from Tsukuba, Japan to the world

NIMS

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Special Features

Introduction of 20 New Projects and Recent Achievements - Nano System Functionality Center -

Preface "From Nano Functions to Nano System Functionalities"

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More than 40 years ago, in 1959, Richard Feynman gave a famous lecture entitled "There's plenty of room at the bottom," in which he left several extremely important messages, represented by the statement that "there's no physical limitation on reducing the size of a computer memory bit to a single atom." This was an insightful prophesy which foresaw the development of today's nanotechnology. At the time, however, people thought Feynman was joking, saying "you can talk like that because you're a theoretician, but there's no technology that can realize this fantasy." About twenty years after Feynman's speech, Gerd Binnig and Heinrich Rohrer of IBM's Zurich Research Laboratory invented the scanning tunneling microscope (STM), giving us a new kind of microscope which makes it possible not only to observe, but also to manipulate individual atoms. The STM and various other kinds of scanning probe microscopes (SPM) derived from it, beginning with the atomic force microscope (AFM), have played a key role in today's astonishing progress in nanotechnology, and in various senses, Feynman's dream is now approaching reality.

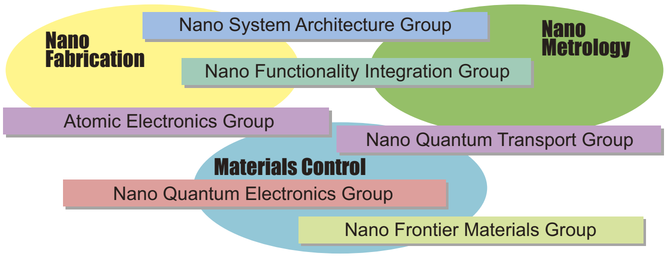

Fig. Organization of the Nano System Functionality Center.

Certainly, nanotechnology has achieved remarkable progress. On the other hand, however, there is also concern that nanotechnology may not ultimately achieve the impressive results originally expected. There is feeling that another technological breakthrough is necessary if real progress is to be achieved in nanotechnology.

The author has tried to imagine what Prof. Feynman would say if he were to come back today and look at current nanotechnology. I'm sure that he would make surprising comments, but without a doubt, the following meaning would also be included in whatever he said: "It's almost meaningless to create individual nanostructures with interesting functions. The problem is how to arrange and link those nanostructures in order to realize novel functionality as a system. Unless you can develop that kind of technology, the quantum computer that I proposed will remain a dream within a dream."

As the name of this Center indicates, the fundamental objective of the Nano System Functionality Center which NIMS launched earlier this year is to develop and apply the technologies necessary to organize "nano" functions as "systems," and from these, create novel "functionalities." To realize this objective, 6 research groups have been created in the Center (see **figure**). These following 6 articles in this special issue will introduce some of the research activities of these respective groups.

in this issue

NIMS News

NIMS and Rolls-Royce Join Forces to Develop Superalloys

Dedication ceremony.

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Candidate for Nano-Architectonics Extreme Nano 3-D Integrated Device Using High-T_c Superconductor

Takeshi Hatano, Akira Ishii,
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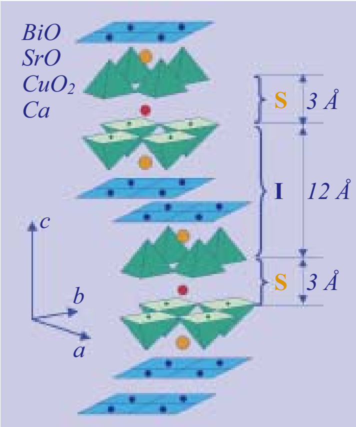

Fig. 1 Crystal structure of Bi high-T_c superconductor.

In copper oxide superconductors, the crystal as such possesses the basic structure of a superconducting device (that is, an SIS junction comprising an insulating layer, I between two superconducting layers, S; see **Fig. 1**). In semiconductors, this corresponds to the PN junction. However, in the case of bismuth (Bi)-based high-T_c superconductors, the size of this junction is 1.5 nm, which is the unit length of the c-axis direction of the crystal, and the material is a crystal with a periodic arrangement of atoms. This means that Bi-based superconductors form in a serial array of several million junctions from one end of the crystal to the other. Because this device structure exists intrinsically in the substance, it is called an "intrinsic Josephson junction." We have already succeeded in micro-processing in the ab plane direction of the crystal to the submicron scale. This alone gives integration on the order of 100 million (10^8) junctions/cm^2, but the formation of an array of several million junctions in the direction perpendicular to the above-mentioned plane, in other words, in a 3-dimensional structure, results several hundred trillion (10^{14}) junctions/cm^3. This can be considered a candidate for an extreme nano 3-dimensional integrated device. In comparison with semiconductor devices, superconducting devices are two orders superior in both operating speed and power consumption. Thus, one of our objectives is to contribute to solving problems now facing humankind in the fields of information technology and energy by realizing applications of this 3-dimensional integrated device which nature has given us.

