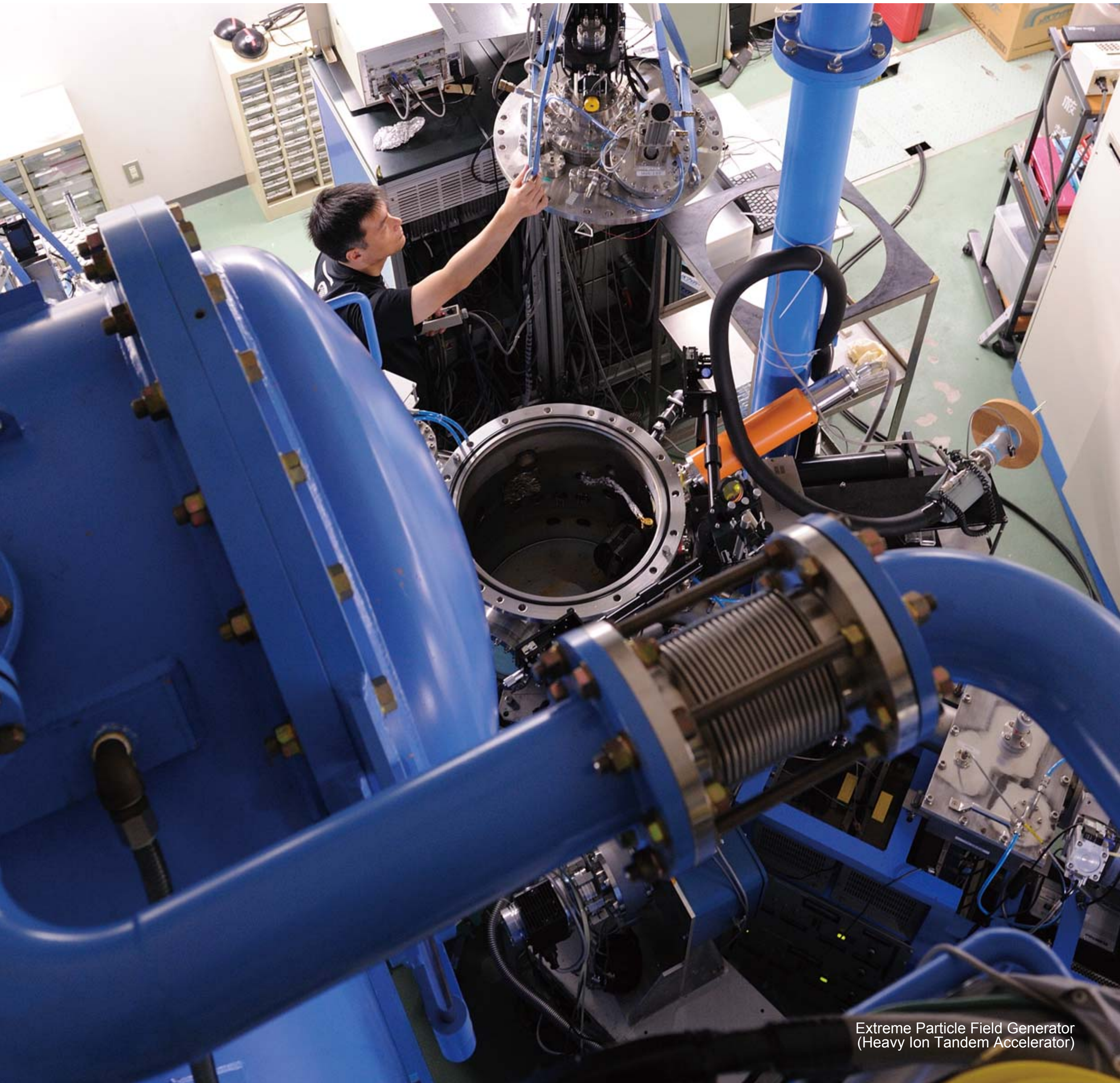
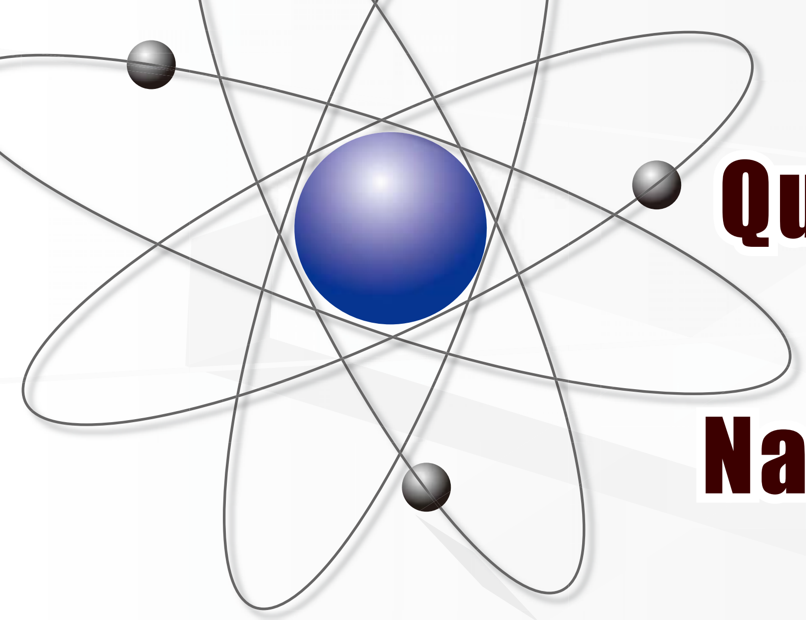
NIMS NOW International

2009. December

Quantum Beams Opening Up Nano-innovation



Extreme Particle Field Generator
(Heavy Ion Tandem Accelerator)



