NIMS NOW International

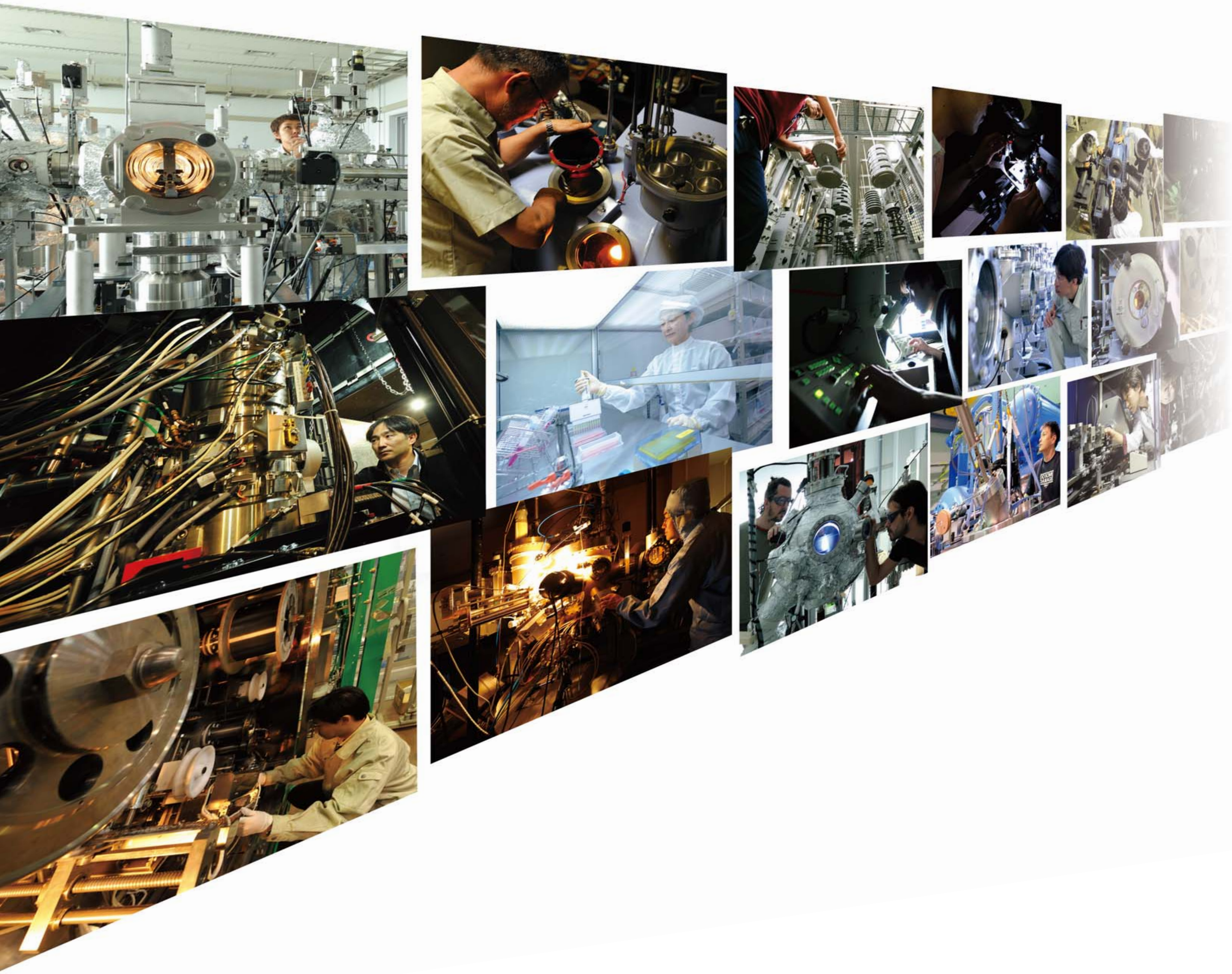
2011. March

2006-2010 A Review of NIMS Strategy

NIMS Booth at nano tech 2011 (display of SiAlON phosphor)

2006-2010
A Review of NIMS Strategy

**The Second Five-year Plan for NIMS ends in March 2011.
What targets did we set five years ago? Were we able to achieve them?
As we embark on even more challenging research in the Third Period,
we take this opportunity to review our own performance.**



On the conclusion of the NIMS Second Five-year Plan

The Second Five-year Program, which began in April 2006 and covered a five-year period, ends in March 2011.

The goal of the Second Five-year Plan was to improve the level of research in the traditional metallic and inorganic materials areas, and further to develop new research areas including environment and energy, information technology, and biotechnology. We pursued "Nanotechnology-driven materials science for sustainable society," placing special emphasis on nanotechnology as a basic means of materials development. During this period we established 6 areas of research as shown below. Within each area, the centers, exploratory labs, and stations, conducted comprehensive materials research in an integrated manner.

We launched the International Center for Materials Nanoarchitectonics (MANA) to create a Center of Excellence in nanotechnology-based materials research, to promote international research environment, and in addition to train researchers who will provide the driving force for future progress. This project has already achieved many impressive results.

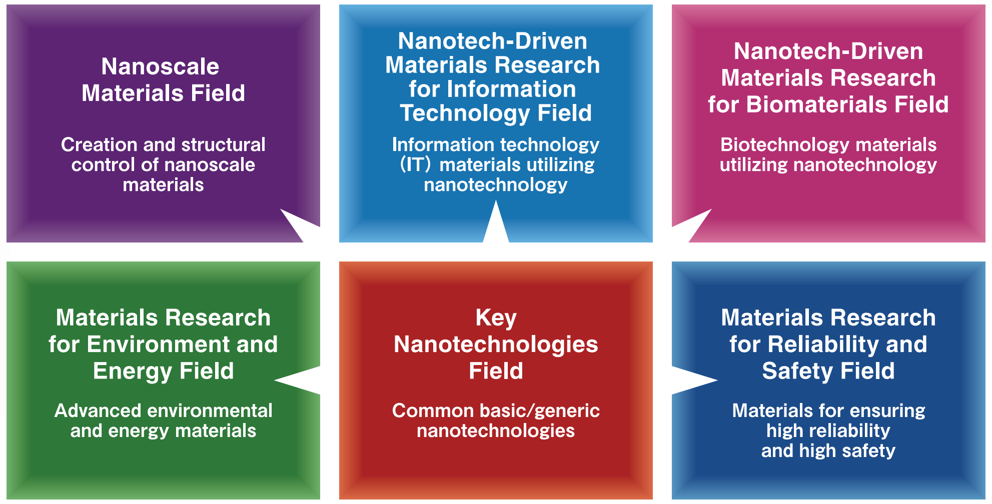
In order to maintain Japan's global leadership in materials research, NIMS played a key role in several important national programs. These included the establishment of the "International Center for Nanotechnology Network", "Global Research Center for Environment and Energy based on Nanomaterials Science (GREEN)", and "Low-Carbon Research Network (LCnet)." Also NIMS played a leading role in the founding of "Tsukuba Innovation Arena (TIA)".

To return the fruits of our research to society, NIMS established a number of noteworthy ties with industrial companies by establishing several cooperative research centers including: "Rolls-Royce Centre of Excellence for Aerospace Materials", "NIMS–TOYOTA Materials Center of Excellence for Sustainable Mobility", and "NIMS Saint-Gobain Center of Excellence for Advanced Materials."

The level of research can be benchmarked in the citation ranking*1 for research papers in the field of materials science; NIMS now ranks No. 1 in Japan and No. 3 internationally. The number of research papers and patent applications per researcher also rank No. 1 in Japan*2. Furthermore, NIMS had many other achievements that deserve mention; it is now a top-ranking research institution in the number of collaborations with industries, in funding from external sources, and in income from patents.

As we embark on the Third Period, we are committed to a diverse program of even more challenging research by taking advantage of the knowledge cultivated during the Second Period. We expect great leaps in the coming years.

Prof. Sukekatsu Ushioda, President of NIMS

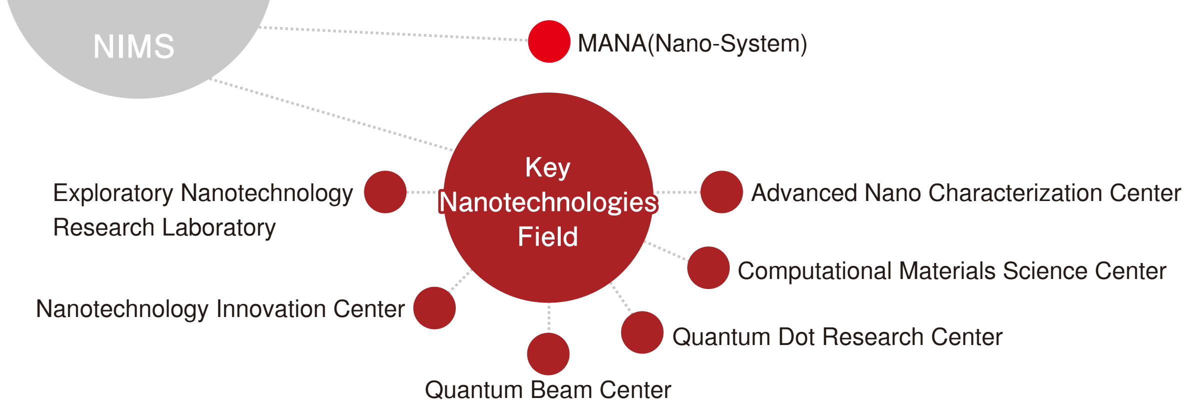


6 Fields of Project Research at NIMS

*1 According to Thomson Reuters.
*2 Materials of the Council For Science and Technology Policy, November 28, 2007.