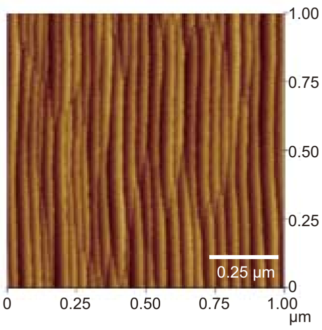

Fig. 2 Fabrication of regular nano-structured surface at surface by heat treatment of vicinal MgO substrate .

What has been described thus far can be called a fusion of so-called "top-down" nanotechnology with the inherent nanostructure in a crystal, but we also envision a combination which would include self-assembly techniques. In our Group, we have succeeded in fabricating regular nanostructures by heat treatment of a vicinal magnesium oxide (MgO) substrate (**Fig. 2**). By employing this technique, we believe that it will be possible to integrate the structure called the "step edge junction" by self-assembly (**Fig. 3a**).

On the other hand, it is known that Josephson junctions are created at grain boundaries when grain boundaries are formed artificially with an in-plane misorientation by approximately 24°. In the process of growing a thin film of a Bi-based superconductor on an MgO substrate, we discovered that the thin film has an intra-plane orientation of ±12° with respect to the crystallographic axis of the substrate when in a condition of thermal equilibrium (**Fig. 3b**). This suggests the possibility that 24° grain boundaries can be formed (integrated) naturally in a thin film by using this property, and as a result, grain boundary junctions can be fabricated without using a bi-crystal substrate.

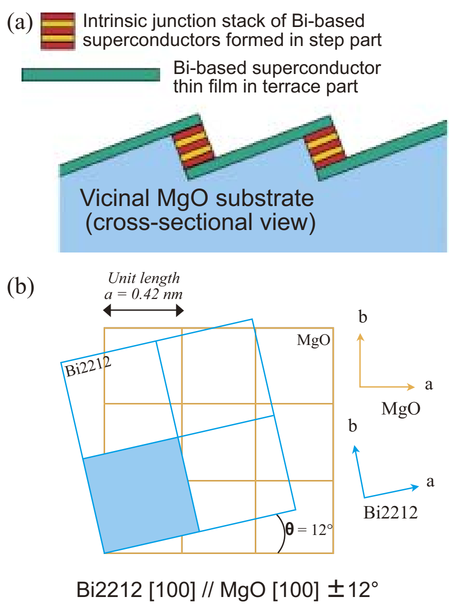

Fig. 3 (a) Integration of step edge junctions by self-assembly. (b) Intra-plane orientation relationship between MgO substrate and Bi2212.

NIMS News

NIMS Signs MOU with Canada's University of Toronto

Front row, from right: Prof. Mostaghimi (Director, CACT), Dr. Kuroda (Managing Director, CCC); center (standing): Dr. Watanabe (CCC Senior Researcher), back: CACT staff members and students.

(May 19, Toronto) -- The NIMS Composites and Coatings Center (CCC) signed a memorandum of understanding (MOU) on research cooperation with the Centre for Advanced Coating Technologies (CACT) of the University of Toronto, Canada. CACT is engaged in outstanding research and development work focusing on simulations of the materials production process for coatings, etc. and process development. The two institutes plan exchanges of researchers and research information, joint research, and other activities in the field of coatings and composite materials, beginning with joint research on composite material coatings.

Toward the Creation of Nanoscale Functional Structures and Their Integration

Tomonobu Nakayama, Tadaaki Nagao, Takashi Uchihashi, Yoshitaka Shingaya, Osamu Kubo, Katsumi Nagaoka
Nano Functionality Integration Group, Nano System Functionality Center

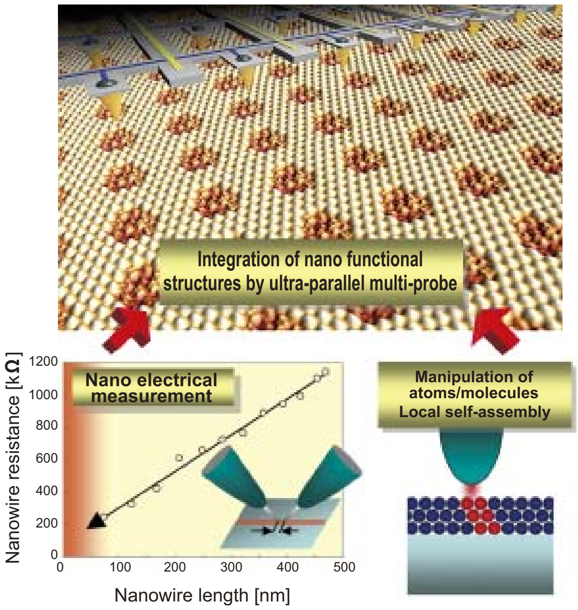

Fig. Integration of nano functional structures using ultra-parallel multi-probe.