Quantum Beams Opening Up Nano-innovation

Managing Director of the Quantum Beam Center
Naoki Kishimoto

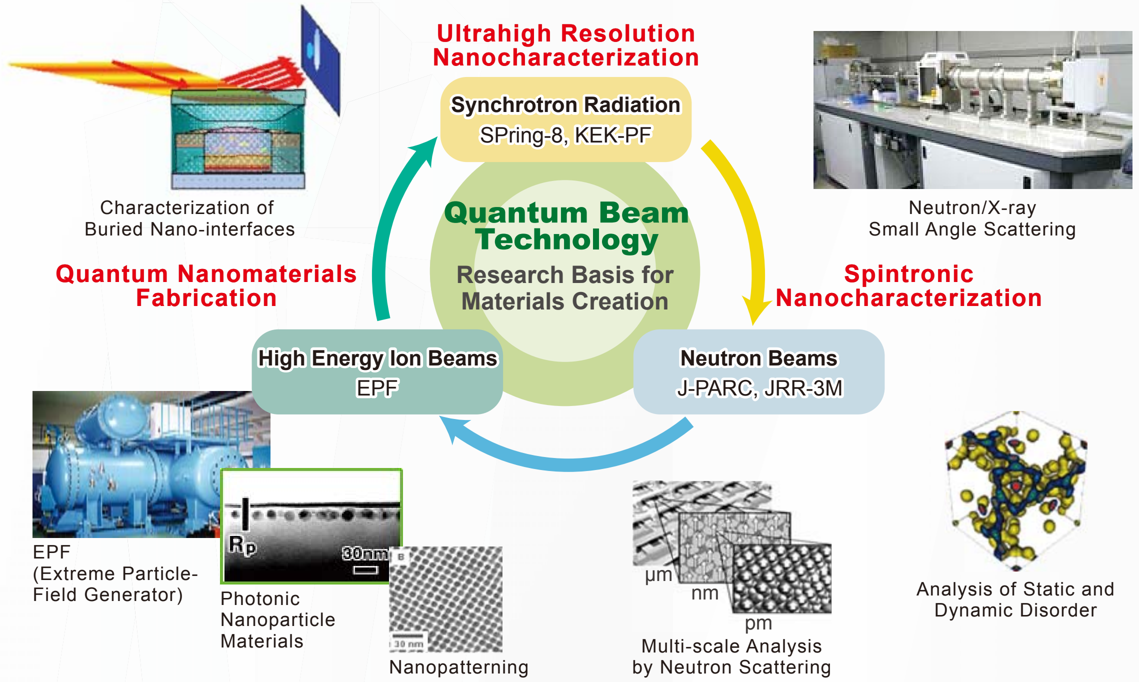
What is a Quantum Beam?

A "quantum" is the smallest discrete unit of a physical quantity that expresses the property of a material and that displays either "particle characteristics" or "wave characteristics". A "quantum beam" is a "controlled ray" of such quanta. In practice, the quantum beam is generic naming for photon, ion, neutron, or electron beams, which are produced in such sources as particle accelerators, lasers or nuclear reactors.

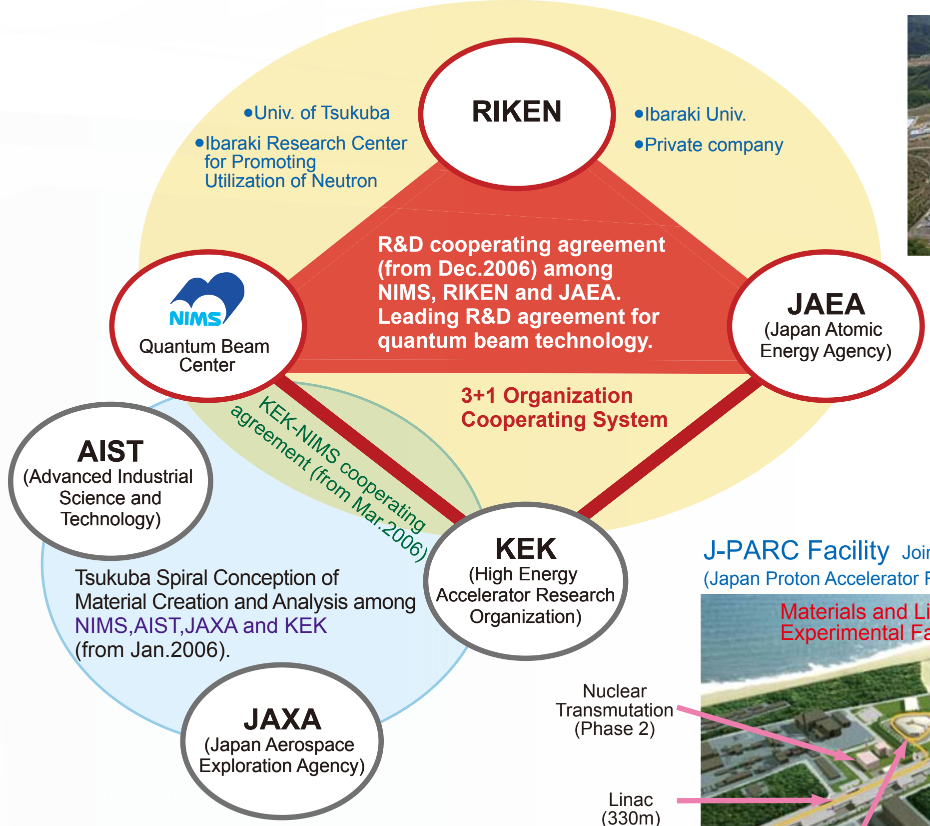
A material shows quantum behavior on the atomic or molecular scale. The radiation of a quantum beam has high resolution/sensitivity, transmission, and coherence with respect to atoms, molecules and their ensembles (crystal, amorphous, polymer etc.), and provides unique reactions such as diffraction, magnetic scattering, or the injection of extrinsic atoms. If we measure or use these elementary processes, highly accurate characterization of materials, or even creation of novel materials becomes possible.

Each quantum beam differs in the particle- vs. wave natures and in how much spin it has etc. If we skillfully complement these different quantum beams with each other, it becomes capable to measure and create novel materials.

R&D of Quantum Beam Center in NIMS



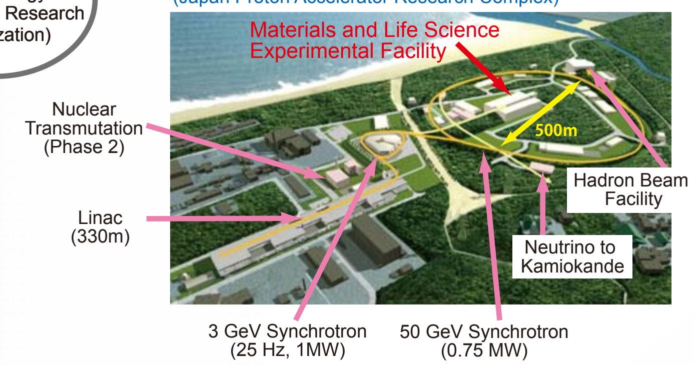
All-Japan R&D cooperation for the quantum beam technology



Whole view of SPring-8. The storage ring with a circumference of about 1.4km surrounds Mihara Kuriyama hill; the arrow points to the NIMS beamline BL15XU.

Courtesy of SPring-8

J-PARC Facility Joint Project between KEK and JAEA (Japan Proton Accelerator Research Complex)



Courtesy of JAEA/KEK J-PARC Center

Applying Quantum Beams to Nanotechnology

In the NIMS Quantum Beam Center, we are carrying out synthetic R&D with high- brightness synchrotron radiation, neutron beams, ion beams and atomic beams.

The synchrotron radiation has very high intensity/brightness and its high parallelicity in the range of soft X-ray to hard X-ray. If we irradiate materials with this radiation, we can quickly find out their precise crystalline structures. Furthermore, if we selectively excite particular energy states, it is capable to carry out an extremely precise analysis of the electronic states. Recently, real-time structural analysis for microscopic regions have been intensively performed with a depth-resolution down to the sub-nanometer level.

Since the neutron beam has strong penetratability, and is scattered by the atomic nucleus, we can use it to distinguish light elements and isotopes. Also, since it has both the wave-and particle natures, it is useful for such things as microstructural analyses of atomic arrangements including light elements, magnetic materials, and multi-phase structures, over a wide range of length scale.