Research and development in the NIMS Key Nanotechnologies Field

Daisuke Fujita
Coordinating Director, Key Nanotechnologies Field



Position in the NIMS 2nd Five-year Plan.

Nanotechnology is a key technology supporting the science and technology of the 21st century. In fields such as the environment, energy, life sciences, and information technology, it will be necessary to maintain innovative generic and infrastructural technologies for nanotechnology in order to continue to lead the world in various fields of advanced science and technology well into the future. The Key Nanotechnologies Field was established for developing innovations in materials science utilizing Japan's nanotechnology under the NIMS 2nd Five-year Plan, with the aim of achieving higher levels of technology in creation, processing, and fabrication of materials at the nano-level, measurement, characterization, and theoretical and computational sciences as advanced, common infrastructural technologies for nanotechnology, and to develop these technologies in convergence. Focusing on nano-level structures and functions, this field is promoting the development of cutting-edge common infrastructural technologies for nanotechnology toward the design and creation of materials which display novel phenomena and unprecedented functions.

Evolution of research in the Key Nanotechnologies Field.

When this field was created in 2006, it comprised five centers with the mission of promoting projects under the Five-year Plan. Five centers (Nano System Functionality, Advanced Nano Characterization, Computational Materials Science, Quantum Dot Research, and Quantum Beam Centers) with outstanding developmental capabilities were placed in charge to achieve the goals as follows; Developing technologies for structural control of the structures of materials that will result in innovations in the nanodevice field, measurement and evaluation technologies with ultra-high resolution reaching the surface, sub-surface layer, and interior of solids, simulation techniques capable of analyzing and predicting the functions and physical properties manifested by nanostructures in terms of quantum theory, and process technologies for realizing nanostructures and structures of those materials. Although a reorganization was carried out in fiscal year 2007 accompanying the launch of the International Center for Materials Nanoarchitectonics (MANA), projects under the Nano System Functionality Center were continued in the Key Nanotechnologies Field. With worldwide attention turning to the safety and standardization of nanomaterials, a new "Social Acceptance of Nanomaterials Project" was begun in FY2008. This Project was placed in the Key Nanotechnologies Fields, as these issues are unique to nanotechnology. In FY2009, two new units were launched, these being the Nanotechnology Innovation Center, which is responsible for infrastructure, and the Exploratory Nanotechnology Research Laboratory, which conducts exploratory research. Through these changes, the role of the Key Nanotechnologies Field is now a comprehensive research base for nanotechnology, which is involved in work not only in the development of advanced infrastructure technologies, but also in exploratory research, research on the social acceptance of nanotechnology, and support for advanced nanotechnology research.

Activities and achievements of the Key Nanotechnologies Field.

In next-generation nanotechnology, the development of technologies for organizing large numbers of nanostructures as systems and realizing new functions in the system as a whole will be essential. In the "Development of Technologies for Nano-Functions/Structures Project," the aim is to realize nanosystems which possess useful new functions. In particular, **atomic electronics based on integration of atomic switches** was developed to practical nanosystems. The Advanced Nano Characterization Center developed various advanced nano characterization technologies, with extreme field scanning probe microscope (SPM), high-resolution transmission electron microscope (HRTEM), high field solid-state NMR, surface/sub-surface layer precision electron spectroscopy, and ultra-high speed time-resolved measurement among the core technologies. In particular, the Center is engaged in work aimed at achieving high resolution in STEM-EELS, and was the **first in the world to successfully perform atomic-column discrimination imaging** **(Fig.1)**.

The Computational Materials Science Center has constructed a theoretical foundation and design rules for realizing next-generation materials with new functions in the nano field, and has proposed novel physical properties and functions. For a comprehensive analysis of the correlation of structure, electronic states, and physical properties and functions, this Center developed advanced nano simulation techniques such as first-principles simulations, ultra-large-scale analysis, multi-property and function analysis, strongly-coupled modeling, and multi-scale analysis, among others. As one particular achievement, the Center realized the **world's largest-scale first-principles simulation** by development of the order-N first-principles method **(Fig.2)**.

The Quantum Dot Center pursued the creation and functions of new nano structures by convergence of design, creation, and characterization techniques for quantum dots, photonic crystals, nanowires, etc. In particular, the Quantum Dot Center **succeeded in fabricating quantum dots** with extremely small internal stress, structural anisotropy, and defect density by the **droplet epitaxy method**, and achieved a dramatic reduction in anisotropy of exciton emission energy **(Fig.3)**.

The Quantum Beam Center comprehensively develops and uses synchrotron radiation, neutron, ion beam, atomic beam, and other technologies to realize striking improvements in creation, fabrication, control, and measurement, and established infrastructural quantum beam technologies. In particular, in the field of neutron multi-scale characterization techniques, the Center **developed the next-generation multi-purpose pattern fitting system RIETAN-FP** and the **three dimensional visualization system VENUS**.

Overview of past 5 years.

In research and development in the Key Nanotechnologies Field, dramatic progress has been achieved in the course of the Five-year Plan, resulting in a number of world's top level research achievements. This field was created as a core base for promoting materials research utilizing Japan's nanotechnology. Realizing that collaboration with outside research institutions, universities, and industry will be indispensable for translating the fundamental and basic technologies which we have developed in this field into innovations, the Key Nanotechnologies Field will continue to emphasize fusion-type research based on the needs of society.

A Special Feature on the Advanced Nano Characterization research was published in Jan-Feb 2011, Computational Materials Science research was in April 2010, Quantum Dot research was in May 2010, and Quantum Beam research was in December 2009 edition of NIMS NOW.

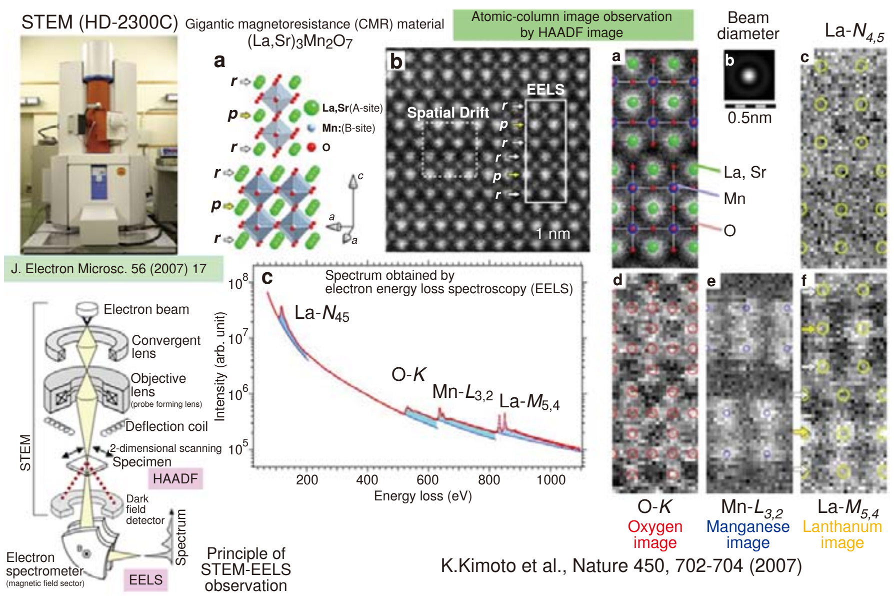


Fig.1 Success in atomic-column discrimination imaging by development of high resolution STEM-EELS method.

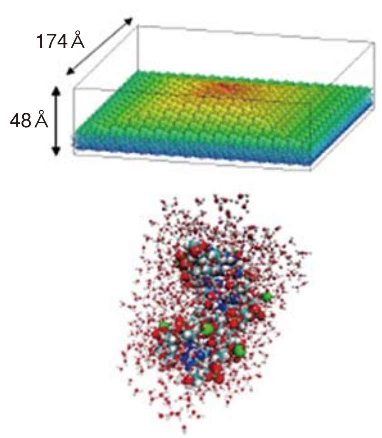


Fig.2 Realization of the world's largest scale first-principles simulation by development of order-N first-principles method. (top: Structure of Ge quantum dot; bottom: Model of hydrated DNA structure).

