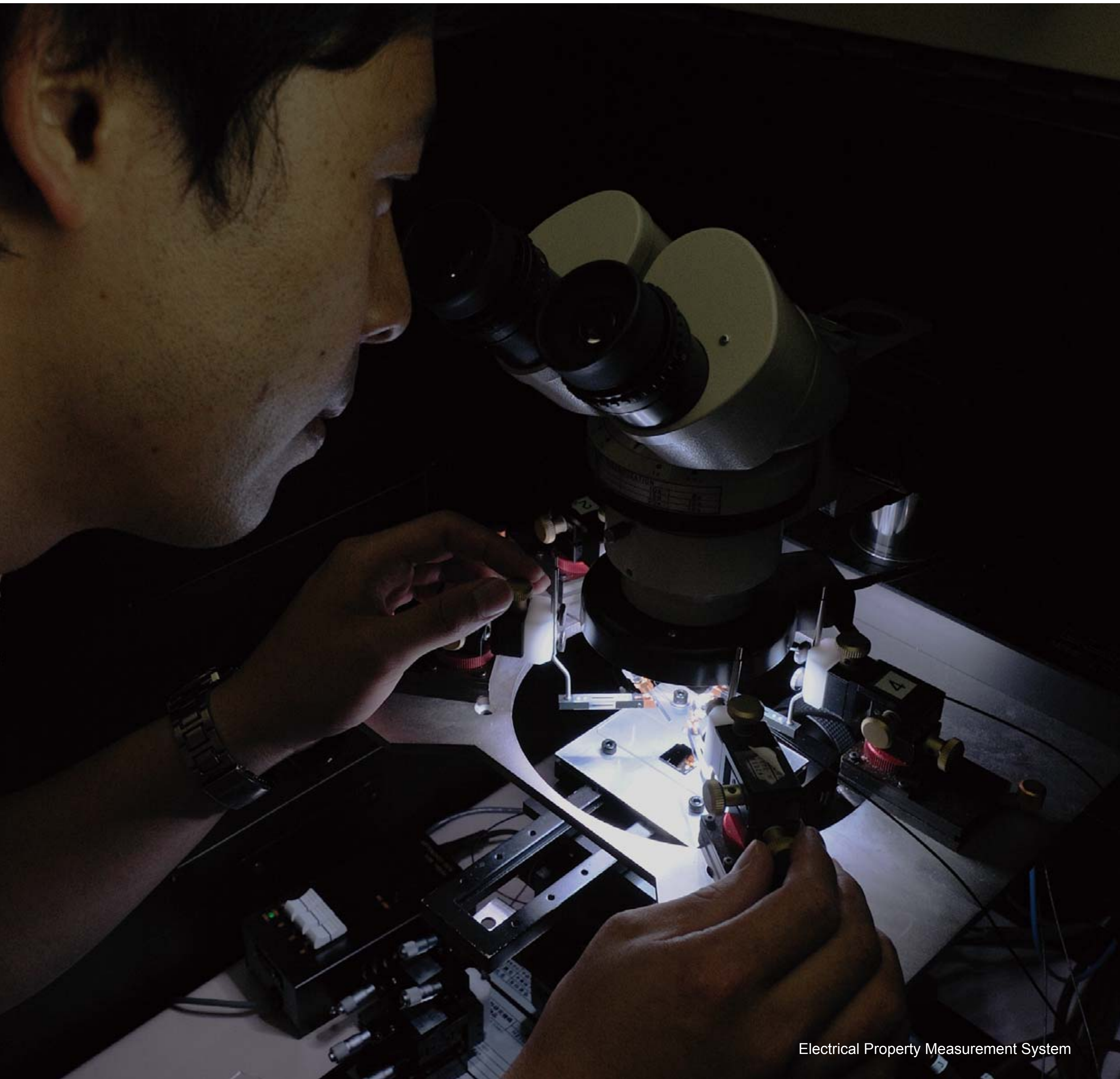
NIMS NOW International

2010. Jul-Aug

From Structures to Materials



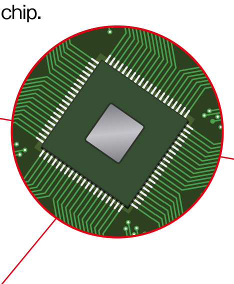
Electrical Property Measurement System

From Structures to Materials

**Semiconductor technology is evolving daily, and is continuing to answer the needs of society with greater miniaturization and higher integration.
At the same time, various problems occur at the atomic level.
One answer to this is new materials.
This Special Feature introduces approaches to semiconductor materials that are only possible at NIMS.**

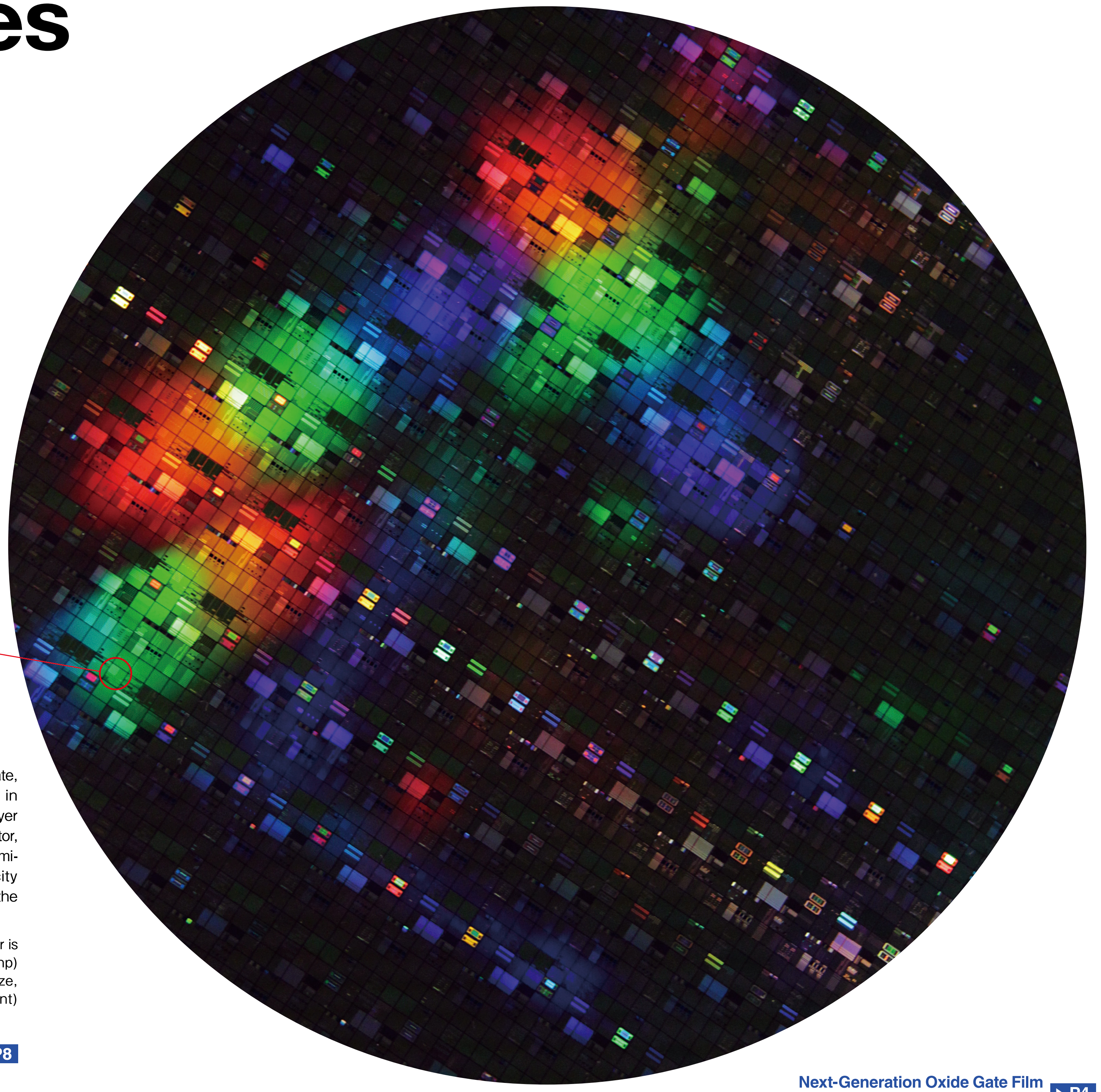
Incorporated in virtually all electronic devices.

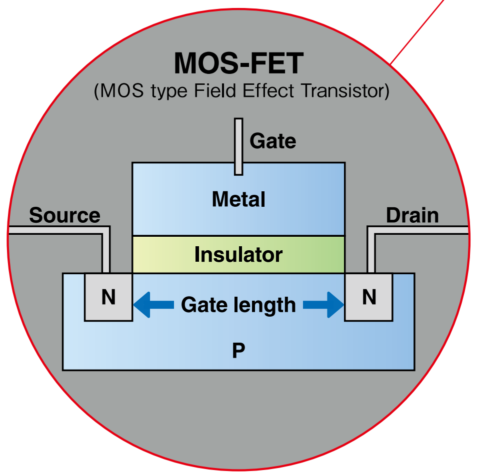
Memory IC (memory device): RAM , NVM, etc.
Logic IC (logic device): CPU, MPU, etc.



A semiconductor chip is cut out, and an integrated circuit (IC) is fabricated.

More than 10 million circuits exist on one chip.





When voltage is applied to a gate, a positive charge is generated in the metal plate; an inversion layer forms in the p-type semiconductor, and connects with the n-type semiconductor. As a result, electricity flows between the source and the drain.