The ion beam, precisely controlling the projectile range of arbitrary elements, can give novel functionality on a nano-scale. Furthermore, the excited neutral atomic beam, with polarizing the spins, has successfully been utilized for nano-characterization.

Thus the quantum beam technology can diagnose the nano-scale world and directly control nano-materials. In recent years, there has occurred an active movement centered in Europe and US to promote nanotechnology with the quantum beam as its key.

Also in Japan, the pulsed neutron source, J-PARC, has launched, and there rises a new demand throughout the country to synthetically develop and use the quantum beams. The three forerunners in this field, the JAEA,NIMS and RIKEN, as the core of cooperation, are promoting the development of nanotechnology using quantum beams, centering on complex electronic-system materials, and fuel cell materials. In Japan, we should strategically promote the development of quantum beam-based technology to create innovations, especially in the field of materials science and technology, in order to strengthen the international competitiveness of industry.

New Opportunities in Materials Research with Synchrotron Light Source

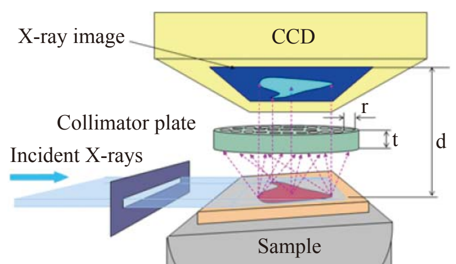
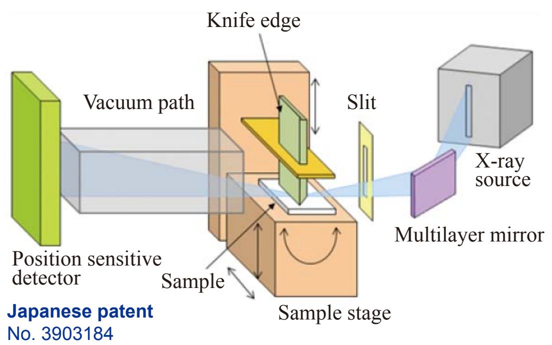
Kenji Sakurai Synchrotron X-ray Group, Quantum Beam Center

New advanced light source with extremely attractive properties such as brilliant, parallel, polarized and short pulsed beams

Synchrotron radiation is an electromagnetic wave emitted from a circular or linear accelerator where electrons or positrons are boosted to extremely high energy levels, close to the speed of light. After Rutherford's discovery of the atomic nucleus in 1911, physicists displayed a keen interest in various theories as to the structure of the nucleus. A high-energy accelerator was subsequently developed as one of the most promising tools for examining those proposed theories experimentally. At first, synchrotron radiation was considered a nuisance, because the emission of synchrotron radiation simply entails a loss of energy, thereby imposing a limit on the maximum velocity of the particles. However, later, it was found that synchrotron radiation constituted a wonderful light source. The spectrum of this electromagnetic wave includes the terahertz, visible, ultraviolet, vacuum ultraviolet, and X-ray regions. The light was found to be much more brilliant than other conventional light sources, and the beam has parallel, polarized, and pulsed structures. In the vacuum ultraviolet and X-ray regions, synchrotron radiation is the best of existing light sources. As such attractive properties are useful in scientific research as well as industrial and medical applications, many accelerators dedicated solely to providing synchrotron radiation (not for high-energy physics) have now been built all over the world. In April 2009, an X-ray laser that appears to have come from the realm of science fiction was at last realized at the SLAC National Accelerator Laboratories in Stanford, United States. This X-ray laser marks the start of a new generation of synchrotron light sources.

Live Measurement with Synchrotron Radiation

In modern materials science, the strongest way of discovering promising new materials is to employ state-of-the-art analytical techniques and instruments. When it becomes possible to detect and visualize previously unknown phenomena in materials, we will be able to proceed to the next stage both in science and in industry. Synchrotron radiation has an important role in these advancements. At NIMS, extremely rapid real-time X-ray measurements are under way in many kinds of environments. We have even succeeded in X-ray movie imaging of the chemical composition and crystal structures of inhomogeneous changing systems. We have also developed a new instrument for conducting live analysis of the surface and interface of thin films and multilayers. Such in-house developed techniques need to be polished further for use in more realistic applications. We will continue working in order to make a significant contribution to progress in materials research. In the case of much faster phenomena that cannot be caught by live measurement, e.g., structural phase transitions, generation of some functionalities, chemical reactions etc., it is necessary to take a different route. We plan to develop a new spectrometer for time-resolved measurement by using synchrotron X-ray pulses.

	Imaging of chemical composition and crystal structure	Surface and interface structures of thin films and multilayers
Principle	 Japanese patents No.3049313 No.3663439 No.3834652	 Japanese patent No. 3903184
Available information	Mapping of elements, chemical states of elements and crystal structures in the viewing area of the specimen	Non-destructive depth profiling of thin films and multilayers in terms of electron density (density and thickness of each layer, roughness of surface and each interface etc.)
Main features	Realtime imaging of quite wide area (~cm^2) with high resolution (1000×1000 pixels or even more) without XY scan of the sample. Measuring time 0.03~ 1 sec. Spatial resolution 15 micron	Realtime X-ray reflectometry. Measuring time 0.1~20 sec
Applications	Combinatorial materials screening Safety diagnostics of materials Scientific research on non-equilibrium and non-linear systems	Quality control of industrial products Monitoring of thin film growth and function evaluation Scientific research on anomalous phenomena such as phase transitions of surface and interfaces
Remarks	World first X-ray movie imaging of elements by using synchrotron X-rays at KEK	Achievable even with a laboratory X-ray source

Structure Analysis of Materials Performed at SPring-8

Keisuke Kobayashi Station Leader, NIMS Beamline Station

SPring-8; The World's Top Class Performance

The large synchrotron radiation facility, so-called SPring-8 (Super Photon ring-8 GeV), in Hyogo prefecture, has been in operation since 1997. 8 GeV stands for 8 giga electron volts, being the electron energy in the storage ring and shows the highest performance in the world. At present, about 50 beamlines are in operation, and BL15XU, one of them, is the NIMS contract beamline. BL15XU is equipped with the revolver undulator, which generates phase-coherent-radiation, can cover a wide energy range from 2.2 to 36 keV **(Fig. 1)**. At BL15XU, there are two experimental systems of: high-resolution powder X-ray diffraction (XRD) and hard X-ray photoelectron spectroscopy (HXPS).

The high-resolution powder X-ray diffractometer with the angular resolution of extremely high at 0.003 degrees has been used in the structural analysis of various complicated materials, helping in the R&D for functional materials. **Fig. 2** shows the structural analysis result of the new layered lanthanoid hydroxide synthesized by Takayoshi Sasaki, Fellow of the International Center for Materials Nanoarchitectonics (MANA). Due to the large unit cell with a complicated structure, the determination of the crystal structure could not be analyzed by using a conventional powder X-ray diffractometer while the crystal structure analysis was succeeded through the XRD measurements at BL15XU.

Fig. 1 Photograph of the revolver undulator for the NIMS contract beamline BL15XU.