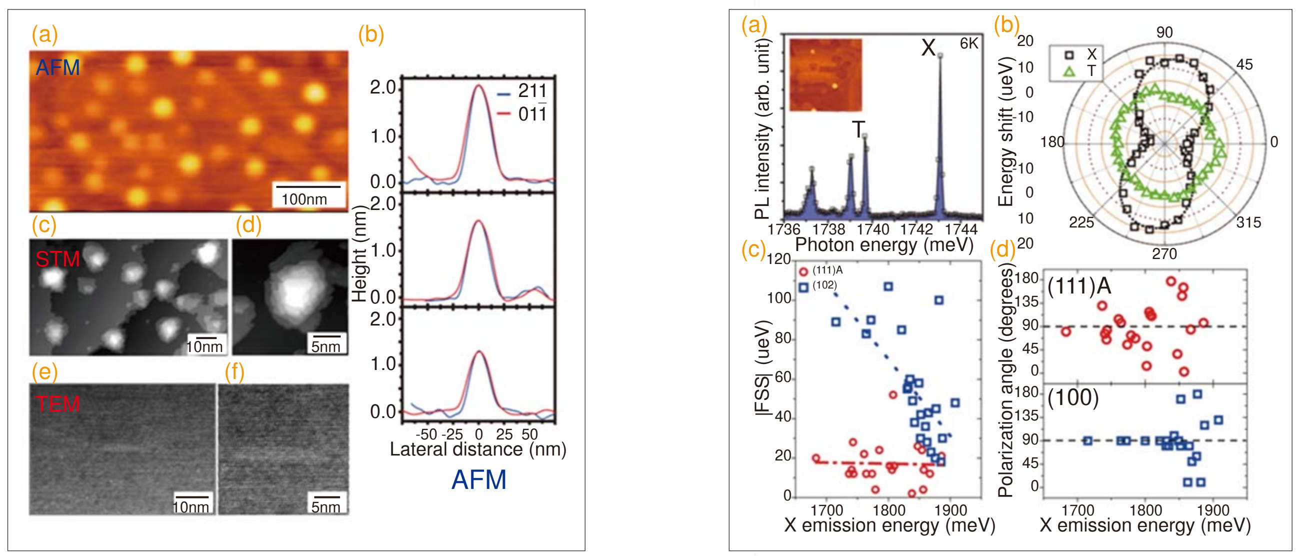
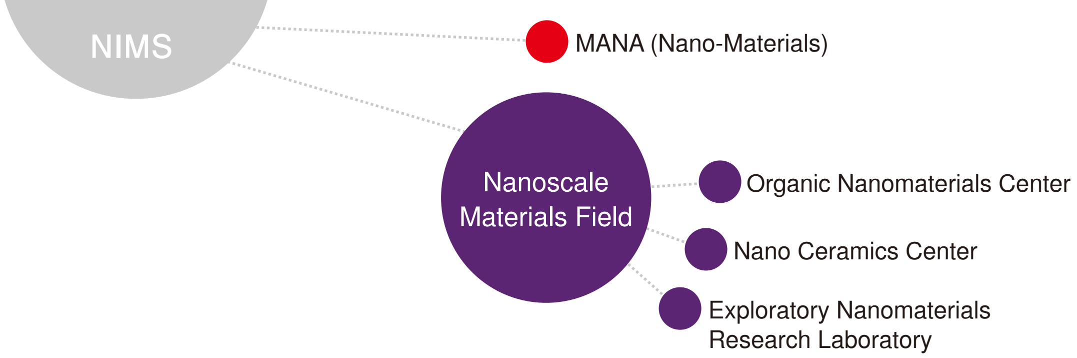


Fig.3 Left: Isotropic GaAs quantum dots fabricated by droplet epitaxy on the surface of AlGaAs(111)A.
right: Achievement of dramatic reduction ((c) red circles) of anisotropy of exciton (X) emission energy (FSS).

Efforts toward creation and structural control of new nanoscale materials

Takayoshi Sasaki
Coordinating Director, Nanoscale Materials Field



Successfully synthesizing more than 20 types of new nanoscale materials.

In this field, NIMS is engaged in research aiming at creating new materials with nanometer-range sizes and shapes, and developing the next-generation electronics and environmental- and energy-related technologies. The objects of this research encompass a wide range of material systems from inorganic to organic materials.

In the synthesis for new nanoscale materials, we make full use of various synthesis methods incorporating NIMS-original technologies, and have successfully synthesized more than 20 types of new nanoscale materials, such as 1D nanotubes, nanowires, and 2D nanosheets based on oxides, nitrides, hydroxides, and carbides.

Through investigating their structures and properties from various aspects, we have discovered many new physical properties and enhanced functions which reflect the nanoscale size and shape of these materials.

This article introduces representative examples of the new nanomaterials synthesized by NIMS.

BN nanotubes and tantalum oxide nanosheets.

Fig.1(a) shows **boron nitride (BN) nanotubes** synthesized in this research by Chemical Vapor Deposition (CVD) method. High output production (several 100 mg/hr) of high-purity nanotubes with a small diameter of about 10 nm was made possible by using lithium oxide (Li_2O) and magnesium oxide (MgO) as catalysts. Based on this achievement, NIMS is developing nanocomposite materials by dispersing the nanotubes into polymer matrixes. Application of the composites to heat sinks, which take advantage of the excellent heat conduction and chemical stability of BN nanotubes, is expected.

Fig.1(b) shows a **tantalum (Ta) oxide nanosheet with a thickness of only 2 nm**, which was obtained by a unique process of chemical delamination of layered compounds into single layers. The structure of this nanosheet is closely related to the famous perovskite structure, which is a representative functional ceramic. Because flexible design of composition and structure is possible with this structure, a wide variety of nanosheets with superior dielectric properties, photocatalytic properties, and fluorescent properties were obtained.

Construction of multilayer films by using nanosheets as a "nanoscale building block".

In order to fully utilize the functions of nanoscale materials and produce useful materials and devices from these, precisely controlled assembly and integration of nanomaterials at the nano-level and hybridization with other types of materials are necessary. Likewise, the Nanoscale Materials Field also carried out a wide range of research and development taking advantage of soft chemistry, colloid chemistry, and similar approaches.

For example, nanosheets can be obtained as colloidal 2D crystals dispersed in aqueous media. We discovered an interesting phenomenon in which the nanosheets spontaneously float at the air/liquid interface, like drift ice floating in the ocean, and developed a technique for arranging those nanosheets on the water surface and then transferring them to a substrate of glass, etc. By repeating this process, we established a **process for artificial buildup of lamellar nanostructures**.

Such nanofilms with thicknesses of 5-20 nm constructed with titanium (Ti) or niobium (Nb) oxide nanosheets **(Fig.2)** demonstrate superior dielectric performance greatly exceeding that of conventional materials. Based on this property, they are considered to have great promise as **high-k materials, which will be indispensable for next-generation condensers and transistors**. Joint research is now being conducted with private companies aiming at practical application.

Furthermore, focusing on the fact that a regular 2D lattice can be introduced on the substrate surface by this technique, we also developed a new technique that can facilitate **oriented growth of functional crystal thin films** on glass and plastics.

Limitless possibilities in the synthesis, integration, and hybridization of nanomaterials.

As one more example, NIMS researchers succeeded in synthesizing a **porous membrane (Fig.3)** by mixing hydroxide nanostrands with a diameter of approximately 2 nm, which were synthesized by adding base to aqueous solutions of zinc (Zn) or cadmium (Cd), with a spherical rigid protein in an aqueous solution, and after composition of these two materials, chemically crosslinking the protein.

Because channels are formed when the nanostrands are removed by acid treatment, the resulting membrane has a high filtering ability; **organic compounds can be separated and concentrated at a rate approximately 1000 faster than with conventional water treatment membranes**. Practical application of this technology as a filter for artificial dialysis is under study through licensing agreements with chemical manufacturers in Japan and other countries.

The NIMS researchers in this field have also produced a wide variety of important results, both scientific and applied, as exemplified by the development of a dense, transparent sintered material by interfacial control of ceramic nanoparticles. The possibilities in this field, that is, in the synthesis, integration, and hybridization of nanomaterials, can truly be called limitless. High expectations are placed on continuing development and new achievements in the future.

A Special Feature on the Nano Ceramics was published in the Nov. 2010 edition of NIMS NOW.

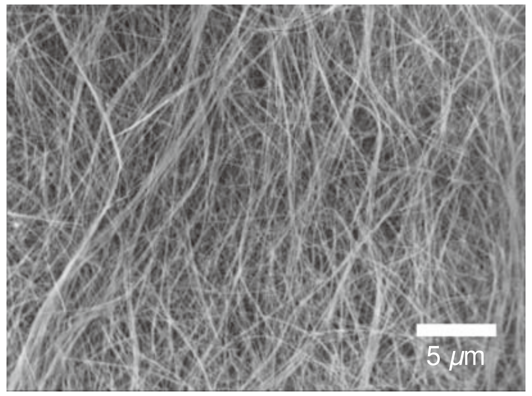


Fig.1(a) TEM image of high purity BN nanotubes.

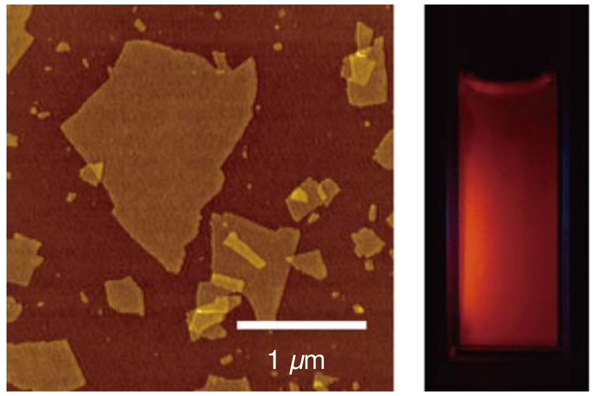


Fig.1(b) AFM image of Ta oxide nanosheets ($La_{2/3-x}Eu_xTa_2O_7$)(left). The colloidal suspension emits red fluorescence under irradiation with ultraviolet light (right).