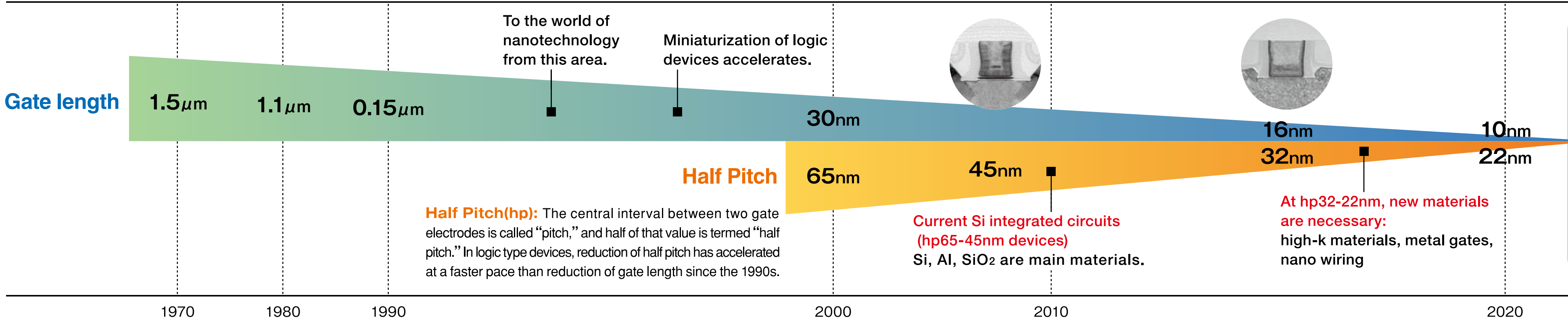
【Problem point】 When the insulator is made thinner, or the half pitch(hp) becomes smaller at the nano size, leaks of current (leakage current) increase.

Materials Development Technology at NIMS ▶ P8

Next-Generation Oxide Gate Film Evaluation Method: "EBIC" ▶ P4

Next-Generation Memory Using Quantum Dots: "Single Electron Memory" ▶ P5

Requirements: High speed, high integration, and multi-functionality.



Half Pitch(hp): The central interval between two gate electrodes is called "pitch," and half of that value is termed "half pitch." In logic type devices, reduction of half pitch has accelerated at a faster pace than reduction of gate length since the 1990s.

Current Si integrated circuits (hp65-45nm devices)
Si, Al, SiO_2 are main materials.

At hp32-22nm, new materials are necessary:
high-k materials, metal gates, nano wiring

Post-scaling generation

- Fusion of top-down and bottom-up.
- 3-dimensionalization of structures.
- Diverse structure and interface control.

International Trends ▶ P6

Photo : Courtesy of Intel Corporation

Challenge of the Nano Device Material

Toyohiro Chikyow
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Evolution of silicon semiconductors and their limits.

The requirements demanded in semiconductor devices are (1) high speed, (2) high density integration, (3) multi functionalities, and (4) low power consumption. The requirements of high speed and high density integration are realized by miniaturization, while high functionality is possible by merging new functions such as sensors, etc. with silicon (Si) devices. The function of low power consumption has been realized by Complementary MOS (CMOS).

Up to the present, Si devices have been limited to simple materials such as Si and silicon dioxide (SiO_2), and functions such as logic and memory have been created by manufacturing diverse structures by nano scale fabrication using photolithography.

As a result, the structures of Si devices have become increasingly complex over time. Representative examples include structures in which a gradient concentration of an impurity is applied to the electrode part (Lightly Doped Drain: LDD), sidewall structures for manufacturing those devices, and structures in which the charge accumulation layer of the memory is deeply engraved as a trench (groove).

With miniaturization, limitations due to the existing materials have become apparent. Examples of this are increased leakage current between the gate and drain accompanying reduction of the gate oxide film thickness, higher resistance of W in via wiring, signal delay in multilayer interconnections, etc. Thus, the materials and techniques used to date are approaching their limits with respect to the further miniaturization, higher performance, and reduced power consumption of the future.

Si semiconductors at a turning point.

Today, Si semiconductors are at a major turning point, which can be characterized as a change "from structures to materials." Development of new materials is currently in progress in order to satisfy both further miniaturization and higher integration. Concrete methods include the introduction of high-k (high dielectric) gate oxide films and metal gates. First-generation high-k and metal gates have already been applied in some devices and are contributing to reduced power consumption.

As a future direction of Si devices, there is a continuing move toward "materials technology and process technology as a source of added value." The device structure is simplified, and functions are realized by the materials. Representative examples are nanodevices comprising mainly materials, such as atomic switches as logic devices and ReRAM as memory devices, among others.

The challenge of "from structures to materials" in nanodevices has now truly begun.

MOS: Metal-Oxide-Semiconductor structure.

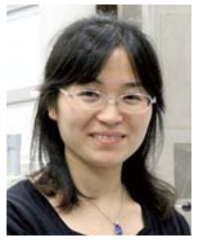
FET: Field Effect Transistor

high-k material: Material which suppresses leakage current and accumulates the same charge as when the thickness of SiO_2 is reduced, which is realized by increasing the thickness of the film using a high-k material with higher permittivity than SiO_2 as a new insulating film. Materials in which SiO_2 or SiN is mixed in a material using an ionic crystal, such as HfO_2, La_2O_3, etc. are used.

Atomic switch: Switch based on a new principle, which is operated by controlling the movement of atoms rather than the movement of electrons.

ReRAM: Resistance Random Access Memory. Features include operation with extremely small current, low power consumption, easy structural refinement, etc.

NIMS-Developed Next-Generation Gate Oxide Film Evaluation Method: EBIC



Jun Chen
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Problems in manifestation of functions of high-k materials.

The metal-oxide-semiconductor (MOS) structure is a fundamental structure which manifests functions in next-generation integrated circuits. Polycrystalline silicon is used as a gate material in this structure, and SiO_2 is used as the gate oxide film. However, with progressively higher integration and miniaturization, the SiO_2 gate oxide has become excessively thin, and gate leakage current becomes a major problem. High dielectric-constant gate oxides, or so-called high-k materials, attracted considerable attention as a new insulating film which makes it possible to prevent gate leakage current.

When high-k materials were actually used, however, it was not possible to reduce leakage currents as expected. The reason for this is unclear, but was not particularly due to the high-k film itself. Because high-k gate oxide film is located under gate electrode and surface passivation film, it cannot be observed by conventional evaluation methods. Until now, only models which explained phenomena based on changes in electrical properties had been established. An outstanding method which solves this problem is the electron beam induced current (EBIC) method. Using this EBIC method, we made it possible to discover the position of leaks in MOSFET devices with high-k materials and to clarify the occurrence of the leakage current and its behavior.

The position of leakage currents located by the EBIC method.

As shown in **Fig.1**, in this EBIC method, electron-hole pairs are generated in the specimen by an electron beam injection, and electrons and holes are extracted from the upper electrode and Si substrate. When there are no defects in the high-k film, generated electrons and holes will not leak through the film. If there are defects in the film, the leak of electrons and holes will be observed as leakage current. In images acquired by the EBIC method, this leakage current appears as a white spot. It is possible to visualize the location of defects by gaining the image of the EBIC signal with moving the electron beam in a scanning electron microscope.

This method makes it possible to identify the location where a leakage current is occurring in an actual MOS device. This was a "world's first" achievement by NIMS, and was also a major advance in reliability evaluation techniques for high-k materials (**Fig. 2**).

Evolution of the EBIC method.

Recently, leakage sites have been observed with the transmission electron microscope by slicing techniques, and more detailed observations become possible. As a result, various points which were not understood before have been clarified. At the leakage site, the stack is heated by Joule heat[*], causing a reaction at the high-k/SiO_2 interface which results in slight thickening of the SiO_2. It was also found that the number of leakage sites in a high-k film depends on the material of top electrode.

By making various changes in the parameters of EBIC observation, it is possible not only to observe the distribution of structural defects and/or faults, but also to understand the energy level and depth dependency of the defects.

NIMS is now taking on the challenge of developing "multi-dimensional EBIC" as a multi-functional evaluation method by combining of various measurement techniques with EBIC. In the future, we will also undertake development of new functional devices with new semiconductor materials using this method (**Fig. 3**).

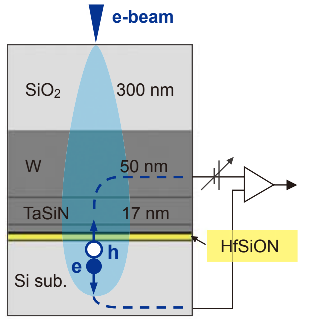

Fig.1 Principle of the electron beam induced current (EBIC) method: Electrons and holes are generated in a specimen by irradiating the top of the specimen with an electron beam, and a current is obtained by extracting the electrons/holes from the top electrode and the substrate Si. If a defect exists in the film, the numbers of electrons and holes will be different at that site, and this is expressed as contrast.

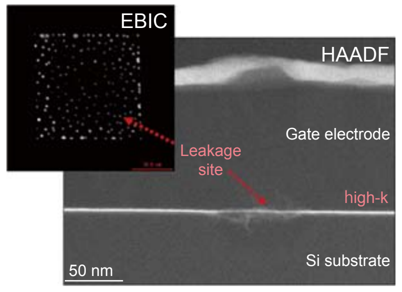

Fig.2 An example of an EBIC image of a high-k MOSFET, and a TEM image of the cross section at the leakage site.

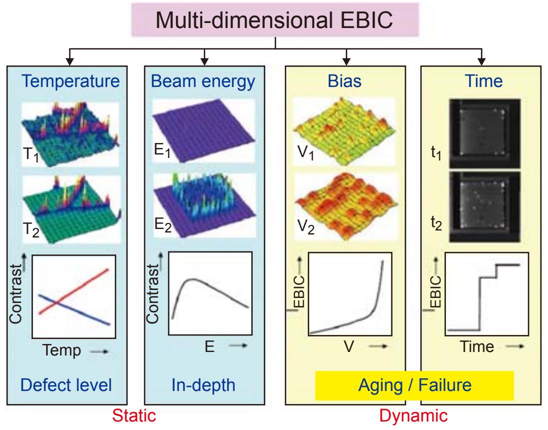

Fig.3 Schematic diagram of the proposed "multi-dimensional EBIC" method combining EBIC and various other measurement techniques.

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[*] Joule heat: Heat generated when an electric current passes through a conductive material.

Profile
Jun Chen (left)
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Takashi Sekiguchi (right)
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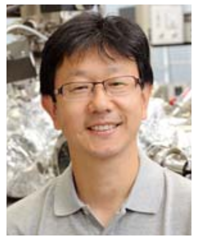
Next-Generation Single-Electron Memory Using Molecules



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Next-generation memory using quantum dots.

Single-electron memory is a type of next-generation memory devices in which charge accumulation can be controlled at the level of individual electrons by using the Coulomb blockade effect, by which individual electrons enter quantum dots,[*1] and their electrical resistance changes in staircase shape. High expectations are placed on this structure as a next-generation memory because it offers a combination of low power consumption and multi-valued operation. However, in spite of the fact that this idea was introduced for more than two decades ago, it still has not been realized.