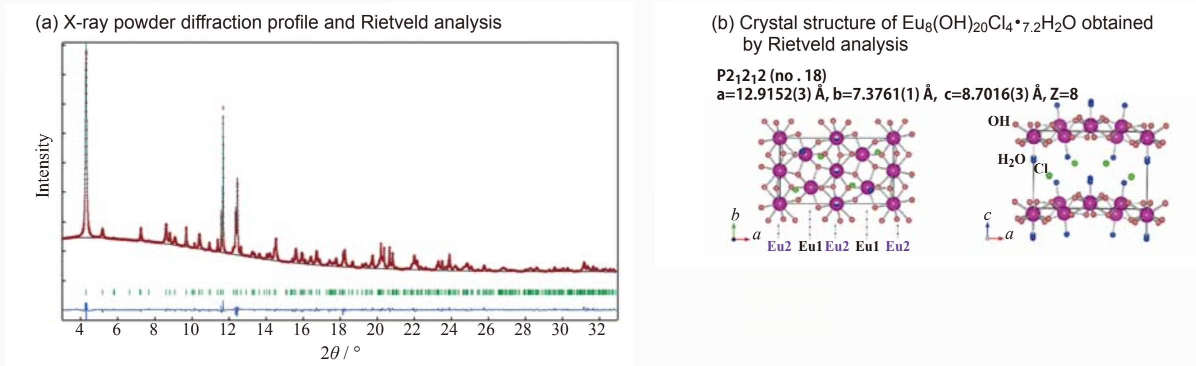


Fig. 2 Crystal structure of new layered lanthanoid hydroxide with anion exchange feature. The result was obtained from the high-resolution powder X-ray structural analysis of $Eu_8(OH)_{20}Cl_4 \cdot 7.2H_2O$ crystal.

(F. Geng *et al*., Chem. Eur. J. **14**, (2008), 9255. F. Geng *et al*., J. Am. Chem. Soc. **130**, (2008), 16344. F. Geng *et al*., Inorg. Chem. **48**, (2009), accepted.)

High Precision Analysis of Both Electronic and Chemical Bond States

High-resolution HXPS has been developed at SPring-8 since 2002. Conventionally, by using photoelectrons excited by ultraviolet light or soft X-rays, photoelectron spectra give us the surface electronic states of materials. By the use of hard X-rays for photoemission experiments (HXPS) as an excitation light source, HXPS allows one to prove bulk electronic states of materials. Utilizing this large proving depth of HXPS, we can examine the bulk electronic and chemical bond states even without applying any surface cleaning treatment. For example, the half-metallic Heusler alloy Co_2MnSi based device, which has been developed for the high tunnel magnetoresistance devices, has the MgO overlayer with a maximum thickness up to 20 nm **(Fig. 3)**. One can see that HXPS enables us to measure the electronic structure of the varied Heusler compound.

Thus, we can perform high precision experiments to examine the structure of materials, electronic states, and chemical bond states at BL15XU of SPring-8. We can expect many leading-edge results from our research using XRD and HXPS apparatuses, seen nowhere else in the world,.

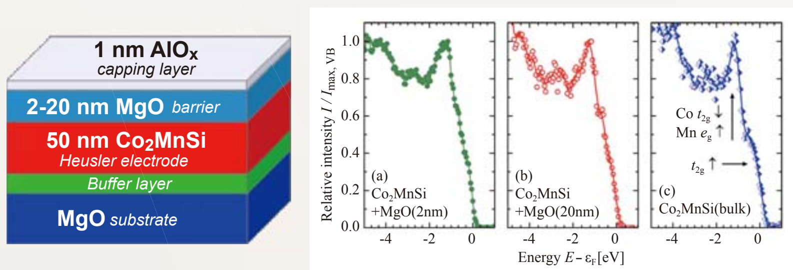


Fig. 3 Experimental results of the magnetic tunnel device using hard X-ray photoelectron spectroscopy (HXPS). The sample was a 50nm thick half-metallic Heusler alloy Co_2MnSi with an overlayer of 2 to 20nm thick MgO grown on a MgO substrate, then covered with a 1nm AlO_x layer.

(G. H. Fecher *et al*., Appl. Phys. Lett., **92**, (2008), 193513)

A New Field in Materials Research Opened Up by Neutron Beams

Hideaki Kitazawa Group Leader, Neutron Scattering Group, Quantum Beam Center

Neutron beams are scattered by the nucleus and magnetic moments in materials

A neutron with a neutral charge, which is smaller particle than the atom, displays a larger penetration depth than that of an α particle or an X-ray. When the neutron is generated from a nuclear research reactor via a proper moderator, e.g. paraffin and water etc., the neutron with few dozens of meV of energy (thermal neutron) exhibits diffraction and interference phenomenon just like light or sound waves. Since the wavelength of the thermal neutron is about 0.1~0.3nm, like that of X-ray, it can be used for analyzing the structure of crystals.

Although both waves have the similar wavelength, x-rays are scattered by the electrons in materials, whereas neutrons are scattered by the atomic nuclei in the material. In other words, scattering objects are very different. The X-ray scattering length for light elements such as hydrogen, lithium and oxygen, is less than that for heavier elements. On the other hand, the neutron has comparable scattering length for both elements. Therefore, it is useful to determine the position of such as water molecules in protein and the lithium in lithium batteries. And for these reasons, there are high expectations for its use in development of research relating to life sciences, environment, and energy. Also, by using the spin (micro magnet) of the neutron and the energy transfer of the thermal neutron, we can examine magnetic structures of the magnetic materials and the appearance of the lattice or the molecular vibrations, respectively.

Recent research topics: Observation of the magnetic structure of multiferroic materials

In recent years multiferroic materials in which ferroelectricity coexists with ferromagnetism have been attracting much attention. Multiferroic materials can control polarization of electricity in a magnetic field, and magnetization in an electric field, so it is envisaged that they can be developed into low power consumption control components and high-speed large capacity memory components.

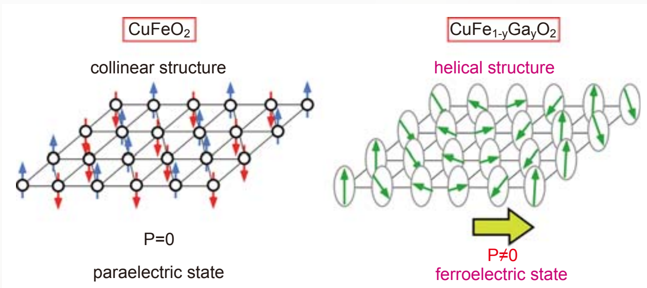


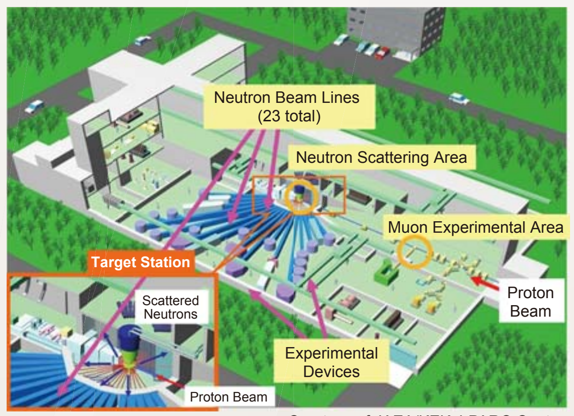
Fig. 1 $CuFeO_2$, consisting of only up-spin and down-spin collinear magnetic structures, does not show electric polarization (P=0), but if some of the Fe sites in $CuFe_{1-y}Ga_yO_2$ are substituted by the nonmagnetic Ga ion the magnetic structure takes on a helix structure with a strong dielectric state ($P \neq 0$).