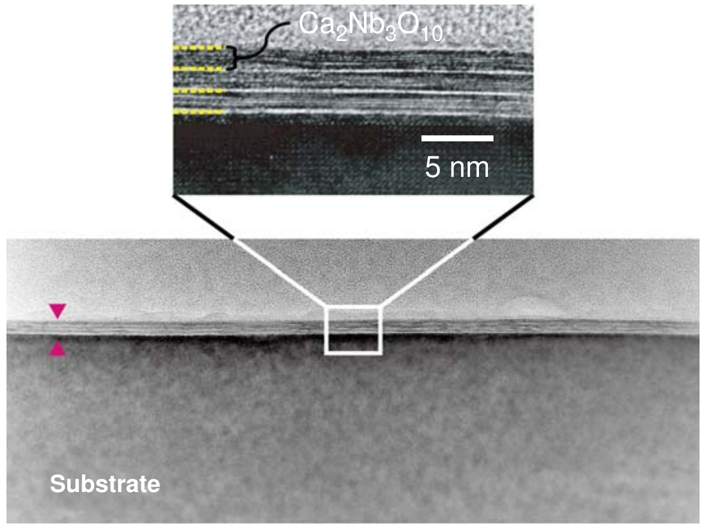


Fig.2 3-layer film of a perovskite nanosheet ($Ca_2Nb_3O_{10}$) (cross-sectional TEM image). The nanosheets were assembled layer-by-layer into a highly ordered nanostructure. It demonstrates specific dielectric constant exceeding 200.

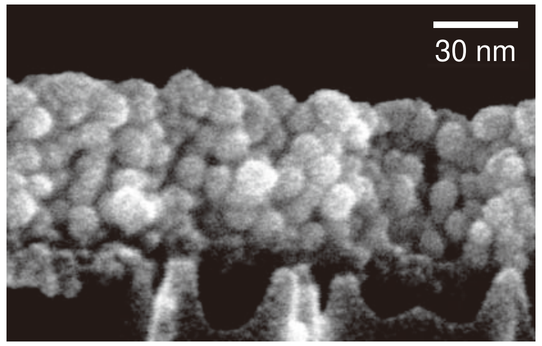
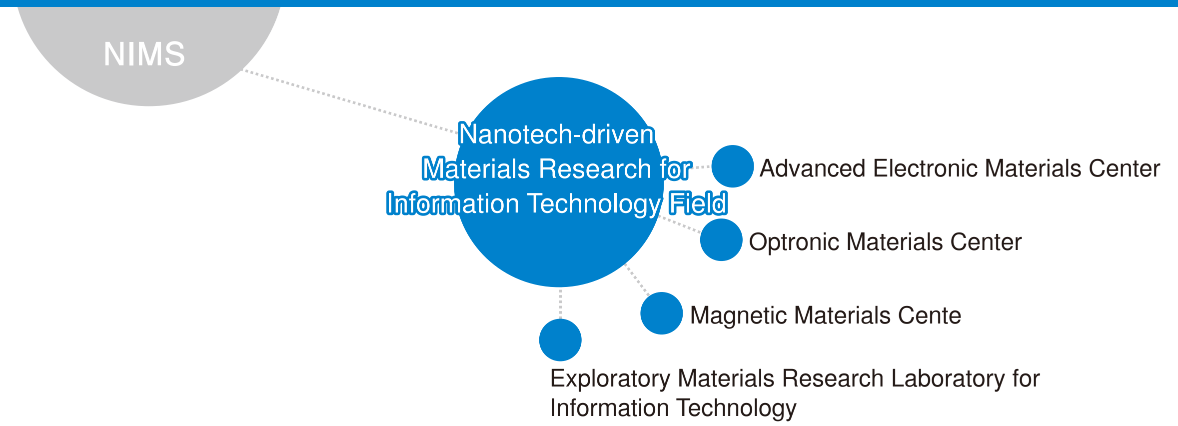


Fig.3 Porous filter membrane of ferritin with internal channels having diameters around 2 nm (cross-sectional SEM image).

Solutions to many fundamental problems of next-generation IT equipment parts

Yasuhiro Horiike
Coordinating Director, Nanotech-Driven Materials Research for Information Technology Field



Targets of this field.

In information technology (IT) equipment for a ubiquitous society, high integration, high speed, large memory capacity, and low power consumption, etc. are demanded. To meet these requirements, the NIMS Nanotech-Driven Materials Research for Information Technology Field is targeting (1) insight into the physical properties originating in crystal structures and electron orbits, (2) creation of those nanostructures by original synthesis techniques, (3) new physical properties discovered at the nano-level by various types of novel observation and measurement techniques, (4) development of materials which display novel functions by control of the properties at the nano size, resulting in (5) achievement of research policies for realizing devices with various materials in the areas of semiconductors, optronic materials, and magnetic materials.

Advanced Electronic Materials Center.

One problem for the gate stacks at the heart of next-generation CMOS was Fermi level pinning (FLP). In cooperation with the University of Tsukuba and Selete (Semiconductor Leading Edge Technologies, Inc.), the NIMS Advanced Electronic Materials Center clarified the fact that FLP occurs when electrons migrate to oxygen vacancies (O vacancies) generated in a high-k film (**Fig. 1(a)**). Researchers also evaluated the relationship between the type of gate material used and O vacancies in high-k films by the electron beam induced current (EBIC) method, and found that the quantity of O vacancies in high-k films decreases in the order of polycrystalline silicon (Si), metallic silicide, nitride, and carbide metal.

Therefore, an amorphous metal gate which has excellent micro-fabrication properties and enables control of the work function was developed. As a result, a material with an amorphous structure, which is obtained by addition of yttrium (Y) to tantalum carbide (TaC), enables 0.8eV flat band control, and is stable on hafnium oxide (HfO_2), was discovered **(Fig. 1(b))**. Direct connection without causing an oxidation film on the Si under high-k materials is also needed. A search was conducted for this material from the thermodynamic viewpoint using a combinatorial technique, and a **CeHfAlOx system high-k material** which displays good compatibility with metal gates was discovered **(Fig.2 (c))**.

Optronic Materials Center.

The Optronic Materials Center carried out research on the formation of light sources with arbitrary wavelengths from ultraviolet (UV) to infrared (IR) using optical materials based on ceramics. Hexagonal boron nitride (h-BN) was prepared by flux growth using a metal solvent, and a deep ultraviolet (215 nm) UV source using electron excitation was developed. As wavelength conversion to 193 nm was successfully achieved with the formed quasi-phase matching (QPM) device by applying pressure to a quartz plate, development of a solid-state ArF (193 nm) laser is expected. On the other hand, a wide-range wavelength conversion device was developed using permanent QPM with a lithium niobate ($LiNbO_3$) ferroelectric, expanding applications from medicine to wavelength-division multiplexing, etc. A large diameter single crystal of a barium magnesium fluoride ($BaMgF_4$) ferroelectric which is transparent to deep UV was also developed, and conversion to 277 nm UV by QPM was achieved. Colloid photonic crystals change color in response to stress, making it possible to visualize the locations of stresses, such as strain. Development of large-area materials for safety/security of buildings, etc. is underway. Utilizing the band structure of colloid photonic crystals, an organic flexible laser combined with fluorescent materials was developed, and excellent results have been obtained with **tunable lasers** as an application of this technology (**Fig. 2**).

Magnetic Materials Center.

The Magnetic Materials Center developed ultra-high density magnetic storage aiming at $1Tbit/in^2$ and high coercivity magnets for electric vehicles (EV). As a particular feature, the nanostructure is controlled using nano observation techniques such as the 3D atomic probe, etc. In the area of read heads, the Center first began development of a tunnel magnetoresistance (TMR) device and developed a Heusler alloy $Co_2FeSi_{0.5}Al_{0.5}$ (CFSA) system which achieves a MR ratio of more than 400%. On the other hand, because the resistance of TMR devices is high, the Center also developed a current-perpendicular-to-plane giant magnetoresistance (CPP-GRM) device using the CFSA system, and achieved an MR ratio of 43% at room temperature and 130% at low temperature, suggesting the possibility of application to next-generation HDD heads. In perpendicular magnetic recording media, thermally assisted magnetic recording with a size dispersion of 1.5 nm was achieved with particles of 6 nm and under using an $L1_0$-FePt system, with the prospect of achieving $1Tbit/in^2$. In magnets, researchers succeeded in **increasing coercivity to 20kOe by nano control of the interface in a Nd-Fe-B system without use of dysprosium (Dy)**. As this was possible without using the rare earth element Dy, this result could play a key role in element strategy **(Fig. 3)**.

Summary of the year and key achievements.