One major obstacle of using single-electron memory is the extreme difficulty of uniformly controlling the size of quantum dots at the nanometer scale. In order to realize a quantum mechanics phenomenon like the Coulomb blockade effect at room temperature, it is necessary to develop uniform quantum dots with several nanometers in size.

The idea of using molecules as quantum dots.

We are attempting to overcome the problem described above by utilizing the fact that the "molecule" itself is an ideal quantum dot, and utilizing accumulating electrons in molecules as memory. Our aim is to create quantum dots with new distinct functions by making use of the functionality of organic molecules (**Fig. 1**).

There are several advantages of using molecules as quantum dots. First, molecules themselves are uniform particles with several nanometers in size, thus the problem of non-uniform size, which arises with inorganic materials, is not an issue. Secondly, the energy level of the matrix molecule can be controlled freely by adding substitution groups which make it possible to decrease or increase the electron density. This means the electron density can be controlled and multiple values can be realized by using combinations of these molecules. Finally, photocontrolled single-electron memory devices can be fabricated by using molecules which possess the property of photochromism, that is, molecules which change color due to changes in the structure or electronic state of the material when irradiated with light.

We have succeeded in observing the so-called Coulomb staircase, in which resistance changes in a staircase manner due to the Coulomb blockade, in a single-electron tunneling phenomenon by using various molecules, beginning with fullerenes and phthalocyanines, in a Metal-Oxide-Semiconductor (MOS) structure, which is the basic structure of single-electron memories.

With additional improvements, operation is possible at near-room temperature.

However, this phenomenon has been limited to cryogenic temperatures on the order of 20K (-253.15 °C). A part of the reason that we observed Coulomb staircase in such low temperature was because it is extremely difficult to form a high-quality insulating film without destroying the molecules. In order to overcome this problem, the development of high-quality insulating thin film is necessary. By using an atomic layer deposition technique, an experimental apparatus that specially designed to grow high-quality insulating materials at low temperature, we successfully formed aluminum oxide thin film with excellent insulating properties, but most importantly without destroying molecules while controlling the thickness of the individual layers. As a result, particularly when using fullerenes as quantum dots, we were able to obtain extremely revolutionary results, in which we observed the Coulomb staircase at a near-room temperature of 260K (-13.15 °C; **Fig. 2**). Until now, the Coulomb blockade effect has been usually considered as a phenomenon that only occurs at cryogenic temperatures. However, this achievement demonstrated that the Coulomb blockade effect can also occur at room temperature. This means that realization of single-electron molecular memory devices which operate at room temperature can be expected in the near future. We believe that this kind of demonstration is worthy of attention, since this study introduced a new prototype of memory device concepts such as the use of single electron, quantum dots and organic molecules.

In the future, we plan to integrate new functionality of these quantum dots to new prototype devices which could not be realized with conventional silicon devices technology, such as multi-valued operation devices using heterogeneous molecules and photocontrol memory devices using photochromic molecules.

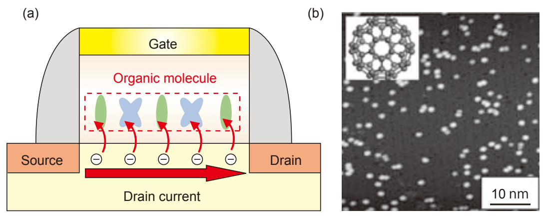

Fig.1 (a) Schematic diagram of single-electron memory using molecules as the charge accumulation layer, and (b) SEM image of C_{60} molecules dispersed as single molecules on an Si(111) substrate. It can be understood that the individual molecules are dispersed in an isolated state.

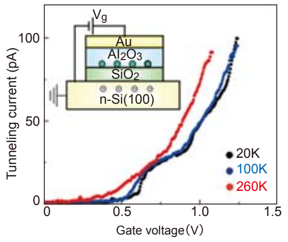

Fig.2 Current-voltage characteristics in an Au/Al_2O_3/C_{60}/SiO_2/Si-MOS structure. A Coulomb staircase was observed at near-room temperature of 260K.

[*1] Quantum dots: See the May issue of NIMS NOW.

Profile
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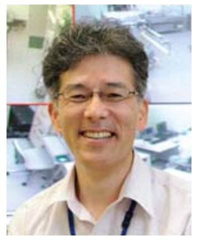
International Trends in Development of Silicon Semiconductors



Toshihide Nabatame
General Manager,
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Approach to semiconductor development different in each country.

In silicon semiconductor technology, a number of issues exist in the area of scaling, as described in the Semiconductor Roadmap (ITRS2009). According to Moore's scaling law, it is possible to produce planar devices, i.e., planar structures like those up to now, to the 16.9 nm technology generation. Beyond this generation, a transition to 3-dimensional structures using multi-gates (More-Moore) and multifunctional electronic devices (More-Than-Moore) is considered. As part of this, distinctive features can be seen in the respective trends and approaches to the development of semiconductors in Japan, the United States and Europe.

Half pitch (hp) is used as an index which expresses miniaturization in terms of gate length. For example, in the hp65 nm generation, the distance between the source and drain is on the order of 30 nm. In terms of this index, an important turning point in technical development occurs between the hp45 nm and hp32 nm generations. Here, new metal gate electrodes and high dielectric oxide (high-k) gate insulating films are introduced in place of the conventional materials. All companies are engaged in a fierce competition to develop the related technologies. The largest issue in this technology is control of the threshold voltage turning the current on and off.

Two major players in the US: Intel and IBM.

The United States is playing the leading role in More-Moore. In particular, Intel succeeded in commercializing the hp45 nm generation by developing a low-temperature device manufacturing technology for a metal/high-k structure called the "gate-last process," in which the gate stack structure is fabricated last, after manufacturing the underlying source and drain. This process has the advantage that the threshold voltage can be controlled simply by using a metal gate material with a different work function.

On the other hand, a group of several companies led by IBM is developing a technology for manufacturing a metal/high-k gate stack structure by a "gate-first process" at the State University of New York Albany. This process features the development of a high quality high-k film, and is a continuation of the conventional process from the viewpoint of reliability. This is a method in which the gate stack structure is fabricated first, followed by fabrication of the source and drain by ion implantation, and is advantageous for miniaturization. With this process, activation of the impurities after ion implantation is necessary, and fabrication of a more stable metal/high-k interface is an essential. Since the conventional Si process can be followed and the quality of high-k film can be also improved by high temperature annealing, there is a big merit that high reliability is provided by commercial production of a device as a result.

Semiconductor development in Japan and Europe.

In Japan, technical development for manufacture of an hp32 nm generation metal/high-k gate stack structure by the gate-first process was recommended by Selete (Semiconductor Leading Edge Technologies, Inc.), which is a consortium of Japanese semiconductor manufacturers. Technical development of the process was completed in fiscal year 2009, and the participating companies are now transferring the technology to their own development/commercialization processes. Toshiba is promoting development by participation in the IBM group, while Renesas Electronics and Panasonic develop jointly, and Fujitsu Microelectronics is involved in joint development with TSMC of Taiwan.

While Japan and the U.S. are pursuing the More-Moore approach focusing on miniaturization, Europe is moving in the direction of More-Than-Moore by adding new functions to semiconductor devices, and thus is prioritizing the development of multifunctional electronic devices. The various European countries have constructed nanotechnology and nanoelectronics clusters with industry, university, and government participation, and are attempting to respond flexibly to a wide range of fields by collaboration of these clusters.

Attention focused on high-k/SiO_2 hetero-interface.

As a common topic amid these trends, hetero-interfaces (interfaces of different types of materials) of high-k/SiO_2, which is formed by placing a high-k film with strong ionic oxide in contact with SiO_2 film with covalent oxide, have attracted considerable attention in the technical development of metal/high-k gate stack structure. When a high-k film is directly deposited on SiO_2 film, the charge transfer caused by the movement of the oxygen in the high-k/SiO_2 interface for the structure stabilization is one of the major factors which cause the flatband voltage change.

NIMS has been systematically investigated the effect of oxygen at the hetero-interface on the flatband voltage shift (**Fig. 1**). When active oxygen is introduced into the HfO_2 film by the annealing process in oxygen ambient using the catalytic effect of a Pt (platinum) electrode, it is clear that the flatband voltage shifts toward positive direction with increasing the oxidation annealing temperature. This is considered that the number of electric charge changed with the increase in oxygen at the hetero-interface, and as a result, the strength of dipole changed. .

The scientific understanding of hetero-interface between two oxides is expected to be extremely useful in solving problems related to hetero-interface with 3-dimensional structures, such as nanowires and FinFET (3-dimensional transistors).

Trends in Various Regions

Region	Direction of development	Companies developing	Trends
United States	More-Moore	Intel	Commercialization of hp45nm generation products using the gate last process.
		IBM	Development of 32nm and after using the gate first process.
Japan	More-Moore	Selete (Semiconductor Leading Edge Technologies, Inc.) (With participation of various semiconductor makers)	Technical development of the gate first process has been completed, and work has now moved to the in-house development processes in each company. → Toshiba: Development of 32nm and after with IBM and other companies. → Panasonic: Joint development of 28nm with Renesas Electronics. → Fujitsu Microelectronics: Joint development of 28nm with TSMC (Taiwan)
Taiwan	More-Moore	TSMC	Moving to Fab level; development of the gate last process is now in progress.
Europe	More-Than-Moore		Development of multifunctional electronic devices.

Gate First Process and Gate Last Process

Process	Fabrication method	Advantages	Problems
Gate first process	After gate is fabricated, the ion injection source and drain are fabricated by a high temperature process.	Can follow the conventional process. High quality of high-k film. High reliability. Advantageous in miniaturization.	Essential to fabricate a metal/high-k interface which is stable at high temperatures. Threshold value control of band width is difficult. Cost is high due to increased number of masks in the cap process.
Gate last process	The source and drain are fabricated first by a high temperature process, and the gate is fabricated in the final process.	Possible to control the threshold voltage simply by using a metal gate material with a different work function. Wide range in selection of materials, including low temperature processes, etc.	Overlap control of source/drain and gate in miniaturization is difficult. Fabrication of high aspect gate stacks is essential. Quality of the high-k film is low.