The multiferroic material $CuFeO_2$ at low temperatures displays antiferromagnetical ordering which the magnetic moments aligns either upwards or downwards **(Fig. 1)**. The ferroelectricity appears when a large magnetic field of about 6 tesla is applied, but the reason for this is still not understood. We discovered that, if we replaced several percent of the iron (Fe) magnetic ion with gallium (Ga) nonmagnetic ion, ferroelectricity was displayed even without applying a magnetic field. Also, when we examined the spin structure in the material by a neutron diffraction experiment, we found the spin sequence underwent a large change when we substituted in a nonmagnetic ion, and we understood this to be the main cause of the appearance of the ferroelectricity.

(N. Terada et al., Phys. Rev. B, 78 (2008) 014101. Selected for editor's suggestion)

Towards a new age of high intensity pulsed neutron beams

With the neutron beams from nuclear reactors, because strength has been low, a long time for measurement and a large sample have been required. On the other hand, in 2008,Materials and Life Science Experimental Facility (MLF) with a spallation neutron source in J-PARC (Japan Proton Accelerator Research Complex) **(Fig. 2)**, began operation, and in several years they will realize the strength of neutron beams to reach an average of 5 times, with a peak strength of over 100 times that of the nuclear reactor JPR-3 now operating in Tokai village. The desire of our Neutron Scattering Group is to contribute to neutron and materials research, to open up new fields, and using this strong neutron beam, to elucidate the origin of the properties of matter and to develop useful materials.



Courtesy of JAEA/KEK J-PARC Center

Fig. 2 Basic concept of MLF in J-PARC. The world highest intensity pulsed neutron beams are produced by impact of pulsed proton beams with 3 GeV of energy to a mercury (Hg) target. The many experimental apparatus are radially installed.

Ion Beams, the Key to Nanomaterial Creation

Naoki Kisihimoto Managing Director, Quantum Beam Center, Group Leader, Ion Beam Group

A core technology in nano-electronics

An ion beam is a bundle of charged atoms. The ion irradiation not only injects extrinsic atoms into a material, but also conveys strong energy. Compared with light or electron beams, ion beams have a much shorter de Broglie wavelength, having a negligible wave nature so that they show very little blurring due to diffraction, and good spatial resolution.

This technology was originally developed as a tool for elementary particle/nuclear physics, but from the 1960s, it came to be used for implanting impurities into semiconductors. Since then, it has been a core technology for controlling electrical conductivity in the processing of semiconductor electronic devices.

Breaking the limits of nanofabrication

Semiconductor integrated circuits are becoming increasingly tinier and more sophisticated, and Moore's Law states that the level of integration doubles every eighteen ~ twenty-four months. The main technology behind this development has been photolithography, where a pattern is formed by applying a photoresist on the surface and exposing it to light. The limit of miniaturization is thought to be some 10 nm, but since this value is shorter than the wavelength of the light used in lithography (200 nm to 400 nm), it has been already close to the limits of the technology. Currently, competition in the field of nanofabrication development is focused on combination of the top-down methods with bottom-up methods using single atoms as building blocks.

However, we believe that ion beams will prove the most effective means of achieving a breakthrough. Until now, ion beams have been used for broadly and uniformly irradiating semiconductor wafers, while microfabrication has relied on lithographic techniques. If nano-patterning of the ion beam in itself is accomplished, the ion-beam-based nanofabrication offers the possibility of breaking-through these limits.

Nanofabrication using ion beams

To date, we have developed nanofabrication technologies using ion beams, improved the applicable fluence of ion beams, and developed nanostructures and nanoparticle-control technologies using the unique interactions between ions and materials. We are targeting applications in plasmonics, ultra-fast optical communications, high-density recording, bio-patterning and so on.

As part of these efforts, we developed an ion-and-laser combined irradiation method (**Fig. 1**) for spatial control of nanoparticles. We have also developed a nano-masked ion irradiation technology for patterning the supply of ions (atoms) to a material. We made a nanopatterned Si thin-film mask with a thickness of 200 nm, irradiated it with 60 keV negative Cu ions, and succeeded in forming a nanopatterned swelling of SiO_2 crystal (**Fig. 2**).

Furthermore, using a regular porous alumina nanopattern generated by anodic oxidation, we succeeded in implanting a wide-area nanopattern with a diameter of 40 nm. As a result, the existence of the proximity effects inherent in nanoscale patterning became discernible, with its significance. Nano-patterned ion implantation technology will open up the path to technologies for fabricating nanodevices without relying on lithography using electron beams or extreme ultraviolet light.

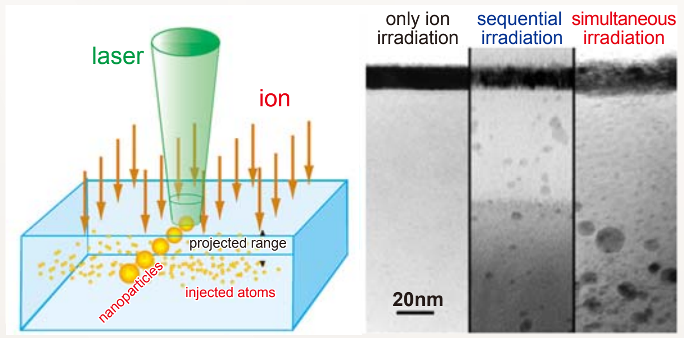


Fig. 1 Cross section of amorphous SiO_2 irradiated with combination of Cu ions and laser (Right: Transmission electron microscope image). The nanoparticles are formed in the case of simultaneous irradiation.

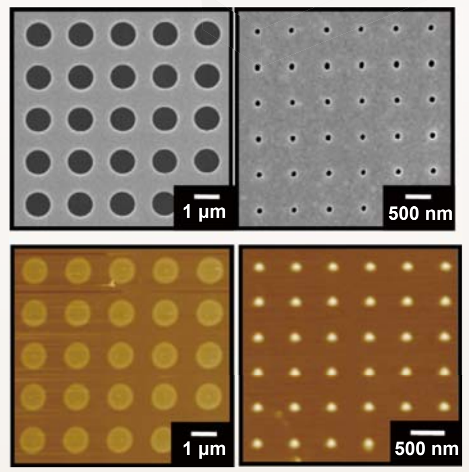


Fig. 2 Swelling pattern induced by ion irradiation to SiO_2 crystals (Bottom: Atomic force microscope image) using an Si thin-film mask (Top: Scanning electron microscope image).

Cover Photo: View of the in-situ characterization/irradiation chamber installed into the negative-ion beamline in the Extreme Particle-Field Generator (heavy-ion tandem accelerator system). This accelerator system is used to form a "field," in which strong ions and photons are superposed and to measure/utilize the interaction between this field and materials. Its distinctive features include a large current negative-heavy-ion source, a simultaneous laser irradiation system, and an in-situ optical detection system.