In this field, particular importance is attached to joint research with industry and transfer of results (licensing). For example, the above-mentioned results in connection with gate stacks have been licensed to Japanese semiconductor companies through Selete, and a hand-held type h-BN deep UV light source was developed jointly with Futaba Corporation. Because h-BN has an ultra-flat cleavage plane, this material is also supplied to graphene researchers around the world when requested, thereby supporting research in this area. Fluoride crystal technology was transferred to Tokuyama Corporation and commercialized as large diameter calcium fluoride (CaF_2). With the wide bandgap semiconductor zinc oxide (ZnO), NIMS researchers succeeded in growing large-scale single crystals, and this is now marketed by Mitsubishi Gas Chemical Corporation Inc. Joint research is also underway on magnets with Toyota Motor Corporation and Hitachi Metals, Ltd., and on MRAM with Toshiba Corporation.

A Special Feature on the Advanced Electronic Materials research was published in July-Aug 2010, and Magnetic Materials research was in October 2010 edition of NIMS NOW.

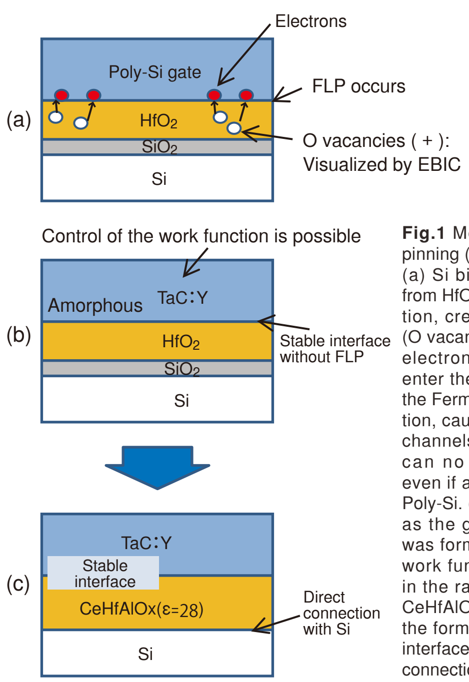


Fig.1 Mechanism of Fermi level pinning (FLP) and NIMS proposal. (a) Si binds to oxygen supplied from HfO_2 bond by interfacial reaction, creating oxygen vacancies (O vacancies; +) in the HfO_2. The electrons which are discharged enter the Poly-Si, where they pin the Fermi level by Coulomb attraction, causing FLP. As a result, the channels at the Si/SiO_2 interface can no longer be controlled, even if a voltage is applied to the Poly-Si. (b) When TaC:Y was used as the gate metal, an interface was formed without FLP, and the work function could be changed in the range of 0.8eV. (c) Use of CeHfAlOx in place of HfO_2 avoids the formation an oxide film at the interface with the Si, making direct connection to the Si possible.

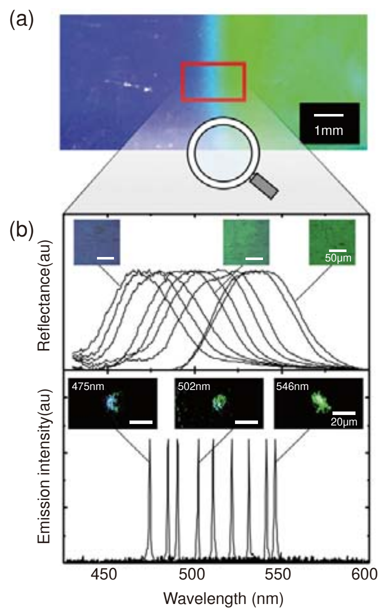


Fig.2 Soft tunable laser
(a) Photographs of a sample obtained by placing a cholestric liquid crystal oligomer between two glass plates, heating to 95°C (left) and 85°C (right), and a hardened glass sample is obtained by supercooling operation. The helical length of the liquid crystal gradually changes, and this demonstrates an effect in which the cavity length changes continuously.
(b) Top: Spectral reflectance microscopy spectrum of the part of the sample where the helical length of the liquid crystal gradually changed, and bottom: the related lasing spectrum. When the measurement position is moved, the reflection band shifts continuously, and accompanying this shift, tuning of the wavelength of laser oscillation is also possible.

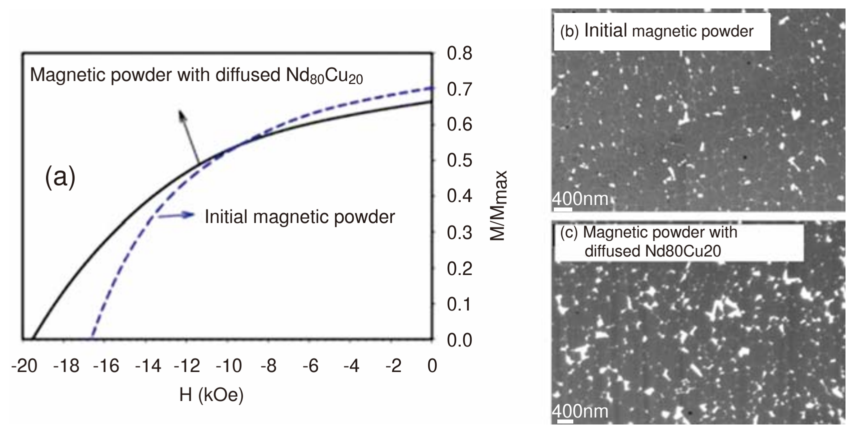
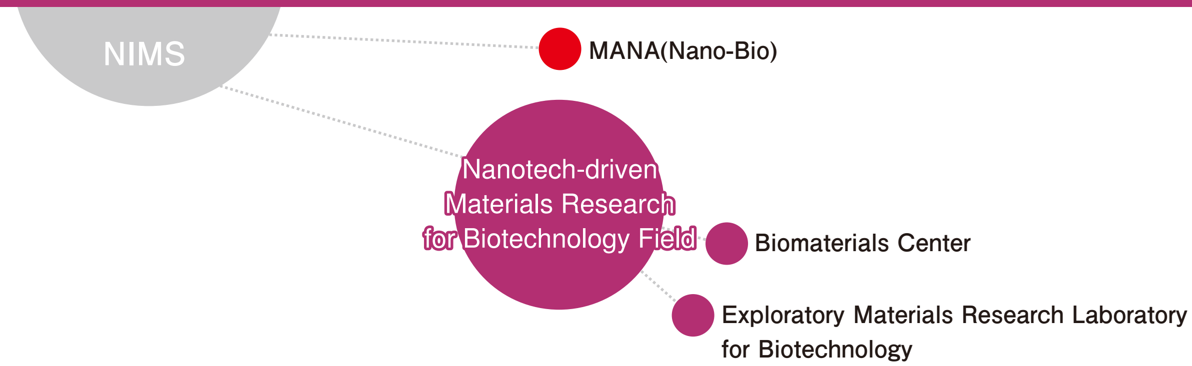


Fig.3 Dy-free neodymium magnet
(a) Relationship between magnetization M and coercivity H. Dotted line in Fig.(a) shows a M-H curve and Fig.(b) shows a TEM photograph of Nd-Fe-B magnetic powder produced by HDDR (Hydrogenation Decomposition Desorption Recombination) treatment, respectively. The powder has a crystal grain size approximately 1 order finer than that of sintered magnets. Solid line in Fig.(a) shows a M-H curve and Fig.(b) shows a TEM photograph of a new magnet, respectively. The magnet was obtained by diffusion of $Nd_{80}Cu_{20}$ alloy along the grain boundaries. It provides Hc～20kOe even for without addition of Dy. Black and white parts of Figs. (b) and (c) indicate $NdFe_{14}B$ regions and Nd-rich grain boundaries, respectively. Addition of a magnetic field magnetizes $NdFe_{14}B$ regions. Since the grain boundaries isolate each magnetic field of $NdFe_{14}B$ regions from that of adjacent regions, whole magnetization is kept to one direction, thus enhancing coercivity of the magnet.



Developing technologies for the medical industry by merging materials science and biotechnology

Takao Aoyagi
Coordinating Director, Nanotech-Driven Materials Research for Biotechnology Field

Objectives and composition of this field.

This field comprises the Biomaterials Center, the Exploratory Materials Research Laboratory for Biotechnology, and the Medical-use Fiber Architectonics Project. Taking advantage of the distinctive features and strengths of the interdisciplinary research system at NIMS, our objective is to vigorously promote the development of new functional biomaterials and medical devices. In cooperation with outside medical institutions, we plan to continue developing technologies for the medical industry through an active fusion of biotechnology with a wealth of knowledge in the field of materials science.

NIMS has accumulated high level research facilities (synthesis and characterization equipment, cell culture rooms, and animal experiment facilities) and the technical expertise necessary for the development of materials and devices. The Biomaterials Center, which is the core unit of this field, is made up of eight groups. As the living body consists variously of hard tissues such as bone and teeth, and soft tissues such as skin, blood vessels, and organs, the artificial materials for repairing these tissues also span a wide range. Each group within the Biomaterials Center brings together experts who have a thorough knowledge of the respective materials. and carries out research which concentrates that knowledge.

In addition to the Biomaterials Center, NIMS also has the Exploratory Materials Research Laboratory for Biotechnology, which is engaged in focused research on simple but accurate diagnostic technologies for preventive medicine. For instance, the Medical Use Fiber Architectonics Project is grappling with research on new tissue reconstruction materials which are based on the control of molecular arrangement through a convergence of different fields in NIMS.