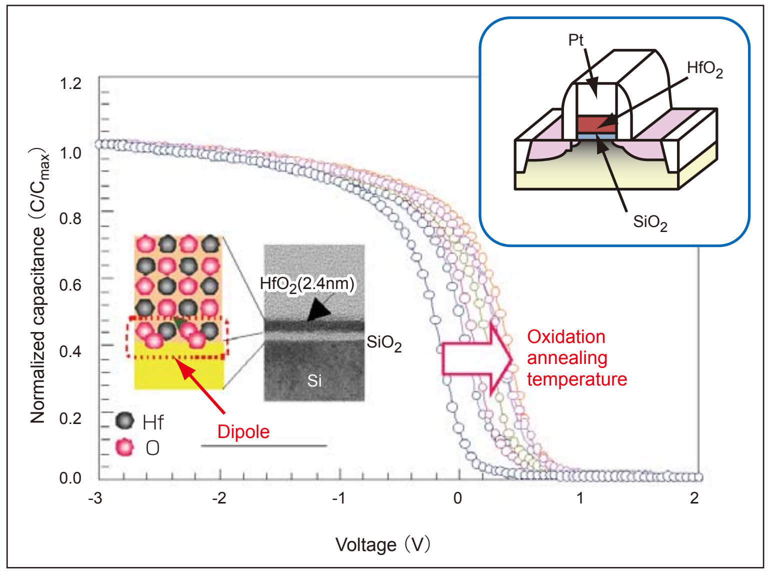
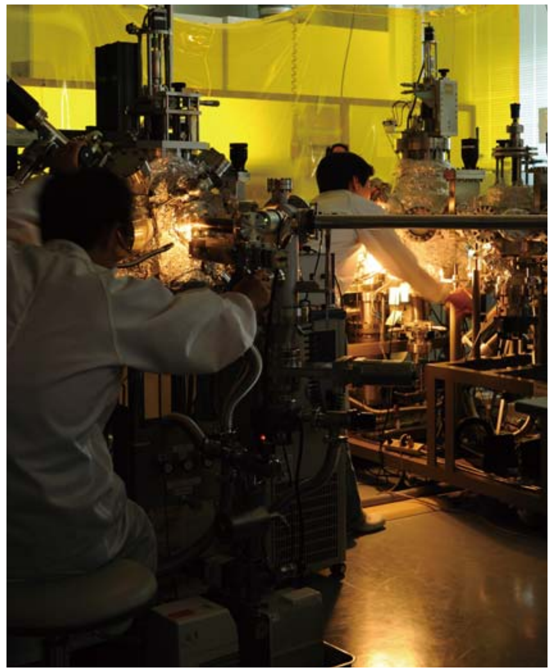


Fig. 1 C-V characteristics of Pt/HfO_2/SiO_2 capacitors with changing oxidation annealing temperature. It clearly shows that the C-V curve shifts toward positive direction with increasing the oxidation annealing temperature, resulting from the dipole formation due to the increased oxygen content at the HfO_2/SiO_2 hetero-interface.



Profile
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Doctor of Engineering. Completed the Tohoku University Graduate School. Joined the Hitachi Research Laboratory of Hitachi, Ltd. in 1987 as Senior Researcher, and joined Renesas Technology in 2003, and current position from April 2009.

Materials Development Technology at NIMS Supporting Next-Generation Semiconductor Materials

Toyohiro Chikyow
Managing Director,
Advanced Electronic Materials Center

Michiko Yoshitake
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Because integrated circuits are aggregates of materials, basic research at NIMS is playing a vital role.

The integrated circuits of today are aggregates of diverse materials, comprising various interfaces. For next-generation Si-based nanoelectronics, a fusion of the functionality of materials with Si devices is becoming necessary. Basic research on these materials is already underway at NIMS.

This Special Feature presents representative examples of that research, such as visualization of nanoscale defects in high-k films by the electron beam induced current (EBIC) method (p. 4) and the possibility of realizing multi-valued memory, which had not existed in the past, by implanting organic molecules in gate oxide films (p. 5).

For example, in order to respond to the miniaturization of devices, amorphous materials with high permittivity are necessary in high-k films and metal gates. From a different point of view, this can be seen as a search for high refractivity glass materials. In fact, La_2O_3 (lanthanum oxide), which is an optical material, is among the candidates for next-generation high-k materials.

In metal gates, multi-element metals which form a stable interface with oxides are demanded as materials which are amorphous and enable work function control. NIMS is also engaged in research on realizing amorphous metals, and it is possible to search for materials by interface evaluation techniques and measurement of the work function combined with photoemission spectroscopy. In addition, the NIMS high-brightness synchrotron radiation beam line at SPring-8 is demonstrating its effectiveness in measurements of the band composition from the metal gate to the substrate Si.

The combinatorial materials synthesis methods[*1] developed by NIMS is also making an important contribution to the development of new materials for nanoelectronics. In particular, NIMS is capable of responding to the synthesis of diverse materials from oxides to metals and has actual results of the development of combinatorial synthesis methods with high generality.

The advantage of NIMS not only in semiconductors, but also in integrated circuits.

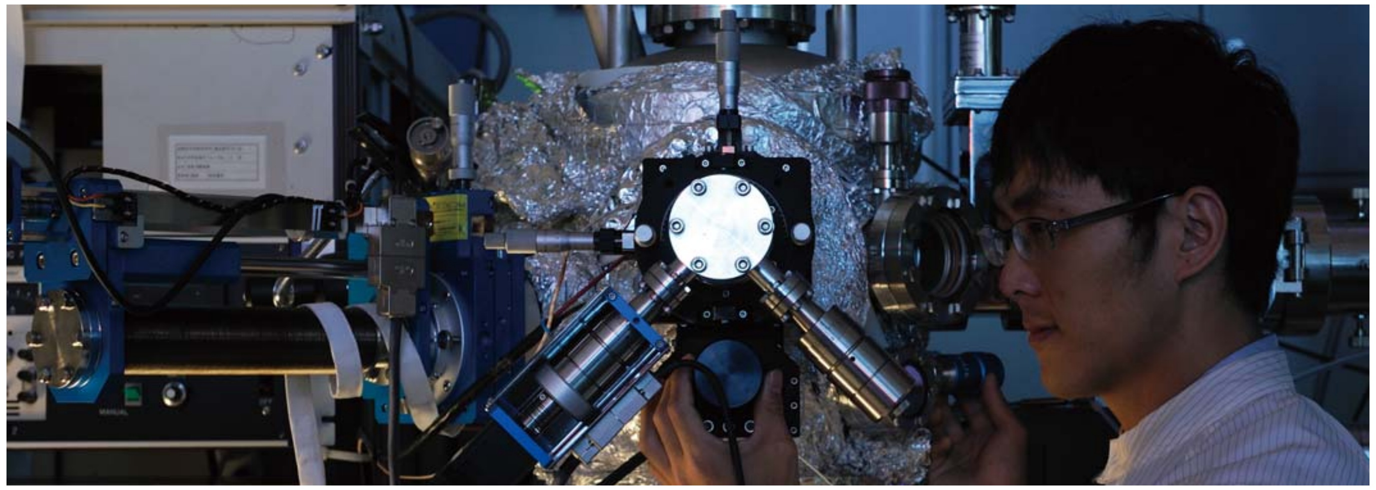
Other research centers in NIMS can also greatly contribute to the semiconductor research. Measurements which are necessary in materials searches are generally difficult. For example, measurement of the high frequency region of high-k films in the GHz band is extremely difficult. However, at NIMS, measurement of permittivity is possible by a characterization technique using microwaves.

It has also become possible to compare these results with the results of calculations such as the permittivity and dielectric response in the high frequency region, and defects and impurity levels in oxides, etc. using first-principles calculations.

In the future, multiplex signal processing by optical wiring will be necessary for multi-layer wiring. For this, Si photonics is important, and it is necessary to incorporate a light source and light conversion device in the chips. NIMS was the first in the world to realize a nonlinear optical device[*2] on a silicon substrate. This satisfied both a nanodomain polarization reversal structure[*3] and adhered-ridge optical waveguide[*4] on Si. NIMS demonstrated that far higher conversion efficiency is realized with this device in comparison with the conventional wavelength conversion method in Si. This contributes to reduced power consumption through reduction of excitation light[*5] source output and is applicable not only to high-functionality silicon photonics, but also to miniaturization/integration of optical telecommunications devices.

NIMS is leading the journey in the search for nanoelectronics/materials.

The highly-reliable NIMS materials database, which was constructed by arranging these results and collecting data from the literature throughout the world, provides guidelines when searching for materials.



Today, nanoelectronics is at the turning point "from structures to materials." Seen from the viewpoint of patents, the number of materials-related Japanese patents surpasses that in the United States. Strategies for utilizing this materials-related intellectual property in industry are necessary.

NIMS possesses the research capabilities, actual results, and infrastructure demanded by the times in next-generation Si nanoelectronics. In comparison with other organizations, NIMS can be seen as an organization which is capable of constructing the "nanoelectronics of the future from the viewpoint of materials."

In the change in devices "from structures to materials," heightened expectations, including those of private companies, are placed on NIMS as the largest materials research institute in Japan. NIMS aims to contribute to this field based on its knowledge, experience, and achievements in materials.

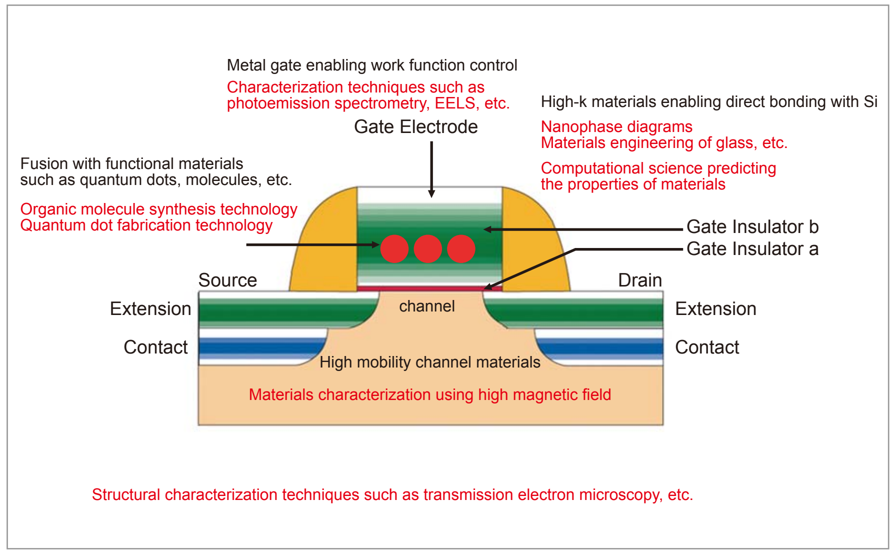


Fig. 1 Latent capabilities of NIMS in nanoelectronics research.