Slow Quantum Beams for Investigating Surfaces

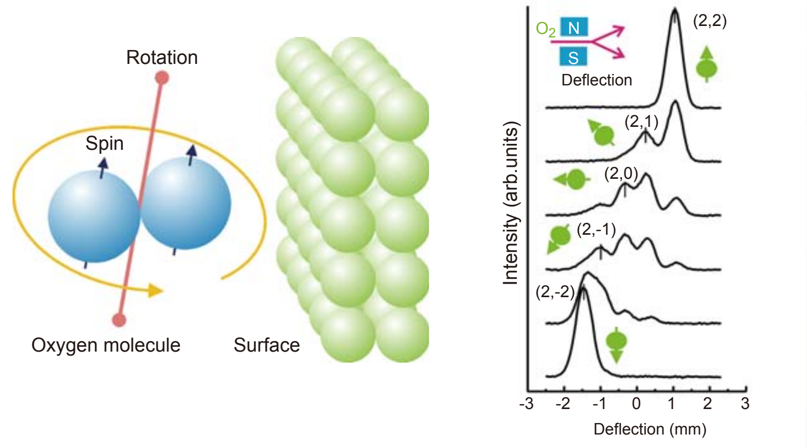
Yasushi Yamauchi Group Leader, Atomic Beam Group, Quantum Beam Center

Successful generation of a state-selected slow O_2 beam

Many of the quantum beams have the property of penetrating deeply into materials. For this reason, quantum beams are often used for investigating the interior of materials, but conversely, the information of the surface can hardly be obtained. Therefore, we created quantum beams of molecules and atoms which travel at about one kilometer per second, far slower than the speed of light.

Since a beam this slow is reflected above the surface, it only interacts with the uppermost atoms. To put it another way, it has the ultimate surface sensitivity. Our group is developing technologies for slow quantum beams of oxygen molecules (O_2), helium radicals (He^*), and helium ions (He^+).

O_2 is a molecule that causes important and basic chemical reactions on which the synthesis of functional oxides and the environmental resistance of metal materials depend. Development up to now has focused on approaches using molecular beams with a single quantum state, for example, spin, for reaction control and mechanism elucidation. However, for technical reasons, this has not been achieved with O_2. Using a sextupole magnet, we established a method for generating a high-intensity beam in which not only the O_2 quantum state but also the molecular orientation are in complete alignment **(Fig. 1)**. This is the world' s first example using O_2. Based on this technology, we are currently developing a surface reaction analysis system using an oriented O_2 beam.



(A) O_2 rotating and approaching to surface (B) Stern-Gerlach experiment

Fig. 1 O_2 retains two unpaired electrons that spin parallel to each other (triplet) while rotating as a diatomic molecule (A). Therefore, scattering at the surface is expected to show rotational orientation dependence and spin dependence. When the Stern–Gerlach experiment was conducted on an O_2 beam that passed through opposite magnetic fields with a range of conditions from diabatic to adiabatic, a sequential transition among five states was observed (B). This indicated that the O_2 molecules occupied spin-rotational quantum states of (2, -2) to (2, 2) as a sum of a spin quantum number of 1 and the lowest rotational quantum number of 1 resulting from the transformation of rotational energy into kinetic energy in the beam formation process.

Slow quantum He beams with a wide range of potential applications

If a slow quantum beam is created using He^*, the He^* excitation energy (approximately 20 eV) can be focused on the uppermost atoms of the surface. This makes it an ideal exposure source for nanolithography using self-assembled monolayers (NIMS NOW December 2006). Furthermore, by aligning the direction of spin, it is possible to examine the electron spin of the uppermost surface (NIMS NOW April 2009).

However, a He^+ beam has relatively high energy (approximately 1 keV of kinetic energy) so that it penetrates several nanometers beyond the surface. When the beam penetrates deeply, the He^+ ions are neutralized so that only the fraction reflected at the uppermost surface can remain as He^+. Measuring these ions consequently provides information about the uppermost surface atoms. We also developed technology for generating He^+ with aligned spin, and we demonstrated that the spin of each element in the uppermost surface can be measured separately. Based on this, we are working with a company to develop a spin-polarized low-energy ion scattering spectroscopy device **(Fig. 2)**.

The slow quantum beam is beginning to open up a wide range of new fields, from nanofabrication to element sensitive spin measurement and state-selected reactions.

Fig. 2 Prototype of the spin-polarized low-energy ion scattering spectroscopy device He^+ ion beam: polarization 25%, energy 10eV – 2keV, current <100nA Analyzer: angle-resolved, hemispherical, electrostatic, theta and phi rotation

FACE フェイス interview

Quantum beam research began with research on nuclear physics. However, quantum beam technology was later applied to semiconductor materials and is now used in research on nanotechnology. In particular, it becomes a key tool for precise structural analysis of nanomaterials, as well as for nanopatterning and incorporating functions into nanomaterials. Dr. Naoki Kishimoto, Managing Director of the NIMS Quantum Beam Center, has passionately been devoted to quantum beam research. In this Face interview, he talks about the importance of beam technology and its particularly interesting aspects.

Inevitable Coupling between Quantum Beam Technology and Nanotechnology Materials Research

Naoki Kishimoto
Managing Director, Quantum Beam Center

Were you interested in quantum beams from the first?

Because my original specialty was semiconductor physics, I actually had no interests at all in quantum beams. When I first joined this institute (formerly NRIM: National Research Institute for Metals), nuclear energy was a focus of research, so I was told to work on radiation damage of materials. That was how I became involved in research handling ion beams. Later, the interest in nuclear-energy materials gradually declined, and it became difficult for me to continue along the same path. As a result, I began using ion irradiation in research not directly related to nuclear energy, and changed the direction of my work to create materials by applying quantum beams.

What is your impression of research on quantum beams now?

I think that quantum beam research is a very enjoyable field. Because we can do things with quantum beams that are impossible with any other tools, it is a research field full of dreams. On the other hand, it is sometimes expensive, and the high cost could be a problem. But then, although there are difficulties from the viewpoint of cost performance, this type of research is destined to become a front runner for the progress of science and technology. For example, although the scale is different, the quantum beam research has similar aspects with the research in space development. In such a situation, the enthusiasm of researchers will be the most important thing. I feel it requisite that we commit ourselves devotedly to pioneer the peaks of science and technology.

Nanotechnology and quantum beam technology are a very good couple, aren't they?

I really think that's true. As a tool for incorporating functions into nanomaterials and also directly diagnosing the nano world, the quantum beams are extremely effective. In Japan, the first thing that comes to mind when we say "nanotechnology" is a very tiny world. People tend to think that nanotechnology has no connection with "big science" like quantum beams. However, that isn't true. In the United States and Europe, they have a different idea, and they stress the fact that big science is essential for researching tiny worlds. For example, research institutes such as Oak Ridge, Argonne, Brookhaven, and Max Planck, which have large quantum beam facilities, are all putting great efforts into research on nanotechnology. The use of quantum beam technology in characterizing and creating innovative, useful materials is greatly expanding the dreams of the human beings.