The significance of nanostructures is in their deeply interesting physical properties and functions. As the most important challenge for nanotechnology, we have made a fresh start in research considering the establishment of a technology for selecting and combining necessary functionalities of nanostructures, in other words, the construction of nanoscale functional structures and their integration.

In order to achieve this objective, we use a combination of the proximity probe microscope technique and self-assembly technique. Because it is possible to manipulate individual atoms and molecules using the proximity probe technique, this can be called an ultimate structural fabrication technique, but as has been pointed out since an early date, extremely poor throughput in structural fabrication is a drawback. On the other hand, the fact that extreme structural control at arbitrary locations is possible with the proximity probe microscope is an advantage which would be difficult to be realized by other methods. We therefore are now developing an innovative ultra-parallel multiple-probe method which is a qualitative leap beyond the multiple-scanning-probe microscopes (MPSPM) developed to date. This new method will not only remarkably improve throughput, but also enable integration of nanostructures.

Using self-assembly, it is also possible to construct functional and complex networks of nanoscale structures with extremely high efficiency. Good examples of this can be seen in various biomolecules, cells, organs, and ultimately the brain. If the conditions for the self-assembly can be induced in intended regions of nanometer scale, this would provide a very powerful technique for constructing functional structures.

Recently, we developed a technique for controlling chemical bonding between fullerene molecules using a proximity probe. In a thin film of fullerene molecules cohering by intermolecular van der Waals force, it is possible to form nanoscale molecular groups connected by chemical bonds (polymerization reaction), and to dissolve these intermolecular chemical bonds locally (depolymerization reaction). This is a nanofabrication technique via manipulation of chemical bonding, and can be considered a technique for inducing self-assembly of molecules under artificially-controlled local environments.

As outlined above, we intend to develop a revolutionary ultra-parallel multi-probe method by innovation in the proximity probe method, and to pioneer new nanostructural functions by integrating various nanostructures in an organical combination of the high throughput atomic/molecular manipulation and the local chemical reaction control using this device and the self-assembly method.

NIMS News

< Continued from p.1

NIMS and Rolls-Royce Join Forces to Develop Superalloys

Involved officials at the opening ceremony.

(June 30, NIMS/Tokyo) -- NIMS has reached a multi-year agreement with Rolls-Royce to undertake research programs into the development of high-temperature superalloys for use in gas turbine engines. The agreement brings into being The Rolls-Royce Centre of Excellence for Aerospace Materials, which is based at NIMS' Sengen Site in Tsukuba. This was celebrated by an opening ceremony at Tsukuba, followed by a reception in Tokyo.

Rolls-Royce joint laboratories exist not only in the U.K., but also extend to EU countries and the United States. However, this joint laboratory with NIMS will be the first in Japan, and is the first example of collaboration with an overseas company. NIMS is particularly pleased that this collaboration coincides with the 50-year anniversary of the founding in 1956 of the National Research Institute for Metals (NRIM), the forerunning of NIMS.

Aiming at the Creation of a New Atomic/Molecular Electronics

Tsuyoshi Hasegawa, Kazuya Terabe, Yuji Okawa, Tohru Tsuruoka
Atomic Electronics Group,
Nano System Functionality Center

We are engaged in research beginning from the search for materials which manifest novel functions aiming at the creation of innovative devices based on new principles. In particular, focusing on materials which have rarely been used in conventional device development, such as ionic conductors and organic molecules, we are developing new types of devices which take advantage of the structural changes that these materials exhibit at the atomic and molecular scale.

To date, using an electronic and ionic mixed conductor (substance which enables migration of metallic ions as well as electrons in a crystal), we have developed an "atomic switch" (**Fig. 1**) which operates by controlling the formation and extinction of nanoscale metallic projections. As a distinctive feature of this atomic switch, irrespective of its small dimensions, resistance in the ON condition is extremely low. Taking advantage of this feature, we are developing a "next-generation programmable logic computing device" which will be capable of realizing all types of functions on one chip in joint work with industry and universities.

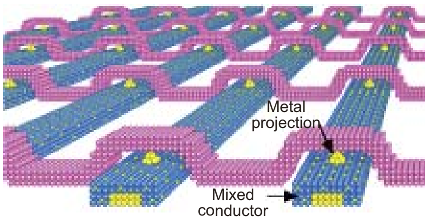

Fig. 1 Crossbar structure formed by atomic switch.