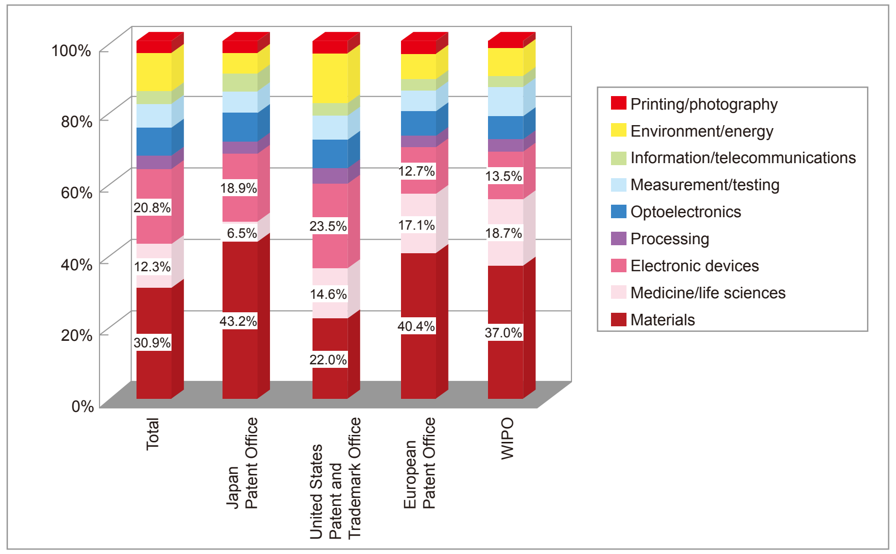


Fig. 2 Trend in nanoelectronics research in Europe and the United States by fields of patents.
(Data courtesy of the National Institute of Science and Technology Policy).
Percentage of applications for nanotechnology patents by 9 fields of technology (2004)

Profile

Toyohiro Chikyow (left)
Doctor of Engineering. Completed the doctoral course at the Waseda University Graduate School. Joined the NRIM in 1989. From 1999 to 2006, participated in the leading research project "Combinatorial Materials Exploration and Technology." Has held his present position since 2006. Visiting Researcher at North Carolina State University 1993-1994, Visiting Professor of the University of Washington, Department of Materials Science and Engineering since 1995. Professor in the NIMS-Waseda University Joint Graduate Program since 2009 (concurrent position).

Michiko Yoshitake (right)
Doctor of Engineering. Graduated Faculty of Science, Ochanomizu University. Completed the master course at the Graduate School of the University of Tokyo. Joined NRIM in 1987 and got doctor's degree at Univ. of Tokyo in 1992. Visiting Researcher at National Institute of Standards and Technology (NIST) in United States from 1992-1993. Current position since 2006.

[*1] Combinatorial materials synthesis method: Technique which enables high speed synthesis of ternary compounds by automatic control of base-plate rotation and moving masks.

[*2] Nonlinear optical device: Device in which the response of light and electrons is not linear, in other words, a device which utilizes nonlinear effects. Various functions can be realized depending on the design, such as laser light wavelength conversion, optical switches that can turn on and off by light, etc. These devices are used in ultra-high speed optical control and optical measurements.

[*3] Polarization reversal structure: Structure which reverses the spontaneous polarization (positive/negative charge separation) of ferroelectrics. If a periodical polarization reversal structure (periodically-poled structure) is fabricated, high efficiency operation as a wavelength conversion device for laser light can be realized. The generated wavelength and polarization can be selected depending on the period, giving a high degree of freedom in designing devices.

[*4] Adhered-ridge optical waveguide: A waveguide is a light path which is fabricated by increasing the refractive index of part of a substance. Optical fiber is a typical example. Because light can be propagated while being confined within a narrow region, leakage is low, and high wavelength conversion efficiency can be obtained by combining this device with polarization reversal. In comparison with the case of no waveguide, 100 to 10,000 times higher efficiency can be obtained. In particular, in adhered-ridge type waveguides, the refractive index changes in a step-like manner in the vertical direction of the substrate and the transverse direction of the waveguide, forming a waveguide with minimal leakage of light from the waveguide and strong confinement.

[*5] Excitation light: Excited light with high monochromacity emitted from semiconductors such as lasers, LEDs, etc.

The Creation and Quest for New Value

Japan Science and Technology Agency (JST), President

Dr. Koichi Kitazawa

Japan is among the world's leaders in science and technology, as exemplified by the epoch-making discoveries in iPS cells and iron-based high temperature superconductors. At the same time, however, there is a prevailing feeling of blockage and a lack of national vitality in the country as a whole. What should we do to create a society which can overcome this situation and inspire hopes and dreams in the young generation? In this Special Interview, the President of the Japan Science and Technology Agency (JST) shares his passionate feelings on these issues.

—You recently published a book entitled "Will Science and Technology Save Japan?"

The current level of Japanese science and technology has become truly amazing. In fact, Japan's science and technology are now among the best in the world. However, even though Japan is in the vanguard in many areas, with the exception of materials technology, we lack depth. It's also a problem that we aren't making full use of our science and technology.

Economics is one reason for this failure to fully exploit our achievements in science and technology. For example, if we make full use of one outstanding technology, it can mean the end of other competing technologies. This is because Japan has, in effect, strictly adhered to a foreign trade formula of exports minus imports equals 10 trillion yen over the past 25 years, and when some new export appears, some other item is dropped from the export list.

—If this is so, is it a mistake to grow the economy by creating and exporting new materials?

The answer is yes. It's not good simply to increase exports of a certain item. If that item isn't also used domestically as a product, GDP will not increase. This may be good for companies because they can locate operations overseas, but if that money is only used in other countries, it does nothing to enrich Japan's domestic economy.

What I stress is that we should pursue the "4th Value" in order to overcome the economic malaise in Japan. Until now, we have pushed process innovation and product innovation as the fruits of science and technology. As a result, we find ourselves in a situation where our material needs are satisfied; we have nothing left to desire, and GDP does not increase. From this viewpoint, we must now think about what new value we might desire. I think this value is different from the 1st, 2nd, and 3rd values.

—The 1st, 2nd, and 3rd values center on food, material goods, and services. Is a new value different from those things?

What would a newer value be like? For example, for young people, I think that it might be a system which encourages large numbers of fellow young people to gather, a place or facility where they can play sports, situations where they can enjoy culture, etc. The environment is conceivable as a 4th value related to science and technology. This is also an advantage from the economic viewpoint, because environmental technologies necessarily include elements that are consumed domestically. So, if we make the environment a priority, it will increase both GDP and employment. I think that new values must be such that they create objects which make it possible to invest in Japan. If we don't do that, domestic unemployment will only continue to increase.

—Investment in objects that have this 4th value is important, isn't it?

I think that investment in the environment fits that description. It's also a value that everyone can easily recognize. Domestically, investment in the environment also includes beautification of Japan's cities and towns, improvement of amenities, and other investments that improve the ordinary person's everyday life. If NPOs and similar organizations can serve as the driving force for that, it will also contribute to expanding the framework and activities among like-minded people.

Technologies which open the road to solving global environmental problems should be cultivated first in Japan, and when they begin to bear fruit, we should offer them to the world. This will give young Japanese a wider range of opportunities where they can play an active role. We have ample funds for this, and there are also several methods of funding that don't depend on spending by the government.

—Could you comment on the relationship between global environmental technologies and the economy?

One example is the popularization of renewable energy by a system under which electric power companies are obliged to purchase, at a set price, electric power generated by individual households and others. This kind of system has already been introduced in Germany, and its effectiveness has been proved. However, Japan has not introduced a similar system due to concerns about the impact on international competitiveness. Ten years have passed, and what have the results been? The system has been very successful in Germany. For example, by 2007, Germany's renewable energy industry had produced 250,000 new jobs. Japan should study this kind of system. We didn't do this, and there were no indications that it improved our international competitiveness.

Up to now, Japanese power companies, METI, and MEXT have supported nuclear power. There is a widely-held view that the introduction of nuclear power is inevitable, considering its cost and speed in realizing a low carbon society. However, many of the children and their mothers in the future don't necessarily consider that nuclear power is the only solution. While we promote nuclear power, on the other hand, we must also explore the possibilities of natural energy. If we don't do this, I think we will destroy the dreams of our children. It is necessary to explore the potential of both types of energy, and it is important to lay the groundwork now, so that the next generation will be able to choose between the two. The JST's role in this is to challenge the possibilities of different forms of energy in the realm of science and technology, with the aim of enabling breakthroughs in energy technology.

—To choose between natural energy and nuclear power at some point in time, is certainly an important perspective.

I'm interested in how France's President Sarkozy is dealing with this issue. As you know, France is the only country in the world that depends on nuclear energy for 80% of its electric power. However, in future energy development, President Sarkozy has said that France will spend equal amounts on nuclear power and natural energy. Japan is different in this respect. We're putting most of our effort into one and reducing the other. This has led to mutual criticism, and the very words "nuclear power" now seem to be taboo. We can't make a convincing argument to our children under these circumstances.

We should say more openly to our children, if there's another good way, if possible, let's stop using nuclear power. But if this isn't possible, then we should increase the use of nuclear power for the time being, while also continuing technical development of natural energy.

—How do we pursue the 4th value?

I think that the approach in the Netherlands offers one example. In the 1980s, the Netherlands was considered a burden on Europe. The business climate was extremely bad, and unemployment was as high as 20%. To solve this problem, the government of the time reduced wages by 20%, but at the same time, they also shortened working hours by 20%. As a result, the 20% unemployment problem was solved with no change in total spending. In this case, there should also be no change in GDP, but in reality, GDP increased. Why did this happen? In fact, NPO activities increased because people had more free time. NPOs carried out a variety of economic activities like building cycling roads, repairing canals, and beautifying the country's famous windmills.

By definition, it would seem that volunteers don't make money. However, this isn't the case. In NPOs, management doesn't distribute earnings, but the NPOs receive funds to carry out projects, so they can pay wages or salaries to the people who actually do the work. Dutch NPOs have steadily expanded, and their income has also grown. As a result, NPOs now account for 20% of GDP and employment in the Netherlands.