Do you think that quantum beam technology has the potential to cause leaps in nanotechnology?

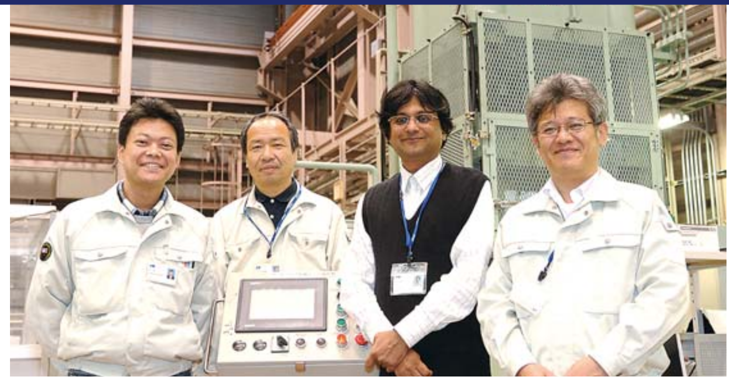
For example, nanopatterning using ion beams has the potential to build nanosized optical devices or switching functions directly into materials. This means that it is capable, in essence, to overcome the limits of the existing optical lithography. In extreme terms, I believe that the next technology which will spur the development of industry can be found only in quantum beam technology.

Finally, do you have any words for young researchers?

Quantum beam research is a precious field where pure basic research is matched with directed basic research. I believe that we are particularly lucky to be involved in this kind of research. I would like young people to perform their research with keenly savoring this happiness.

High Performance Magnesium Alloy without Rare-earth Elements

Lightweight Alloys Group,
Structural Metals Center



Group Leader
Hidetoshi Somekawa, Yoshiaki Osawa, Alok Singh, Toshiji Mukai

Reduction of the body weight of railway cars, automobiles, and other transportation equipment is demanded as a means of reducing energy consumption. From the viewpoints of safety and reliability, it is essential to maintain the strength, toughness, and formability of the structural parts of these products while reducing weight. Thus, the development of materials with high strength, high toughness, and high ductility is important.

Since magnesium is the lightest of the conventional metallic materials and abundant reserves of this resource also exist, it is widely used in a variety of fields, and adoption as a structural material is also being studied. However, for application as a structural material, several problems must be solved. These include the fact that magnesium is brittle, displays "deformational anisotropy," meaning its strength differs depending on the applied stress/strain direction (tensile or compressive deformations), and is difficult to form into complex shapes due to its crystal structure.

Focusing on the unique structure of the quasicrystal phase, we discovered a hint for solving these kinds of problems by treating the quasicrystals as dispersed particles in the matrix (NIMS NOW 2007, No. 9). Because the quasicrystals do not display periodicity, that is, display quasi-periodicity, in the atomic arrangement, the interface between the matrix and the quasicrystal phase has strong bonding. The dispersion of quasicrystals in the matrix is useful for improving brittleness, as these bonds tend not to become the origin of fracture during deformation, and deformational anisotropy is eliminated by randomization of the crystal orientation. However, the quasicrystal phase has been stably formed only in alloy systems containing rare-earth elements, which are expensive and scarce. Therefore, as added elements, we selected aluminum and zinc, which are common, relatively inexpensive elements, as a substitute for rare-earth elements, and succeeded in dispersing quasicrystals based on $Mg_{32}(Al,Zn)_{49}$ or quasicrystal related phases in the matrix by controlling the composition and processing, i.e., heat treatment. **Fig. 1** (left) shows an example of the microstructural observation of the developed alloy. The black arrows show the matrix, and the white arrows indicate quasicrystals, confirming that the quasicrystals are dispersed in the matrix. Furthermore, because the color of each matrix grain is varied, it can be understood that the developed alloy has a random crystal orientation. The alloy does not display deformational anisotropy, and shows strength and ductility equivalent to those of the conventional magnesium alloy with dispersed quasicrystals using rare-earth elements (**Fig. 1** right), and also possesses excellent secondary formability at relatively low temperatures under 300°C. For example, as shown in **Fig. 2**, it was possible to transcribe the NIMS logo and form a gear-shaped part using the developed alloy.

In addition to reducing energy consumption by reducing weight, this alloy will also contribute to reducing material- and forming-costs. Based on these advantages, application to various structural materials is expected, beginning with materials for transportation.

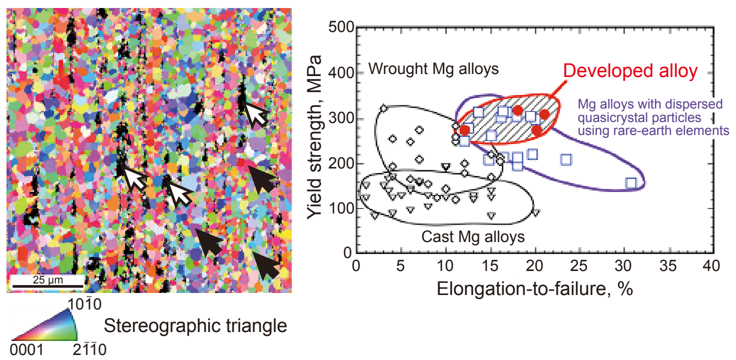


Fig.1 Left: Microstructural observation by Electron Back-Scattered Diffraction (EBSD)* and right: comparison of room temperature tensile strength/elongation properties of various magnesium alloys.
*In general, the matrix of wrought magnesium alloys characteristically tends to concentrate on the same color.

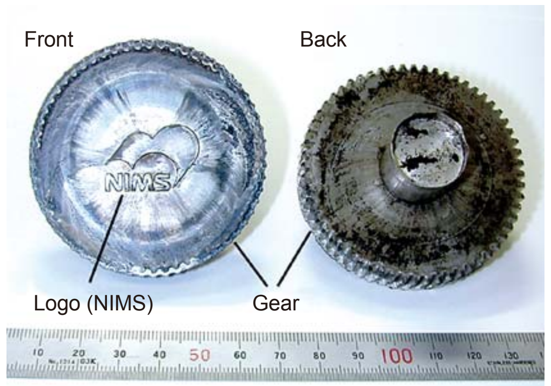


Fig.2 Appearance after forge forming

Research Highlights

Prototype Fe-based Superconducting Wire Using Fe(Se,Te)

Nano Frontier Materials Group,
Advanced Superconducting Wires Group†,
Superconducting Materials Center

Group Leader Managing Director
Yoshihiko Takano, Yoshikazu Mizuguchi, Hiroaki Kumakura†

Materials which show zero electrical resistance at low temperatures are called superconductors. In the superconducting state, it is possible to transmit electrical energy over great distances with no loss. If it were possible to circle the planet with wire manufactured from a superconductor, generating solar power on the sunny side of the globe during daytime and transmitting it to areas on the nighttime side would not be a dream.