On the other hand, the crossbar structure, in which switch functions are arranged at the intersections of nanowires, is expected to enable the construction of novel computer architectures. Our goal is to develop a crossbar structure using the above-mentioned atomic switch and a conductive organic molecule nanowire (**Fig. 2**) developed in original work.

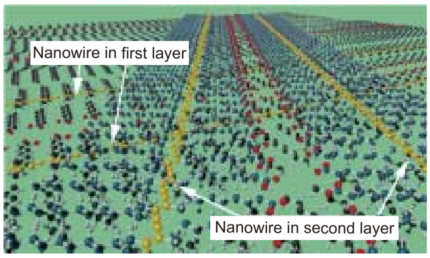

Fig. 2 Crossbar structure of molecular nanowire.

We are also involved in research on devices which go beyond the conventional concepts. In the nanoscale world, there is a greater possibility that high performance devices which also display high reliability can be fabricated by controlling atoms, which exist stably, than by controlling electrons, which are easily extinguished by the tunneling effect. Aiming at control of the movement of single atoms, we are conducting research on 1-dimensional transport of metallic ions. **Figure 3a** shows an electron microscope image of an electronic and ionic mixed conductor nanowire which was fabricated by Dr. Liang (Research Fellow) et al. in this Group. This nanowire comprises silver and silver sulfide parts, and metallic atoms (ions) are transferred back and forth at the interface between the two. By precisely controlling the voltage applied to the nanowire, it is expected to be possible to control transfer in one atom (ion) units. **Figure 3b** shows the results of a measurement of the changes in the electrical properties of the nanowire associated with the transfer of atoms (ions) at the interface. The device switches ON at the positive voltage side, and switches OFF at the negative voltage side. Based on these results, we hope to accelerate research on single-atom devices.

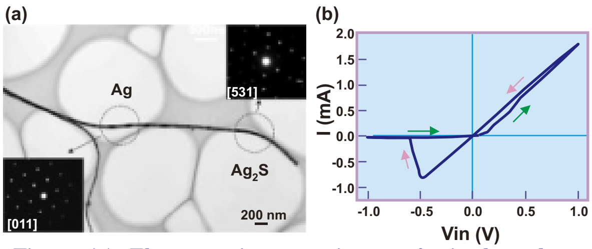

Fig. 3 (a): Electron microscope image of mixed conductor nanowire. (b) Results of measurement of electrical properties.

Research Frontier

Realization of a Light Source for Quantum Information Communication

- A Step toward Practical Application of Quantum Encrypted Communications with Extreme Security -

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Frequency Conversion Group
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Optical fiber communication technology is widely spread, and is used in communication involving personal information and financial, military, and other confidential information. Due to the increasingly high performance of decrypting computers, there is a danger that security cannot be guaranteed with the existing encryption technology. Therefore, quantum encrypted communications which assure extreme security have attracted considerable attention. Quantum encrypted communications use single photon sources which transmit light particles in one particle units for secure secret key distribution. Because eavesdropping can be detected immediately in communications using single photons, security can be guaranteed by changing distribution keys when eavesdropping is detected (**Fig. 1**).

We are conducting research on a wavelength conversion device with a polarization reversal structure using ferroelectric single crystals. Ferroelectrics have an electrical plus and minus charge (spontaneous polarization) which can be reversed by applying an electric field. Devices of this type can be operated with high efficiency as wavelength conversion devices by causing periodical reversal, and can be used to generate photon pairs with a wavelength different from the original wavelength of one photon. In this manner, photon pairs with different properties are intentionally generated and separated

Quest for Novel Quantum Transport Phenomena

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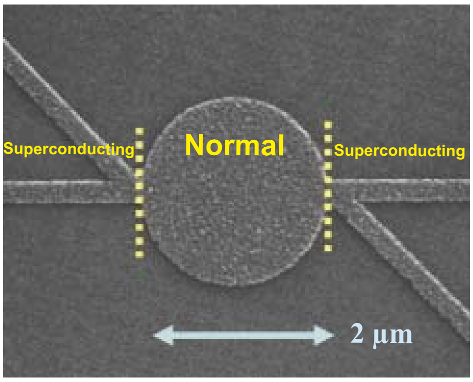

Fig. 1 Quantum disk of Al formed on a Si substrate. By applying an appropriate magnetic field, it is possible to realize a superconducting/normal/superconducting junction with a single metal.