—I'm sure our readers are wondering where the money for NPOs comes from.

It comes from various sources. For example, in Japan, the national government, local governments, and individuals pay for elderly care service, and when mountain forests are thinned, the resulting timber is used to make charcoal for sale, which provides income. People who receive training to work in child-support programs pay lesson fees. Assuming that working for social justice is a precondition for an NPO, the income it generates may be less than that produced by corporate business activities, but an NPO also naturally includes an element of economic activity.

When NPO activities are flourishing, this contributes to the 4th value. Why? Because the 4th value is based on a sense of justice, and on camaraderie. What's more, it's enjoyable. For example, Iida City in Nagano Prefecture is carrying out a town revitalization project based on natural energy. The town is enjoying ecology as an "eco-village," and if this attracts tourists for eco-tours, it also contributes to economic activity. An increasing number of individuals from big cities are also investing in solar cell firms in Iida. Science and technology related to natural energy are contributing to this. I'm thinking about this kind of thing.

—Values are changing, depending on individuals and society, and generations.

I'm part of the immediate post-war generation. For us, the most important values were simply being able to live and making sure that everyone had enough to eat. Today's young people live in a world where it's taken for granted that everyone can eat, and values are becoming increasingly diverse. Being able to find one's own reason for living has become important, and for the political viewpoint, Prime Minister Kan's "least unhappy society" has become a necessity. This is based on the fact that it's no longer possible to determine a uniform choice of overall values. However, I have my own sense of values.

Although I also mention this in my book, today's young generation is a generation that is strongly influenced by the animated film director Hayao Miyazaki. They go off into the mountains and enjoy living with nature every day. In a sense, they are perhaps hostile to people like me, who are involved in development work in an engineering department. This young generation has a strong sense of that we should make amends for the damage done to the global environment. I think that they would also be willing to provide financial support for restoring a more abundant natural environment.

—Values are also different, depending on the object of investment.

Yes. When I look at how younger people define their place in the world, I think they want to live happily while observing certain rules, including peace and good relations among people, not causing trouble to other people, and not harming nature if at all possible.

However, they still do not think that they can actively solve the problems of the future, and this means that they don't have hopes for the future. As a result, they're content simply to enjoy the present moment, and that's a problem. As my message, I want to communicate the idea of a "Planet Earth Defense Corps" to the younger generation, because I think this can inspire them with hopes for the future.

—A "Planet Earth Defense Corps" . . . Could you describe this in more concrete terms?

The idea behind this is that, by creating project groups to solve global-scale problems by science and technology, we can present children with challenging issues which inspire them with dreams for the future, and when they become adults, we can call on them to join this effort and work together to protect the planet. For example, building a global superconducting power grid will make it possible to deliver power to the night-time side of planet, enabling use of solar power anywhere, night or day. Likewise, at the global scale, the wind is always blowing somewhere. Using this grid, the countries of the Sahara Desert can also become power-exporting countries.

In actuality, a decrease in geomagnetism is now being observed. Although the earth's magnetic field has always protected us from cosmic rays, it is now possible that these cosmic rays may reach the earth's surface within several hundred years. Thus, it is also possible that humankind may have to carry out a project to construct a superconducting permanent current loop around the Equator before this happens in order to ensure the survival of the species.

I seriously hope that our children will realize this global superconducting power grid concept.

—How can NIMS contribute to this concept?

Science and technology have the power to inspire children with the dream that they can solve the problems of the future. For this reason, I hope that NIMS will communicate to young people the message of "the possibility of solving problems" of the future. Building a system which makes it possible to propose dreams for the future to the next generation is one role of researchers as we go forward.

I also hope that these messages will be "game-changing." The image that I have in mind is something that will be a great leap from the status quo. I hope that you will propose truly bold ideas, for example, Euglena and Chlorella with 4 times higher photosynthesis efficiency, bees that collect biomass, solar cells at 1/10 today's cost, microbal biosolar cells, silent windmills, and high performance thermoelectric semiconductors.

Profile
Born in Nagano Prefecture, Japan, in 1943. Received his Master's Degree from the Graduate School, University of Tokyo and his Doctorate from Massachusetts Institute of Technology. Prior to becoming President of the Japan Science and Technology Agency (JST), his posts included Professor of the Faculty of Engineering, University of Tokyo. Dr. Kitazawa is a member of the Science Council of Japan and received the 2009 Outstanding Achievement Award of the Japan Society of Applied Physics (JSAP).

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* **METI:** Ministry of Economy, Trade and Industry
* **MEXT:** Ministry of Education, Culture, Sports, Science and Technology

Fascinated by the Nano World

Daisuke Fujita

Managing Director, Advanced Nano Characterization Center

Nanotech research at NIMS aims at nanotechnology innovation by the development and improvement of advanced generic and infrastructure technologies for nanotechnology. Dr. Daisuke Fujita is Coordinating Director and a driving force of the NIMS “Key Nanotechnologies Field” which is in the vanguard in this effort. In this FACE Interview, we asked Dr. Fujita about his everyday work as a frontline researcher and a member of NIMS management, his thoughts on research, and his vision of the future of NIMS.

—First, could you tell our readers where you were born and grew up?

I was actually born in Minoh City, which is in the metropolitan Osaka area. However, both of my parents came from homes in Omuta City in Fukuoka Prefecture, so I spent my childhood in Kyushu, which is a local part of western Japan. Later, we moved several times related to my father’s business. I lived in Tokyo from middle school through university, so when we talk about “where I’m from,” perhaps I can say Tokyo.

—What kind of child were you?

My favorite field was sports. From my kindergarten days, I was a fast runner. In elementary school, I was good in track and field events, including the marathon, relays, and the high jump. I participated in track and field and basketball in middle school, and in track and field in high school and university.

Also, as a child, I liked plays that involved handicrafts, so I liked science and drawing and the manual arts. In my lower elementary school years, I spent a lot of time making plastic models, but from the upper grades of elementary school through middle school, I enjoyed model-making and electrical work. Because my father was a mechanical engineer, I was quite familiar with microscopes and telescopes, the slide rule and T-square, and that kind of thing. My fondness for science and drawing and the manual arts was probably the result of the environment in which I grew up.

—How did you decide to become a researcher?

The big turning point was in the autumn of my second year as a master’s student in graduate school, when my supervisor asked me to become an research associate. At the time, many students were hired as research associates when they completed their master’s degree. As an research associate, I earned my degree while doing research and advising students. My research topic was “Dynamic Processes at the Surface of Solids – Applications to Extreme High Vacuum Technology.” That was research on material surfaces for creating extreme high vacuums on the order of 10^{-12} millibars, which is more difficult than creating ultra-high vacuums. The research that I did at that time has served as a base of what I am doing today. I say that because, even today, I’m investigating how to do characterization of material surfaces at the nano-scale by starting from clean surfaces created in an extreme high vacuum environment.

—What kind of research have deeply impressed you so far?

Recently, the material called graphene has attracted an enormous amount of attention. It isn’t very well known, but surface science researchers had been doing work on single atomic layer, or “monolayer” graphite, in other words, graphene, from the 1970s. The National Institute for Research in Inorganic Materials (NIRIM), which is the predecessor of NIMS, was involved in research on monolayer graphite from late 1980s into the 1990s, centering on Prof. Chuhei Oshima, who is now at Waseda University. At that time, NIRIM was in the top class in extreme high vacuum technology and set a Japanese record for extreme high vacuums in the 80s. The creation of monolayer graphite and pioneering research on characterization at this NIMS predecessor deserves to be remembered as a milestone in graphene research, and was also deeply impressive research for me.

—Today, we could say that you “wear two hats,” since you’re involved in both research and management.

Management, or coordination, is an important job for me in NIMS. A large part of my working time is devoted to jobs as Managing Director of the Advanced Nano Characterization Center and Quantum Beam Center, and Coordinating Director of the Key Nanotechnologies Field. Separately and in parallel with this, I’m also doing my own original research as a researcher. The time that I can devote to research is limited, but I want to work in earnest as a researcher. How an idea is realized is a battle with time, so I depend on the efforts of post-doc researchers and the technical support staff.

As a researcher, the ideal life is to spend several hours every day on one’s own research. On the other hand, support for other researchers through management and coordination and NIMS outreach activities are also important. My goal is to satisfy both.

—Do you have any rivals?

I don’t have any particular rivals, but there are research groups that I think are ideal, for example, the research groups involved in scanning probe microscope characterization techniques at IBM’s Almaden Research Center and the University of Hamburg. It’s truly wonderful to be able to realize a succession of original ideas in the nano-scale world, the way those researchers do. I believe that realizing an idea for the first time in the world has an extremely large value. The fact that Dr. Don Eigler of IBM succeeded in demonstrating atomic manipulation for the first time in 1989 was astonishing. That kind of research is my goal.

—What are your thoughts on the future of NIMS?

For NIMS, the importance of basic research will remain unchanged. However, I think that we should aim at basic research with an engineering viewpoint. Useful basic research is demanded. In order to solve the various problems which society faces today, it is necessary to develop new materials. I believe that one principal mission of NIMS is basic and generic/infrastructure research which provides the foundation for the development of those materials. Because we have a full lineup of outstanding human resources, I am confident that NIMS will be recognized as one of the world’s top materials research institutes in the near future.

Profile

Doctor of Engineering. Completed master’s degree in the Department of Metallurgy and Materials Science, Graduate School of Engineering, the University of Tokyo. After working as an research associate in the Institute of Industrial Science, the University of Tokyo and as a researcher at the NRIM, he is now Coordinating Director of the Key Nanotechnologies Field at NIMS.

Organic Electronic Material with Necklace Structure

Taichi Ikeda
Senior Researcher,
Functional Materials Chemistry Group,
Organic Nanomaterials Center

Organic electronic materials – An urgent field for development.

Electronic materials play a key role in today’s advanced information society. For example, it is no exaggeration to say that the personal computers and cell phones which we use every day are a compilation of electronic materials. Large quantities of rare metals are used in the present generation of electronic devices. If these can be replaced with organic materials, which are lightweight, flexible, and offer a high degree of freedom in design, the effect will be incalculable.

Electronic material with a “necklace” structure.