Recently, Fe-based superconductors have been a topic of great interest as a new type of high temperature superconductor. Our groups has been working to develop wire materials using these Fe-based superconductors. The test material used in this research is a Fe(Se,Te) material, which has the simplest crystallographic structure among the Fe-based superconductors and has a superconducting transition temperature (Tc) of approximately 14K. Because iron, which is its main component, is an element which exists on Earth in great abundance, we devised a unique superconducting wire manufacturing method in which Fe is used as the sheath material (material forming the outer shape of the wire) and, at the same time, also serves as a raw material for the Fe-based superconducting substance which is formed in the interior.

Fig.1 shows a schematic diagram of the wire material manufacturing process. First, an SeTe compound is prepared by reacting Se and Te in advance. These are the non-Fe components of the Fe-based superconductor. This SeTe compound is then filled into an iron pipe, which will form the sheath material. The filled pipe is then rolled into a long, thin, tape-shaped wire material with a width of 4.3mm and thickness of 0.55mm using grooved rolls and flat rolls. The wire material obtained in this manner is sealed in a quartz glass tube so as to prevent reaction with the air, and heat treatment is performed. When this was done, the SeTe compound in the tube reacts with the Fe sheath, and a Fe(Se,Te) superconductor is synthesized inside the sheath. A scanning electron microscope image of the cross section of the obtained wire material is shown in **Fig.2**. A satisfactory filling condition, in which the superconductor was in close contact with the sheath, with no crevices or spaces, was obtained on both sides of the wire material.

Electrodes were attached to the wire material and a current test was performed. As a result, a superconducting current was successfully passed through a wire material using an Fe-based superconductor for the first time in the world. Although the critical current density still shows a small value of $Jc=12.4A/cm^2$, various efforts to achieve higher values are planned, including increasing the filling rate and improving the bonding between the sheath and the superconductor, use of a multicore design, introduction of flux pinnig, etc. This is expected to result in further improvement in the superconducting critical current value in the future.

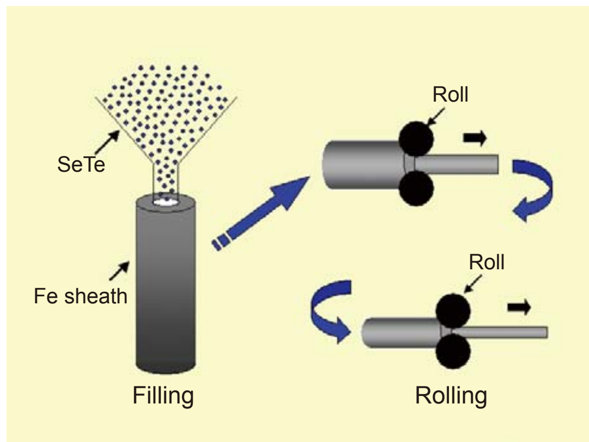


Fig.1 Schematic diagram of the wire manufacturing process.

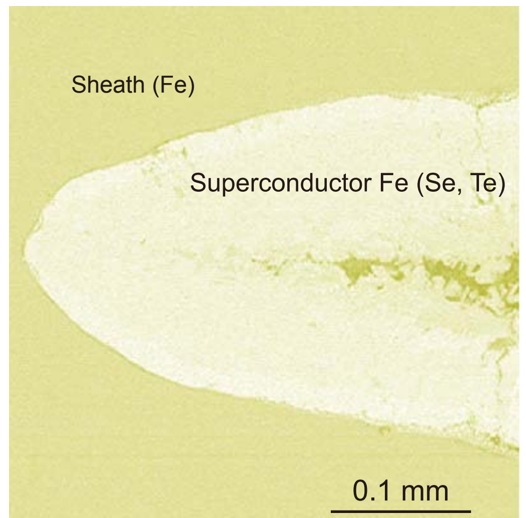


Fig.2 Scanning electron microscope image of cross section of superconducting wire.

Comprehensive Collaborative Agreement with NU

(Dec. 10, 2009) NIMS recently signed a comprehensive collaborative agreement with Northwestern University (NU), which is located in Evanston, Illinois (USA). The agreement was signed by Dr. Daniel Linzer, Provost, Chief Academic Officer of NU and Prof. Sukekatsu Ushioda, President of NIMS on the occasion of a visit by Prof. Robert P. H. Chang, the Director of the Materials Research Institute of NU, who also attended the MRS-Japan 20th Anniversary Symposium.

This agreement will not only reinforce the existing collaboration between NU and NIMS in the fields of 3-D structural analysis and semiconductor nanowires, but also envisions new collaborations and exchanges of researchers. While at NIMS, Prof. Chang visited researchers at several centers, where he exchanged information and engaged in serious discussions on new collaboration.

Prof. Sukekatsu Ushioda (left) and Prof. Robert P.H. Chang (right) at the signing.

MEXT Minister Tatsuo Kawabata Visits Tsukuba

(Dec. 2, 2009) Japan's Minister of Education, Culture, Sports, Science and Technology (MEXT), Mr. Tatsuo Kawabata, recently visited several institutes in Tsukuba, which included a visit to the Sengen Site at NIMS.

Following an overview of NIMS, which was presented by President Sukekatsu Ushioda, Minister Kawabata received an explanation of various recent research achievements, including examples of application of SiAlON phosphors to white light LEDs. He also observed frontline research sites working toward practical application of nickel-base superalloys for jet engine turbine blades to improve aircraft fuel consumption, an area where NIMS is engaged in joint development with Rolls-Royce, and the development of next-generation solar cell materials.

MEXT Minister Kawabata receiving an explanation of next-generation solar cells.

When asked his impressions by accompanying reporters, Minister Kawabata commented that "Materials research may not be particularly glamorous, but it is essential to science and technology. This visit has also given me a better understanding of the significance of research related to the environment." In reply to a question from the press regarding collaboration not only with Japanese companies, but also with foreign companies, Minister Kawabata noted that "Medical research, for example, isn't simply for Japan, it benefits the entire world. From this viewpoint, it's important to create an environment where international researchers will want to do research."

In addition to NIMS, Minister Kawabata also visited RIKEN and the Japan Aerospace Exploration Agency (JAXA) during this tour of Tsukuba City, and heard the views of frontline researchers involved in science and technology development.

Ethiopian Ambassador Visits NIMS

(Dec. 7, 2009) H.E. Mr. Abdirashid Dulane, Ethiopian Ambassador Extraordinary and Plenipotentiary to Japan, visited NIMS and met Prof. Sukekatsu Ushioda, the President of NIMS, to exchange information on current research.

The Ambassador was particularly interested in promoting research related to energy and water supply in Ethiopia. He intended this visit to be an initial step toward cooperating with NIMS, and talked on the necessary steps involved.

Right: Ambassador Mr. Abdirashid at the lab tour

After the meeting, he toured the 3-D Nano-Integration Foundry and Bio-Organic Materials Facility at the Nanotechnology Innovation Center in Sengen, and the High Voltage Electron Microscopy Station at the Namiki Site. The Ambassador, as a chemist, showed much interest in Bio-Organic Materials Facility and asked about the conditions for an Ethiopian researcher to conduct research at the facility.

Second and third from left: Ambassador Mr. Abdirashid and NIMS President Prof. Ushioda

NIMS NOW International 2009.Vol.7 No.10

National Institute for Materials Science

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