Electrons display the properties of particles and the properties of waves. In today's silicon devices, functions are created by controlling the diffusive motion of electrons (non-quantum mechanical electron motion), thus utilizing their property as particles, but the performance of devices of this type is approaching its limits. For this reason, we believe that it is critical to make active use of the wave property of electrons in innovative, next-generation devices. Creation of states which allow electron wave interference (coherent states of electron "charge" and "spin"), and control of this interference, is expected to lead to the discovery of unprecedented new quantum transport phenomena (electron and spin interference phenomena) and quantum functions (e.g., quantum switching functions). Therefore, our aim is to realize novel quantum transport functions and elucidate the mechanism of these functions with a firm commitment to application in next-generation devices. In particular, the objects of this research are 1) superconducting nanostructures, 2) competing magnetism and superconductivity systems, and 3) density wave electronic systems, all of which display remarkably strong coherent electronic states.

1) Superconducting nanostructures

Aluminum (Al) exhibits superconductivity at approximately 1 K. In Al structures of 1 μm order, the critical magnetic field for superconductivity varies greatly depending on the size of the specimen. This means that it is possible to fabricate superconducting/normal/superconducting junctions consisting of a single metal by creating Al structures of different sizes, provided that a magnetic field of the proper intensity is applied (**Fig. 1**). Because junctions of this type do not involve a combination of heterogeneous metals, an extremely high quality junction interface can be realized. The distinctive reflection of electron pairs which induces superconductivity is remarkable at this interface, suggesting that new quantum transport phenomena can be manifest utilizing this reflection.

2) Competing magnetic and superconducting systems

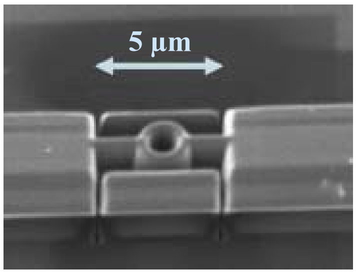

Fig. 2 Quantum ring realized by microfabricaton of a single crystal of $NbSe_3$ displaying charge density wave. When a magnetic field is applied, interference between the CDW passing through the upper and lower parts of the ring can be expected.

Superconductors which contain a large magnetic moment manifest diverse physical properties due to mutual competition and cooperation between the superconductivity and magnetism. We hope to propose novel quantum functions by using the temperature and magnetic field to control the coherent states of superconductivity and magnetism which are realized in the same substance.

3) Density wave electronic systems

In several compounds, charge density waves (CDW) are formed by the aggregation of enormous numbers of electrons under the Coulomb force between the electrons and the crystal lattice. It is known that these CDW move coherently when the proper electric field is applied. Utilizing this wave interference effect (**Fig. 2**), we are investigating the possibility that CDW may manifest unprecedented quantum functions.

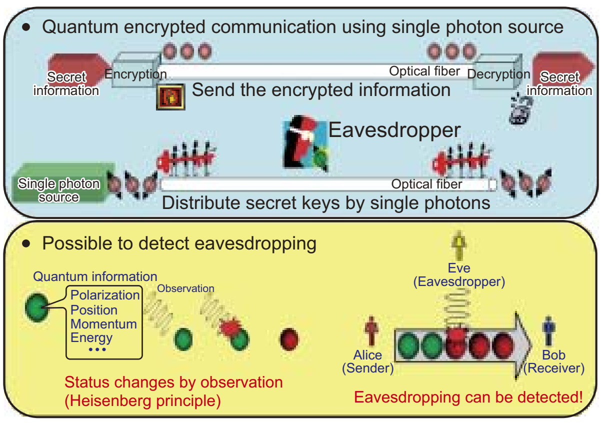

Fig. 1 Quantum IT by single photon source with extreme security.

with high efficiency, and one half of the pair is used in the secret key distribution, while the other is used in gate timing detection (**Fig. 2**). In the present research, we realized a efficient photon-pair-generating device applicable to quantum IT, which operates in the telecommunication wavelength band used in optical fiber, and succeeded in improving the efficiency of the conventional photon pair generating devices by more than 10 times.

This achievement is a dramatic improvement in the properties of the basic light-source technology of quantum IT, and is also expected to contribute in the new fields of quantum computing and quantum teleportation.

This research was carried out as part of the project "Research and Development of Quantum-Controlled Optical Modem Technology" as commissioned research for the National Institute of Information and Communications Technology. The authors wish to express their deep appreciation to all concerned.

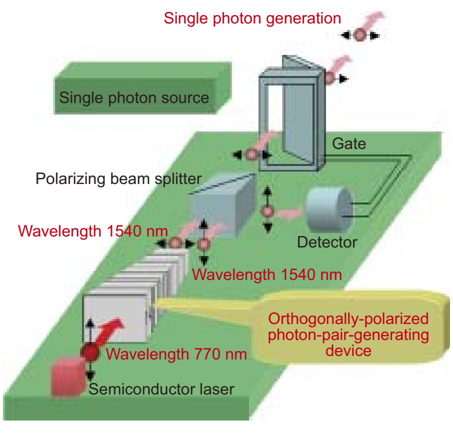

Fig. 2 Single photon source using photon pair generating device.