Because active research on organic electronic materials is underway around the world, it was thought that a novel approach, which would be completely different from the existing research, may be necessary when beginning new research. In the conventional research, multiple units were joined by covalent bonding or arranged by molecular interaction. However, these approaches have drawbacks. When multiple units are joined by covalent bonding, the essential mutual functions of the units change, and if the creation of the new material depends solely on molecular interaction, the respective units undergo phase separation and are no longer mixed. Therefore, in the present research, the author conceived the idea of using interlocked molecules, in which the mutual structural elements are not joined by covalent bonding, but are linked by mechanical constraints and possess a necklace-like morphology.

The author developed an electronic material having a necklace structure like that shown in **Fig. 1** by using polythiophene (PT), which is well-known as an organic semiconductive polymer, as the string of the necklace. When cyclic molecules are synthesized in the presence of dumbbell-shaped molecules, cyclization occurs on the dumbbell-shaped molecules due to molecular interaction, and it is possible to obtain a molecule in which the cyclic molecules are trapped mechanically in the dumbbell-shaped molecules. The author also succeeded in obtaining necklace molecules by performing additional electrochemical polymerization on this molecule. When a voltage is applied to a thin film of this molecule, its color changes from red to colorless (**Fig. 2**). Taking advantage of this property, this substance can be applied as an electronic material for light modulation materials, color electronic paper, and others. In the future, the author also plans to elucidate the various properties of this substance as an organic semiconductor.

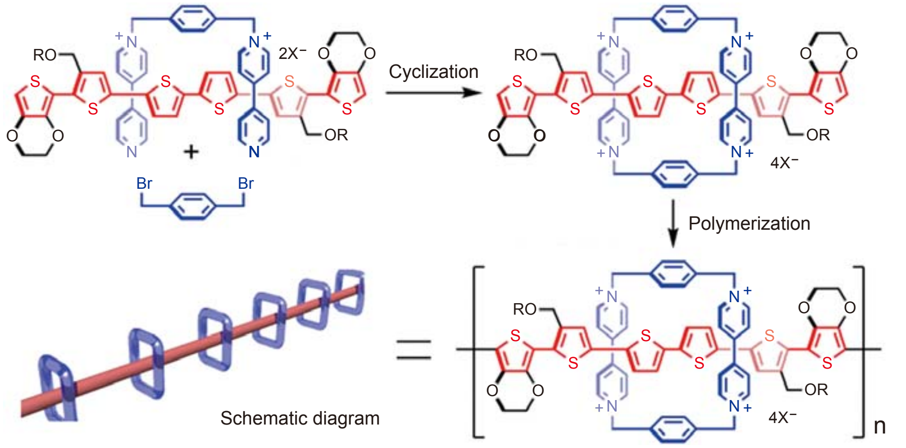

Fig.1 Synthetic scheme of the electronic material with a necklace structure developed in this research.

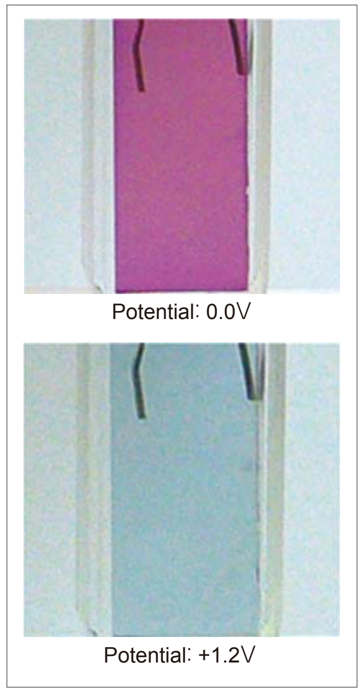
Potential: 0.0V
Potential: +1.2V

Fig.2 Color change when voltage was applied to a thin film of the electronic material with a necklace structure (electrochromism).

Profile

Taichi Ikeda

Doctor of Materials Chemistry. Fellow Researcher at NEDO.After postdoctoral fellow at UCLA, joined NIMS in Oct. 2006.Senior Researcher and Group Leader of MPI-NIMS International Joint Laboratory.

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Control of Chemical Bonding between C60 Molecules at Single Molecule Level for Development of Ultra-High Density Data Storage

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Masakazu Aono
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One dream device produced by nanotechnology is atomic/molecular level memory devices. With the advent of techniques which enable manipulation of single atoms and single molecules in the 1990s, memory devices which assign a single atom or molecule to 1 bit of information were anticipated. However, in reality, this type of memory involved various difficulties, including the fact that a cryogenic environment is necessary in order to prevent movement of the atoms or molecules, and that placement and removal of the atoms or molecules corresponding to binary control (0,1) of individual bits are difficult to be performed repeatedly at the same position, etc.

We discovered a method of forming/dissolving the chemical bond between the fullerene C_{60} molecule at the surface and the underlying C_{60} molecules in an ultra-thin C_{60} film. We also showed that it is possible to realize ultra-high density data storage with a bit density of 190TBit/in^2, which surpasses the bit densities currently in practical application (up to 400GBit/in^2) by nearly 1000 times.

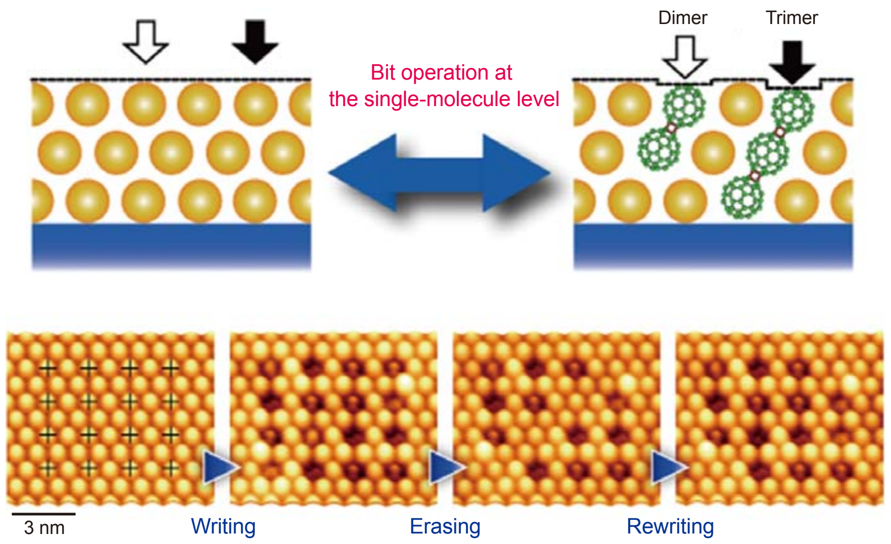


Fig. (Top) Schematic diagram showing bit operation at the single molecule level (control of formation and dissolution of the chemical bonds between C_{60} molecules), and (bottom) an example of ultra-high density data storage with a density of 190TBit/in^2 (STM images).

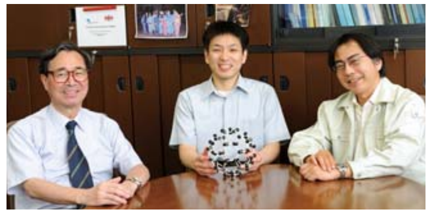
First, the ultra-thin C_{60} film with a thickness of three molecular layers (see **Figure**) is fabricated on the surface of a flat, electrically-conductive substrate. Sufficient attractive force acts on the adjoining C_{60} molecules owing to van der Waals interaction, and the molecules to form a stable film with a face-centered-cubic structure. Therefore, random walk of the individual C_{60} molecules is prevented even at room temperature.

Next, the sharpened metal probe (tip) of a scanning tunneling microscope (STM) is placed in close proximity to this ultra-thin C_{60} film and a bias voltage is applied so that the substrate side of the film takes a negative potential (the metal probe side is positive). This causes ionization of the C_{60} molecules underneath the probe to a negative state, which realizes an advantageous condition for the formation of chemical bonds between the adjoining C_{60} molecules. The tunneling current from the metal probe applies the appropriate energy to this site, completing chemical reaction between the C_{60} molecules. In our experiments, an arbitrary C_{60} molecule at the surface of the ultra-thin film and the adjacent C_{60} molecule in the second layer can be bonded to form a dimer, or the surface C_{60} molecule and the 2nd and 3rd layer C_{60} molecules can be bonded to form a trimer (see **Fig.** upper right).

Conventionally, heating upto 150-200°C had been necessary in order to return these polymers to the single molecule state. However, as a surprising discovery in this research, it is possible to break the chemical bond between the C_{60} molecules at room temperature simply by reversing the polarity of the applied bias voltage. Consequently, it is possible to form and break the chemical bonds between C_{60} molecules repeatedly, any number of times, at room temperature. If the dimer or trimer state is assumed to be "1" and the state in which no chemical bond exists is "0," bit operation at the single molecule level is realized, and the bit density reaches 190TBit/in^2 (see **Fig.**).

We consider this method of controlling the chemical bonds between molecules at the single molecule level to be a promising new principle for the ultra-high density data storage technology of the future, and plan to conduct further research in this direction.

Profile



Tomonobu Nakayama (right)
Doctor of Science. After serving as a research staff at Mitsui Mining & Smelting Co., Ltd. and RIKEN, joined Nanomaterials Laboratory at NIMS in 2002. Principal Investigator of MANA since 2008, also serving as an Associate Professor at the University of Tsukuba.

Masato Nakaya (center)
Doctor of Engineering. After serving as Junior Research Associate at RIKEN and a Junior Researcher at NIMS, assigned to a Researcher at NIMS in 2008. Present position as a Post-Doc researcher at NIMS since 2010.

Masakazu Aono (left)
Doctor of Engineering. Joined NIRIM in 1972 and served as a Senior Researcher at the Surface and Interface Engineering Unit of RIKEN, Professor at Osaka University, Director of Nanomaterials Laboratory and Managing Director of Nano System Functionality Center at NIMS. Present position as the Director-General of MANA since 2006.

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Impurity Activation Technique using Short-time Laser Annealing

Expanding the Options for Doping Elements in Silicon Crystals

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Techniques for doping impurities in silicon (Si) crystals are important technologies for carrier control. In the past, doping techniques have been specially well-developed for the light elements, e.g. phosphorus (P) and boron (B). Recently, technologies using the localized electron spin possessed by impurities in silicon crystals, like spintronics have also been studied. In such devices, heavy elements which form deep-energy impurity levels are advantageous because the disturbance from heat can be suppressed. If doping techniques for heavy elements in silicon crystals are established, integration with conventional MOS transistors will be possible by hybridization with LSI technology, giving silicon devices an overwhelming advantage.