Target for the NIMS 2nd Five-Year Plan.

The target for the 2nd Five-Year Plan is the development of biomaterials utilizing nanotechnology.

The smallest unit of the human body is the "cell." The body is constructed from "tissue," which consists of groups of cells and the matrices which support them, and "organs," which are tissues that are organized so as to demonstrate functions. Thus, the body is made up of extremely complex nanostructures and a hierarchical organization of those nanostructures. Therefore, introducing the concept of nanotechnology in the design and construction of artificial materials, and reproducing intricate structures which are closer to those in the human body, are extremely effective strategies for constructing biomaterials for treating disease.

Research results.

Among many research results in this field, the following introduce some distinctive achievements.

The Ceramic Biomaterial Group continues to conduct research on an oriented open-pore apatite artificial bone material. On August 20, 2009, The Ceramic Biomaterial Group obtained pharmaceutical affairs approval from Japan's Ministry of Health, Labour and Welfare. This material was commercialized by Kuraray Medical Inc. under the name "Regenos®." The pores in this artificial bone material are formed by using ice as a casting mold. By aligning the pores, an ideal mechanical strength close to that of human bone was successfully obtained. Based on this achievement, research on inorganic artificial materials with higher functionality is continuing to bear fruit in a composite with collagen.

The Biomaterial System Group is continuing to conduct developmental research on a **drug-eluting stent** which effectively avoids restenosis. Stents are widely used to expand blood vessels when constriction (stenosis) of a blood vessel occurs due to atherosclerosis, but recurrence of stenosis (i.e., restenosis) had been a problem with conventional stents. Therefore, this group developed a innovative stent in which a bio-originated material with excellent adhesiveness is fixed on the surface of the stent, and the drug tamibarotene is eluted from this matrix. This induces endothelial cells (EC) to the area, promoting the formation of tissue. As a result, it was found that tissue which is virtually indistinguishable from the surface of a healthy blood vessel can be formed stably. This new stent was shown to suppress restenosis over the long term, and animal experiments are now progressing steadily. Early commercialization is expected.

In other research by the biomaterials system group, a **bio-transistor with dynamic interface gate** was successfully synthesized using phenylboronic acid. A self-assembled monolayer with this compound as its terminal group was prepared, and was used successfully in **quantification of sialic acid**. As the relationship between sialic acid and various pathologies has been clarified recently, the development of a simple assay method for sialic acid is expected to make an important contribution to the area of examination and diagnosis.

The Advanced Medical Materials Group is involved in work on the **construction and application of sensor cells** utilizing molecular biology and cell biology techniques. In this approach, the sensor cells express a fluorescent protein in response to a signal, a method that can be used to detect trace amounts of toxic metal ions and anticancer agents. This is expected to be an extremely effective technique for evaluating the toxicity of quantum dots and nanoparticle materials.

Summary and Outlook for 3rd Five-Year Plan.

In the Biotechnology Field, research results that led to products were obtained under the 2nd Five-Year Plan. Other research results have also contributed to the respective commercialization of products.

Looking ahead to the 3rd Period, the theme of "material therapy" will be strongly promoted. In this, cell functions will be actively controlled, with materials playing a key role. This new area of biomaterial research will be carried out by mobilizing the wide range of material technologies available at NIMS. We will endeavor to contribute to society through this research.

A Special Feature on the Nano-Bio Materials Research was published in the June 2009 edition of NIMS NOW.

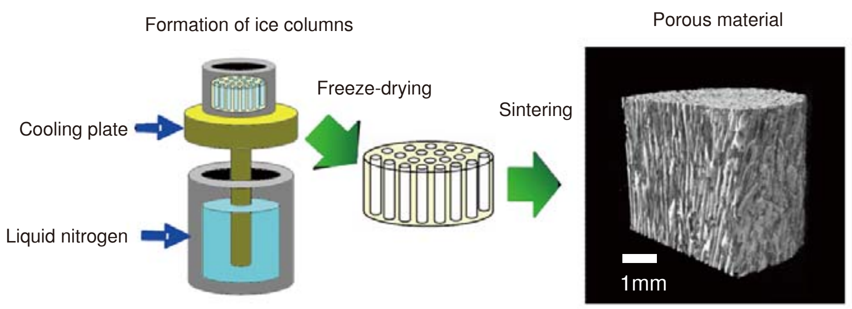


Fig.1 Production method of developed artificial bone Regenos® and actual micro-CT image.

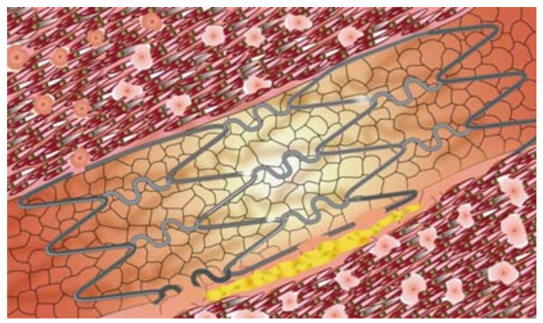
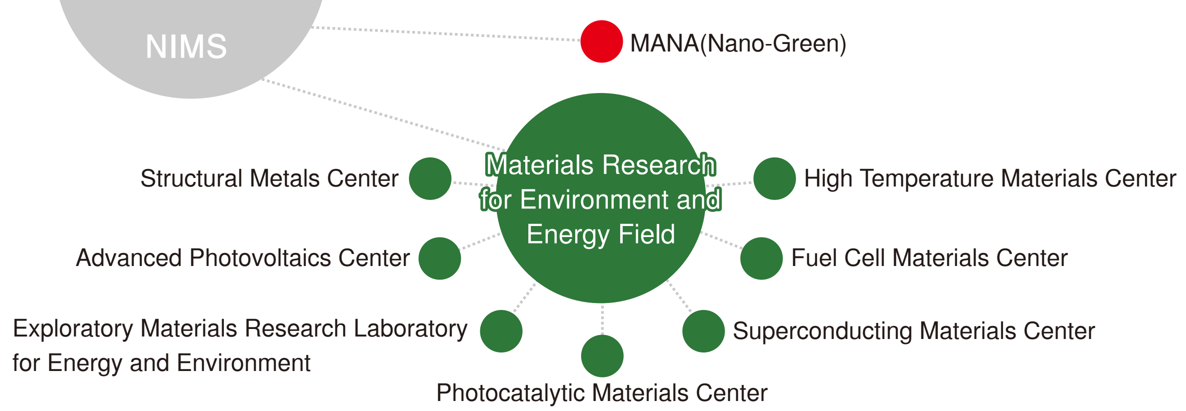


Fig.2 Schematic diagram of stent left in place in a blood vessel.

Fig.3 Surface of blood vessel after leaving the developed drug-eluting stent in place.



Research and development for advanced environmental and energy materials

Kotobu Nagai
Coordinating Director, Materials Research for Environment and Energy Field

Putting fundamental capabilities in material nanotechnology to work for social needs.

The concept of this field is expressed in our desire to apply fundamental materials-related capabilities, which are a great strength of NIMS, to urgent social needs. More concretely, we are steadily contributing to society by discovering material technologies which achieve high functionality, ensure safe and stable operation, and utilize resources and energy more efficiently by nano-level control of material structures and various material reactions.

Heightened expectations and the growth of new seeds.

We began from the development of practical parts using ultra-high temperature alloys, various types of superconductors, and high performance metals, which are the three fields that form the firm base of our work, and the development of visible light photocatalysts and development of medium- and low-temperature fuel cells materials, which are two fields that represent completely new challenges.

First, while material fundamentals remain important, in order to translate this into parts and systems, we achieved an early transition to practical applications more certainly by positioning infrastructural manufacturing technologies as original research and consciously pursuing tie-ups with industry.

However, during this period, the expectations placed on the energy and environment field increased at an accelerating pace. Therefore, based on an immediate grasp of social needs, we quickly launched research in a variety of new fields, such as a next-generation photovoltaic cells, platinum group metals, LED phosphors, all-solid-state lithium rechargeable batteries, thermoelectric materials for power generation, and others.

In these respective fields, the researchers in this field have produced a steady stream of new ideas, not limited to results in line with the expected targets. Due to space restrictions, the following will introduce selected examples of results symbolizing this work.

Installation in the jet engine of a civil aircraft. Ni-base single crystal superalloy turbine blade.

Fossil resources are not unlimited. High efficiency use contributes to conservation of those resources, and at the same time, also reduces generation of carbon dioxide by combustion. For the same reasons, efforts are being made to improve the fuel efficiency of large-scale jet engines. Because higher fuel efficiency can be realized by increasing the combustion temperature, alloys which can withstand these higher temperatures are necessary.

NIMS has developed several ultra-high temperature Ni-base superalloys which boast the world's highest performance, and we took up the challenge of applying one of these to the turbine blades of large-scale jet engines. This material passed various material evaluation tests and **turbine blades have been cast successfully**, and full-scale study of adoption in engines for Boeing's next-generation passenger aircraft is underway. Following various tests, operation in commercial flights is expected in the future (**Fig.1**). In this work, we reached the final product stage through cooperation with private companies, based on fundamental research.