For more details: http://www.nims.go.jp/fcg/index_eng.html

New Developments in Nano Function Metrology

- Development and Application of New Photon-Detecting STM (P-STM) -

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The Nano System Functionality Center is developing new nano function metrology techniques in order to measure local physical properties and functions. Although the multi-probe scanning tunneling microscope (STM) which is discussed in another article in this issue (page 3) is one example, in this paper, we would like to introduce a new type of photon STM (PSTM) with other capabilities. The PSTM itself is not new, but innovations in this device have made it possible to obtain new information which could not be obtained in the past.

In this method, an optical detection system, which enables measurement of i) energy spectra, ii) linear polarization, and iii) circular polarization of light from the vicinity of the tunneling gap between the tip and the sample, is added to the STM (see the schematic diagram in **Fig. 1a** and photo in **Fig. 1b**; a photograph of the equipment necessary for measurement of circular polarization is not shown). A variety of interesting measurements are possible using this system. Here, however, we would like to discuss the intriguing fact that it is possible to detect spin polarization of nanostructures on the sample surface using measurements of the above-mentioned i) and iii). The novelty of this method lies in the fact that, because a magnetic material is not used in the STM tip, the magnetic structure of the sample surface is not disturbed.

Gallium arsenic (GaAs) is used as the substrate for the spin detector in this method. The electrons tunneling from the STM tip finally enter the GaAs conduction band, and light is emitted as a result of recombination with holes in the valence electron band. Because the quantum efficiency of the light emission is large, a strong light intensity can be observed. This is one advantage for using GaAs as the substrate. The experimental results in **Fig. 2** clearly show that, with an iron (Fe) thin film (thickness: approx. 2 nm) on the GaAs substrate, the electrons tunneling from the tip are spin-polarized by the spin-splitting electronic state of the magnetic thin film when they tunnel to the state, and that circularly polarized light is created according to the optical selection rules in the radiative recombination.

As described here, we have succeeded in developing a promising new technique for detecting spin polarization of nanostructures.

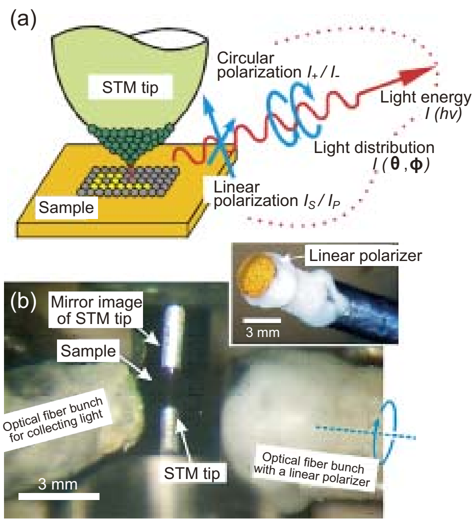

Fig. 1 (a) Schematic diagram of photon STM and (b) light collecting system using optical fiber bunch in ultra-high vacuum STM.

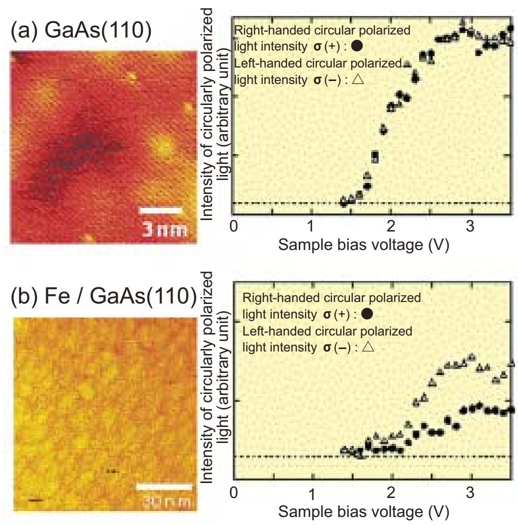

Fig. 2 (a) STM images of GaAs (110) surface and (b) Fe/GaAs (110) surface, and bias voltage dependence of circular polarized light intensity .

Research Frontier

Development of Ultra-Soft X-Ray Spectrometer for Electron Probe Microanalysis

- New Device Enables High Sensitivity Detection of Lithium X-Rays -

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Advanced Nano Characterization Center

When an electron beam is irradiated on a specimen, characferistic X-rays which are unique to that substance are emitted. It is possible to identify the substance (qualitative analysis) and measure the concentrations of its constituent elements (quantitative analysis) from the energy and intensity of these X-rays. The chemical bonding states of the elements can also be analyzed from changes in the peak profile of the X-ray.