We succeeded in the development of activation technique (substitution at positions in the silicon crystal lattice) for impurity bismuth (Bi), which is one of heavy elements, in silicon crystals. In this technique, Bi nanolines formed on the silicon surface are used as the dopant source during further silicon crystal growth. Most of the Bi atoms in Bi nanolines are segregated towards the surface during the growth, and only the several % which remain in the crystal are used as doping atoms (**Fig. 1(a)**). Photoluminescence (PL) measurement* was used to characterize the activation of these impurities.

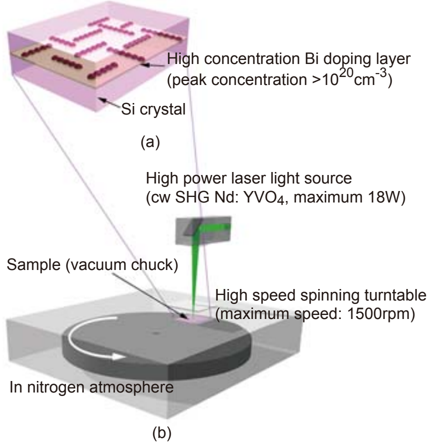


Fig.1 Silicon crystal sample with a high concentration bismuth doping layer, and the short-time laser annealer used to activate the impurity: (a) Sample structure and (b) outline of the short-time laser annealing. It enables focused laser irradiation of a sample on a spinning turntable. The annealing time is several milliseconds, and the achieved temperature is extremely close to the melting point of silicon, reaching up to 1400°C.

In the photoluminescence spectrum of the as-grown sample shown in **Fig. 2(1)**, only luminescence from the silicon crystal was observed. This indicates that no appreciable fraction of the Bi atoms occupy the substitutional sites of the silicon lattice as donors. Then high temperature annealing is necessary in order to activate this impurity. However, when the high temperature annealing is performed for an extended period of time, impurities diffuse, and the desired impurity concentration profile cannot be maintained. Therefore, short-time laser annealing (**Fig. 1(b)**) was adopted, as this technique makes it possible to realize high temperature annealing (up to 1400 °C, which is extremely close to the melting point of silicon) in an extremely short time on the order of several milliseconds. As a result, luminescences related to the Bi impurity (donor) level were observed from the sample on which laser annealing was performed, indicating that the Bi had been successfully activated (**Fig. 2(2)**). At the same time, it was found that several types of defects (the G line, etc.) had been introduced during the laser annealing, but these defects can be eliminated by additional low temperature furnace annealing.

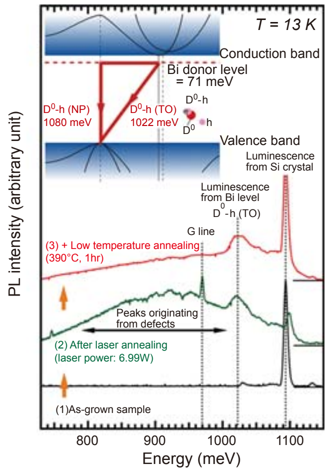
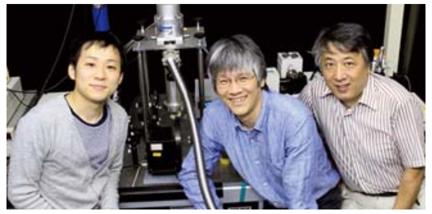


Fig.2 Results of photoluminescence (PL) characterization: (1) As grown sample. Only luminescence from the silicon crystal is observed, and no appreciable fraction of the Bi atoms occupy the substitutional sites of the silicon lattice as donors. (2) Laser-annealed sample. luminescences related to Bi donor level are observed (1022 meV), indicating successful activation. However, at the same time, peaks originating from defects were also observed. (3) The defect peaks were extinguished by additional low temperature annealing. The insert (upper left) is an energy band diagram of the Bi-doped silicon crystal.

This technique developed in this research is potentially useful, because it has the advantage that diffusion of the impurity can be suppressed to an extremely low level. It is a general technology which is applicable to other impurity elements, not limited to the bismuth element.

Profile



Kazushi Miki (center)
Doctor of Engineering. After completing the doctoral course of the Graduate School of Engineering, University of Tsukuba, joined the Electrotechnical Laboratory as a researcher in 1987. Served as a Senior Researcher from 1991 and visiting researcher at Oxford University from 1994 to 1996. Became a Principal Researcher at NIMS in 2001 and has held present position since 2003.

Koichi Murata (left)
Master of Engineering. Enrolled in the Materials Science and Engineering Program (D1), Graduate School of Pure and Applied Sciences, University of Tsukuba. Also serves as a Junior Researcher at NIMS.

Kunihiro Sakamoto (right)
Doctor of Engineering. After completing the doctoral course of the Graduate School of Engineering, The University of Tokyo, joined the Electrotechnical Laboratory in 1986 as a researcher. Served as a Senior Researcher from 1990 and visiting researcher at the University of California, Los Angeles from 1995 to 1996. Assigned to present position in 2007.

Susumu Fukatsu
Ph.D. in Engineering. Completed the master's course of the Graduate School of Engineering, The University of Tokyo. Served as a technical assistant in the Research Center for Advanced Science and Technology from 1987 and became an Assistant Professor at the Graduate School of Arts and Sciences, The University of Tokyo. Assigned to present position in 2010.

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* Photoluminescence (PL) measurement records the intensity distribution of luminescences due to the recombination of electrons and holes formed by irradiating a substance with laser.

References
Koichi Murata, Yuhsuke Yasutake, Koh-ichi Nittoh, Kunihiro Sakamoto, Susumu Fukatsu, and Kazushi Miki. Applied Physics Express 3 (2010) 061302.

Results of IBM-NIMS Symposium

(June 14-15, 2010) The "IBM-NIMS Symposium on Characterization and manipulation at the atomic scale" was held at the International Congress Center Tsukuba Epochal in Tsukuba City, and researchers from NIMS and other organizations and researchers from the research division of IBM were invited to participate in the event.

On the NIMS side, the symposium was held through collaboration among the Advanced Nano Characterization Center, the World Premier International Research Center for Materials Nanoarchitectonics (WPI-MANA), and the International Affairs Office. From IBM, 9 researchers from the Almaden Research Center (US) and the IBM Zurich Research Laboratory (Switzerland) came to Japan in order to attend this symposium.

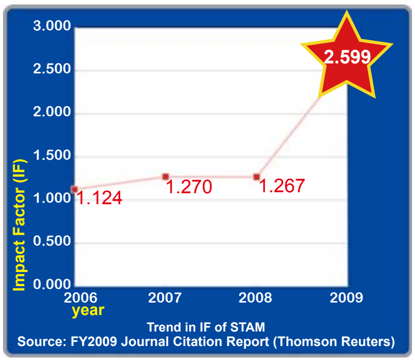
During the symposium, mutual presentations on advanced research were given in individual sessions on "Controlling materials at the atomic scale I, II", "STM to unveil the properties of materials at the atomic and molecular level", "Application of AFM to the characterization of materials", "Application of electron microscopy to the visualization of nanoscale dynamic processes", and "Materials nanoarchitectonics". The symposium made an important contribution as a milestone to activate research exchanges between NIMS and the IBM laboratories in the field of nanoscience.

Participants in the IBM-NIMS Symposium.

NIMS Doubles the Impact Factor of Its English Journal STAM Specializing in Materials Science

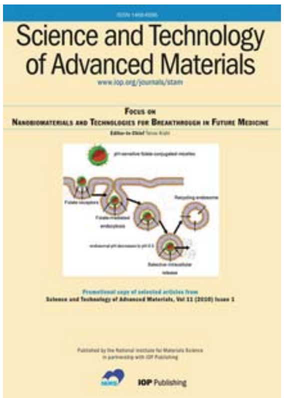
The international English-language scientific journal, "Science and Technology of Advanced Materials (STAM)," which is published by NIMS as a collection of papers devoted exclusively to materials science, has celebrated its 10th anniversary since the inaugural issue. STAM covers the entire range of research fields in materials science, including nanotechnology, in metals, inorganic materials, organic materials, biomaterials, etc., and provides a global platform for dissemination of information on research in connection with materials science. On June 17, Thomson Reuters published its 2009 values for the Impact Factor (IF), which is an index used to evaluate international journals. The IF of STAM was 2.599, which is more than double (+105%) the 1.267 IF of the previous year. The journal ranking of STAM in the field of "Materials Science, Interdisciplinary," to which STAM belongs, also recorded an impressive gain from 86th among 192 journals in 2008 to 36th among 212 journals. This is the result of a wide recognition of the high quality of the papers published in STAM by materials science researchers around the world, and frequent citations of those papers by researchers, and shows that STAM is continuing to have a strong influence on materials science research worldwide.

NIMS was also the first in the world to offer open access online to a materials science journal, which began in 2008, and provides all of the papers carried in STAM free of charge.



Trend in IF of STAM

Source: FY2009 Journal Citation Report (Thomson Reuters)



Science and Technology of Advanced Materials

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Hello from NIMS

Ujjal K. Gautam(India)
ICYS researcher(4 years at NIMS)

First time I came across Japan was way back in elementary school, when I had to remember a country with a King. That was a time when the heavens, the moon and Japan meant no difference. In 2006, I landed in Japan to join NIMS as a post doc and from then on, have enjoyed the last 4 precious years of my career. Life in Japan is different from India and has been an enriching experience professionally and personally. NIMS has provided a vibrant international atmosphere, a great support system and an atmosphere conducive for quality work, besides mentoring young researchers. I visited many places in Japan and had some exhilarating experiences. The beauty of sunrise from the summit of Mt. Fuji was beyond description! A local train trip to Hokkaido got me acquainted with the fascinating interiors of Japan. Most remarkably, I brought my parents here, to see a foreign country and fulfilled a long cherished dream. To me, what sets Japan apart from other countries is its hospitality and kindness to foreigners, deep rooted patriotism, strive for perfection and unmistakable consistency from Hokkaido to Fukuoka. Japan will remain an evergreen, integral part of me throughout.

[Sunrise at Mt. Fuji]

[With family in Asakusa temple]

NIMS NOW International 2010.Vol.8 No.6

National Institute for Materials Science
http://www.nims.go.jp/eng/news/nimsnow/

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