Success in development of ultra-high strength, high-toughness 1800MPa class bolt.

Increasing industrial production worldwide is threatening the sustainability of natural resources. For this reason, the future will be a period of competition not in production volume, but in effective utilization of resources. A common need in every industrial field where huge amounts of materials are necessary is lightweight, safe, economical basic materials that can be produced using ordinary resources. When attempting to realize this with steel, avoiding indiscriminate dependence on alloying elements, and the multiple contradictions of realizing high formability with high strength and high safety with high strength are barriers.

Therefore, in this field, we first realized a breakthrough by **developing a material which provides high strength and is also resistant to fracture by control of the nanostructure of the steel**. We then succeeded in further improving this material and forming bolts in collaboration with a company which possesses excellent forming technologies (**Fig.2**). Although bolts produced by the conventional method are brittle, the bolts produced by the developed forming method have a ductile fracture mode, and thus demonstrate high safety. These are basic research results which show that Japan is the world leader in effective utilization of resources.

Success in development of visible light-responsive photocatalyst, opening the way to the dream of artificial photosynthesis.

Sunlight is a source of energy for the entire planet. High expectations are placed on photocatalysts which make direct use of sunlight as a clean energy technology which offers an alternative to fossil fuels. In particular, the function of producing hydrogen by photodecomposition (photolysis) of water can also be called "artificial photosynthesis," as it is similar to the photosynthesis seen in plants. Because titanium dioxide, which is a representative photocatalyst, is only responsive to ultraviolet (UV) light, efforts were made to **develop a visible light-responsive photocatalyst** which can overcome this weak point.

In oxygen generation tests by photolysis of silver phosphate, the quantum yield under visible light showed an astonishing value of approximately 90% (**Fig.3**). Although this is still only an early finding, it is a valuable result of basic research which suggests tremendous potential. In the future, we will endeavor to expand these possibilities by elucidating the mechanism responsible for this phenomenon.

A Special Feature on the ultra-high temperature alloys was published in the Oct. 2010, on the superconductors was in Sep. 2010, and on the photocatalysts was on the March 2008 edition of NIMS NOW.

Fig.1 Single crystal turbine blade for use in large-scale jet engines.

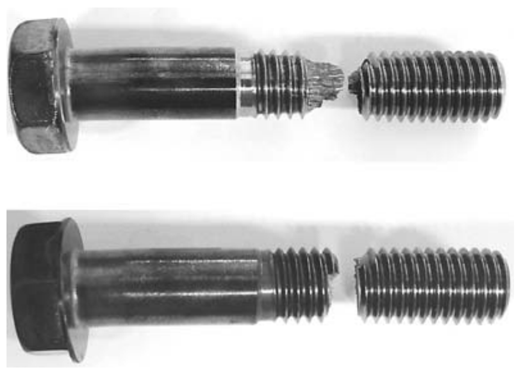


Fig.2 Bolts produced by the developed forming method with ductile fracture mode, and thus demonstrate high safety.
Fracture mode of the developed hexagonal bolt (M12) (tensile strength = 1848MPa).
Fracture mode of a conventional hexagonal bolt (M12) (tensile strength = 1833MPa).

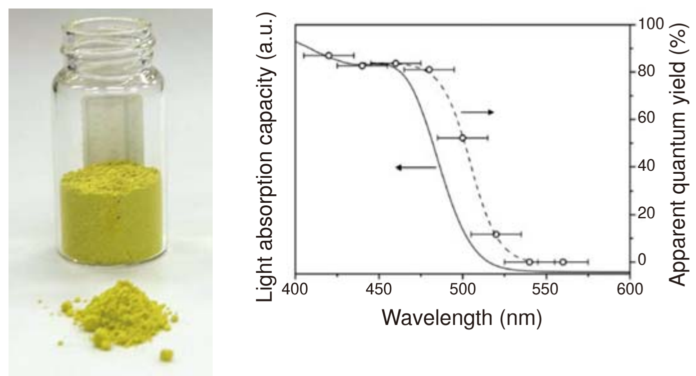
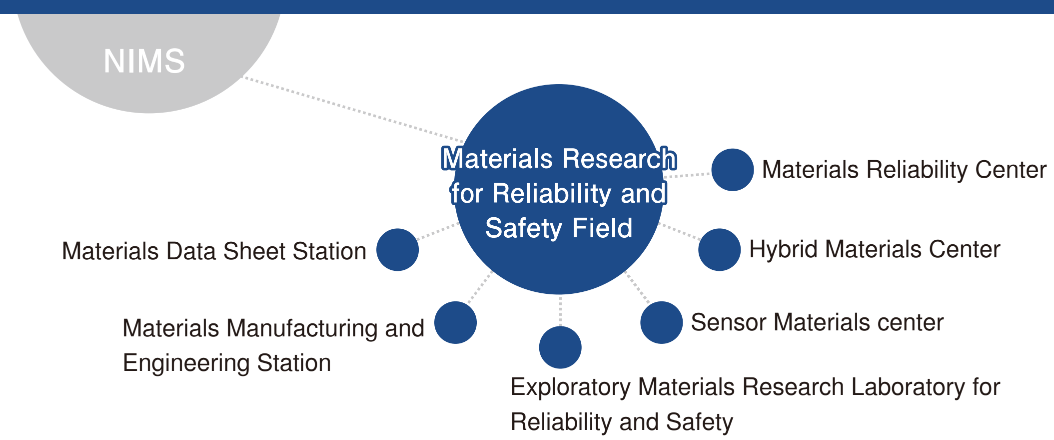


Fig.3 Visible light-responsive photocatalyst.
Silver phosphate powder (left)
Wavelength dependence of light absorption capacity (left axis) and apparent quantum yield in oxygen generation test (right axis) of Ag_3PO_4.



To provide solutions to "old, yet new problems" and "problems that take long periods of time to be solved"

Yutaka Kagawa
Coordinating Director, Materials Research for Reliability and Safety Field

Target of this Field.

In order to prevent dangerous accidents in structures due to failure of the materials, improvement of mechanical performance in structural materials has been recognized as an important area of research and development. The research and development could help guarantee the reliability of structures in service, and thus, assure the safety and security of such structures for our daily life. This research and development field has a long history and recent activity has become relatively low compared with that of functional materials. As a result, although the importance of the field is recognized, the field has less attention and numbers of researchers in this field has decreased, not only in Japan, but also internationally.

On the other hand, contrary to this research and development situation, dangerous accidents related to failure of structural materials have shown an increasing tendency. For example, degradation of old infrastructure materials, which have been used under service for a long time, *e.g.*, steels used in bridges and buildings etc., accelerates this recent trend. Thus, research in the field of materials reliability is still a very important research and development field in materials science and engineering; the methodology of research and development should depend on the current and near future application conditions of structural materials, however.

To provide solutions to these old, yet new problems and problems which can only be solved over long periods of time, NIMS organized the "Materials Research for Reliability and Safety Field" simultaneously with the start of its 2nd Five-Year Plan in fiscal year 2006. When this field was established, it comprised three centers. Subsequently, the Materials Data Sheet Station and the Materials Manufacturing and Engineering Station were added during FY2009.

Inter-relationships among Centers and significance of the existence of the field.

The three centers can be classified into three different situations of structural materials applications; before failure, during failure and after failure. The topics of the individual centers were decided based on the entire purpose of the research field; *i.e.*, to provide solutions to "old, yet new problems" and "problems that take long periods of time to be solved." The three centers are,

(i) Sensor Materials Center (which aims at detecting a material failure event before it occurs)
(ii) Materials Reliability Center (which focuses on the mechanism and other features during failure)
(iii) Composites and Coatings Center (which develops failsafe hybrid material systems to cope after failure; this Center was later renamed to the Hybrid Materials Center).

The three centers cover a wide range of history for the practical application of structural materials, and solutions for future new technologies in traditional and advanced structural materials. The project, including "wide range of service time," is quite unique and the research activity of the field has had a large impact in this research and development field, both individual research activities and related field activities.

The introduction of new organizations such as the Data Sheet Station, Materials Manufacturing and Engineering Station, Exploratory Materials Research Laboratory for Reliability and Safety, etc. indicates that the areas of research included in the field had significantly expanded in recent years. This recent re-organization of the field will contribute towards new research and development proposals in the next five-year period.

Representative research results of the Materials Research for Reliability and Safety Field.

Here, due to the limitation of available space, we will focus on selected research results from the results of the three centers. It should be noted that these centers have obtained many original results, which can be found in the Annual Report, NIMS NOW, etc.

The Materials Reliability Center conducts research and development to assess the mechanisms of time-dependent degradation phenomena such as creep, fatigue, and stress corrosion cracking in the actual service environments of engineering structural metals, and to predict the timescales when metals will reach failure under service environments. Simple low-cost detection procedures for degradation of metals under corrosion environments is an important achievement. By designing a specially designed specimen with an artificially narrow gap, detection of corrosion becomes possible **(Fig.1)**. This device is effective at detecting degradation of metals under corrosive environments, thus indicating the limitations of metals under these conditions.