Lithium has been widely used in recent years and is a key component in fuel cells and lithium batteries for example. Although improvement in the energy conversion efficiency of these kinds of cells is important from the viewpoint of preventing global warming, spectral analysis of lithium was impossible with the conventional X-ray analyzer.

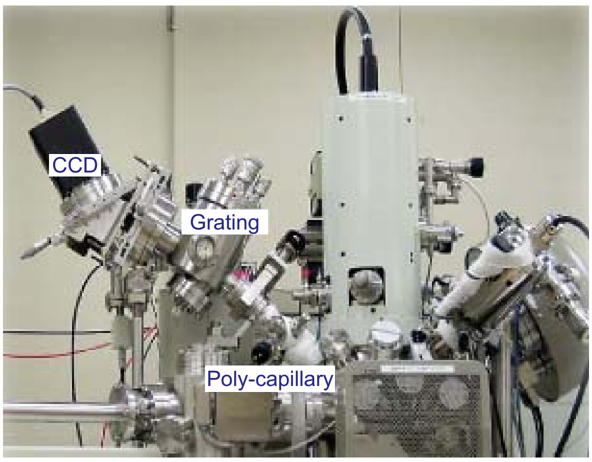

Fig. 1 Overview of new Ultra-Soft X-ray Microanalyser.

Research on Diamond Superconductors

- Aiming at the Creation of Novel Nanodevices -

Yoshihiko Takano
Nano Frontier Materials Group
Nano Systems Functionality Center

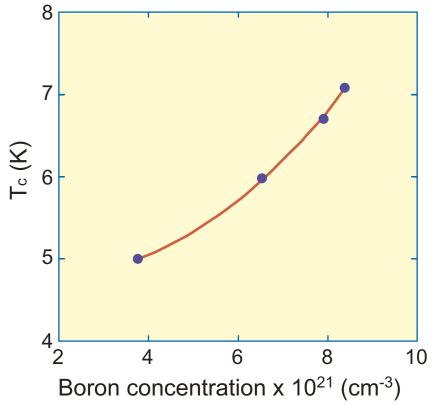

Fig. 1 Relationship between B concentration and superconducting transition temperature T_c.

The diamond, which is known as the king of jewels, is not only beautiful, but also has many deeply interesting properties. For example, the diamond is the hardest substance, has the highest thermal conductivity at room temperature, and is an excellent electrical insulator. Natural diamonds are created under high temperature, high pressure environments in the deep earth. In contrast to this, about 20 years ago, a chemical vapor deposition (CVD) process for synthesis of diamonds from gases such as methane or ethanol was developed, enabling comparatively simple synthesis of high quality diamond thin films.

With CVD, it is also possible to dope boron (B) to diamonds. Although pure diamonds are an insulator which prevents the flow of electricity, when a small amount of B is doped, the diamond takes on a beautiful blue color and becomes a semiconductor. Diamond semiconductors are a subject of research and development as a next-generation semiconductor material. When larger quantities of B on the order of 10^4-10^5 times or more are doped, the diamond becomes black in color and displays metallic electrical conduction. Recently, it was found that superconductivity, meaning electrical resistance of zero, appears in specimens of this material when cooled to low temperatures. The relationship between the temperature at which superconductivity appears (superconducting transition temperature, T_c) and B concentration is shown in **Fig. 1**. It can be understood that T_c increases with B concentration. It would seem that further increases in T_c are possible if a greater amount of B can be added. We have taken on the challenge of achieving a further increase in T_c.

Because diamond superconductors are considered to display a rare type of superconductivity which occurs in semiconductors, elucidation of the mechanism by which superconductivity is manifest is required. We therefore performed angular-resolved photoemission spectra measurements using the principle of the photoelectric effect (emission of electrons under exposure to light), which was clarified by Einstein. The electronic states of a diamond semiconductor and a metallized diamond which displays superconductivity are shown in **Fig. 2**, at the right and left, respectively. When the B concentration is increased, the energy bands (parts simulated by white lines) of the diamond shift upward and appear to intersect with E_F (Fermi energy). This indicates that the origin of metallic superconductivity is a phenomenon attributable to the energy bands of the diamond. On the basis of these results, our aim is to develop novel devices which possess both the properties of semiconductors and superconductors. This work was carried out as joint research with Prof. Kawarada's laboratory at Waseda University and Prof. Yokoya's laboratory at Okayama University.

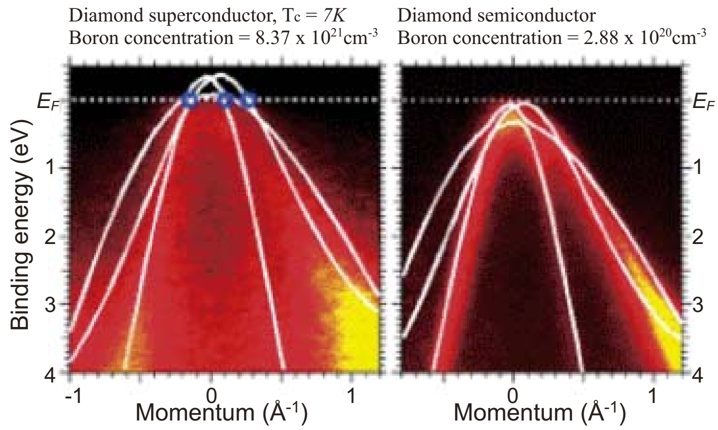

Fig. 2 Electronic states of diamonds.

For more details: http://www.nims.go.jp/NFM/

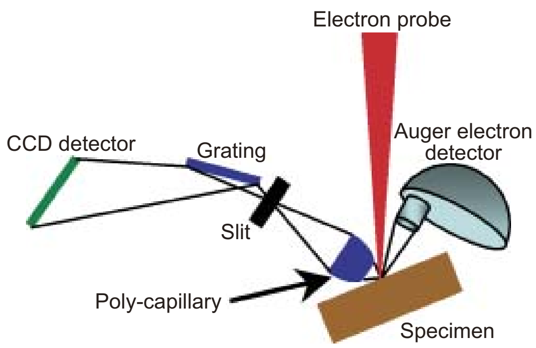

Fig. 2 Schematic diagram of device.

In the system equipment developed in this work, we adopted a method of 2 dimenfional defecting the ultra-soft X-rays dipersed with a grating using an CCD camera, and reconstructing the spectra from the out put of CCD camera. Because this system contains no moving parts, this method made it possible to realize high resolution and high precision in a compact device. The appearance of the device and a schematic diagram are shown in **Fig. 1** and **2**, respectively.

In this device, a lens (poly-capillary) using the total reflection of X-rays was adopted, which was the first attempt to use, and as a result, ultra-soft X-ray detection efficiency was improved by more than 1,000 times. Moreover, because the specimen is placed in an ultra-high vacuum, spectral analysis with other technique such as Auger electron spectroscopy is also arailable. This system is not limited to advanced materials research, but can also be applied in research on surface properties and surface analysis. **Figure 3** shows a comparison of the K-$L_{2,3}$ line spectrum of lithium and the $L_{2,3}$-M line spectra of metallic aluminum and metallic magnesium.

At present, this system which can be applied to any type of sample whatsoever and enables rapid analysis is the only one of its type in the world.

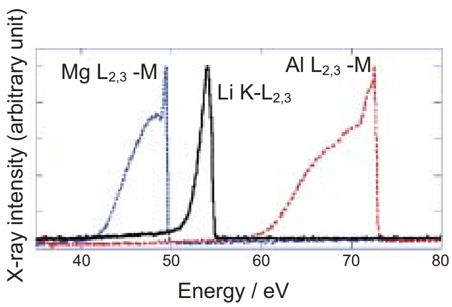

Fig. 3 Comparison of the spectra of metallic lithium, metallic manganese and metallic aluminum. The device shows high resolution, as sharp peaks indicating Fermi energy can be observed.

For more details: http://www.nims.go.jp/ancc/about/about.html

Recruitment

We are seeking highly motivated people!

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   b. Superconductivity, New nanomaterials, Nano-devices
   c. Neutron Scattering Group, Quantum Beam Center
   d. Sensor material synthesis and the development of advanced sensor devices and systems for the detection of chemical species
   e. Solid-state electrochemistry, ionic conduction at hetero-junctions, ion-conductive solids
   f. Development of packaging and interconnect materials on the basis of nanoscale control of material interfaces
   g. Any fields of Materials Science
3. Requirements: Applicants should have a Ph.D. in a related field.
   For more details: http://www.nims.go.jp/eng/employment/
4. Position available from October 1, 2006-April 1, 2007 (negotiatable)
5. Application dead line: Applications for (a-f) must be received by NIMS on or before Friday 29, September 2006. No dead line for (g) (reviewing once in every two months).
6. Application form and detailed information:
   http://www.nims.go.jp/eng/employment/
7. Inquiries and submission: Human Resources Development Office
   Email: nims-recruit@nims.go.jp Tel: +81-29-859-2555

Early Summer in Japan

Photos by M. Sato (July 14-18)

Ladies in yukata (summer kimono) and a float with lanterns at Kyoto's Gion Festival 2006

Gate to Kifune-Jinja Shrine, Kyoto

NIMS National Institute for Materials Science

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Dr. Hisao Kanda

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