Next generation power plants and high temperature plants are requested to reduce CO_2 emissions and save energy. To achieve this, application environments of high temperature metals become more severe and the reduced life under the severe environments should be predicted to allow safe operation. The development of the materials themselves and **the development of techniques for detection of degradation** during the use of those materials are important achievements.

The research activity of the Hybrid Materials Center has been focused on making "Fail-Safe" materials using hybrid microstructures of various kinds of materials. Design of strengthening and toughening mechanisms is also important to obtain high performance Fail-Safe hybrid materials. This Center has developed research on plastic hybrid materials, ceramic hybrid materials, hybrid coatings, etc. The Hybrid Materials Center obtained one **solution to achieving high strength/high toughness multi-scale hybrid materials using the concept of biomimetics** **(Fig.2)**.

Detection of damage of the structural material itself and detection of environmental degradation are important for safety. The Sensor Materials Center developed materials and devices for new sensors. One interesting result is the **detection of flames with a wavelength of less than 260 nm under sunlight** **(Fig.3)**. Combined use with commercially available conventional sensors makes it possible to achieve higher safety margins for daily lives. The unique activity of this center is making devices using developed materials, which allows rapid application of developed sensor materials into sensor devices.

Future research and development.

Various research results obtained in the Reliability and Safety Field have the potential for direct application to current engineering materials and also application to other kinds of material-systems. The research and development activities of the five-year project will be expanded in the next five-year individual projects, which are planned in NIMS 3rd Five-Year Plan in FY 2011 and will appear very soon.

We hope that the results obtained will be useful in the research and development of a wide range of materials science and technologies.

A Special Feature on the Materials Reliability Center was published in the June 2010 edition of NIMS NOW.

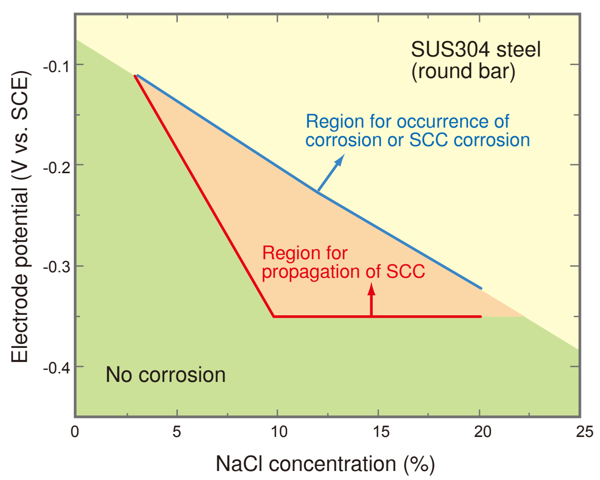


Fig.1 Diagram showing a stress corrosion cracking (SCC) region obtained for SUS304 stainless steel with a crevice in NaCl solution at 80°C. This result is the first time in the world that a stress corrosion crack, which has initiated from a crevice, will progress even under a more moderate environment. This result is useful for enhancing safety under corrosive environments.

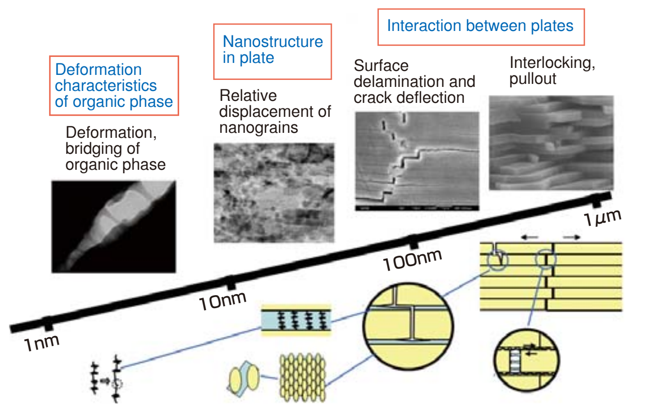


Fig.2 Schematic drawing of the mechanism of multi-scale fracture, which can be used in improving the mechanical properties of hybrid materials in the future. A multiscale strengthening/toughening mechanism can be applied instead of a single scale mechanism. Artificial hybrid materials have also been fabricated using this concept, and the effect has been demonstrated.

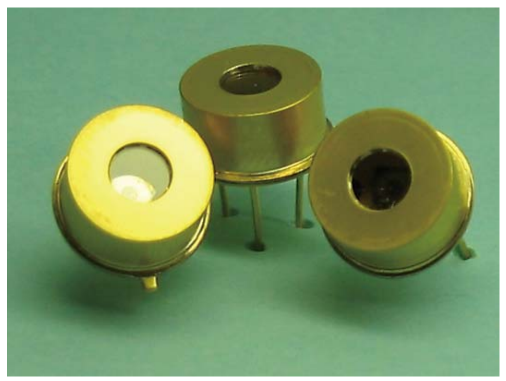


Fig.3 Appearance of diamond deep-UV sensor. This sensor is the result of integrated research and development from the sensor material to the device. By using this sensor, it is possible to detect potential danger in a service environment. Detection helps to guarantee the safety of structural materials.

Workshops on Graphene and Dirac Electron Systems

The Graphene Workshop in Tsukuba 2011 was held with NIMS as its main sponsor, in cooperation with Tokyo Institute of Technology and the University of Tsukuba, at the Okura Frontier Hotel Tsukuba (Tsukuba City, Ibaraki Pref.) on January 17 and 18.

At the conference, defect-free graphene films and the development of related applications was discussed by more than 200 participants. Keynote speeches were given by five speakers, including Prof. Konstantin Novoselov of the University of Manchester (Great Britain), who won the Nobel Prize in Physics for 2010, Prof. Mildred Dresselhaus of the Massachusetts Institute of Technology (United States), who is world-renowned for research on carbon, and Prof. Klaus Müllen of the Max-Planck Institute (Germany), who is known for his work on the chemical applications of graphene.

Following this event, the Workshop on Dirac Electron Systems 2011 was held at the NIMS Namiki Site. The discussions at this workshop focused in particular on cutting edge research in the field of physics, centering on graphene.

Prof. Novoselov also participated in the discussions with approximately 70 researchers, and exchanged ideas with researchers from NIMS and other institutions through debates aiming at the true nature of the new substance "graphene," which has attracted worldwide attention, and the search for the next new material after graphene.

(Top) Prof. Novoselov and (bottom) a group photo of the workshop participants with Prof. Dresselhaus and Prof. Novoselov.

International Symposia on Photocatalysts

The NIMS Photocatalytic Materials Center held the International Symposium "Photocatalysts and Environmental Remediation Materials 2011" at NIMS on January 17-19. At this conference, symposiums were held on five issues, centering on photocatalytic materials and photocatalyst science, porous materials, and the theoretic study of those materials, aiming at the construction of a sustainable society of the future, where environmental purification and environmental remediation will be key technologies. More than 120 persons participated this event.

Following the symposium, the 4th Japan-China Symposium on Advanced Photocatalytic Materials, which focused the theme on photocatalytic materials, was held at the Urabandai Nekoma Hotel with the cooperation of the Eco-materials and Renewable Energy Research Center (ERERC) of China's Nanjing University. This Symposium was held as the closing event for the final year of the Strategic International Cooperative Program, "Science and Technology for Environmental Conservation and Construction of a Society with Less Environmental Burden and Research on High Performance Photocatalytic Materials Related to Hydrogen Production Technologies Using Sunlight (FY2008-2010)," which was promoted jointly by the Japan Science and Technology Agency (JST) and the International Cooperation Bureau of the Ministry of Science and Technology of the People's Republic of China (MOST).

A group photo of the participants in the Photocatalysts and Environmental Remediation Materials 2011 symposium.

Hello from NIMS

Qingsong Mei (China)

ICYS researcher
Dec. 2008 - present

With ICYS director Dr.Miura (third from right), NIMS advisor Dr.Shida (second from right), and ICYS researchers at Millennium Science Forum. Second from left is author.

As a neighbor of China, Japan is somehow familiar as well as strange to me. I was curious to know how people in another country with similar culture origins are different from us. After I came to Japan, I tended to know it is much more than we have similar Kanji but different pronunciations. Of course the international atmosphere in NIMS is another big attraction to me. As an ICYS researcher in NIMS, I have benefited a lot from the variety of researches, easy access to excellent research facilities and moreover the independence to carry out my research work with meanwhile the support from mentors.

My daughter exited at the beautiful kazaguruma (pinwheel)

Now I have lived in Tsukuba for over two years, a period for my daughter to grow from creeping to walking and running. Thanks to the clean air and kindness of people, living in Tsukuba is simple and safe, as when sitting and playing with my daughter on the grass in Doho Park in a sunny weekend afternoon. From the nanostructures in materials I am trying to understand the macro property; from a leaf in Doho Park, I am trying to get a feeling for another culture. Both take time, and I am on the way.

P.S. At this moment, as I am checking the galley of this essay, Japan is suffering from a catastrophe. I was greatly touched by the lost of lives, and the order, calm and iron will of Japanese people even when their lives are threatened. For the respect of ordinary life and peace of heart, Ganbatte, Japan!

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To subscribe, contact:
Mr. Tomoaki Hyodo, Publisher
Public Relations Office, NIMS
1-2-1 Sengen, Tsukuba, Ibaraki, 305-0047 JAPAN
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