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A Single Particle of Light, in this Hand

The Innovative Photonic Materials Project.

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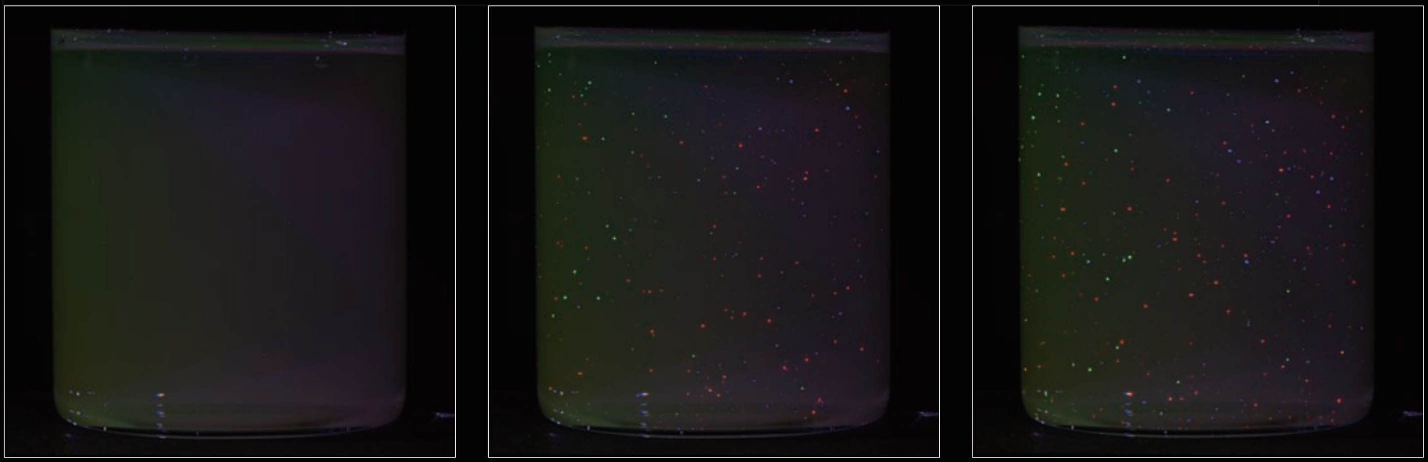
Light. Something that's impossible to grasp in one's hand.
But realizing control of light at the photon level,
and utilizing it in practical materials. . .
This is the mission of the NIMS Innovative Photonic Materials Project.

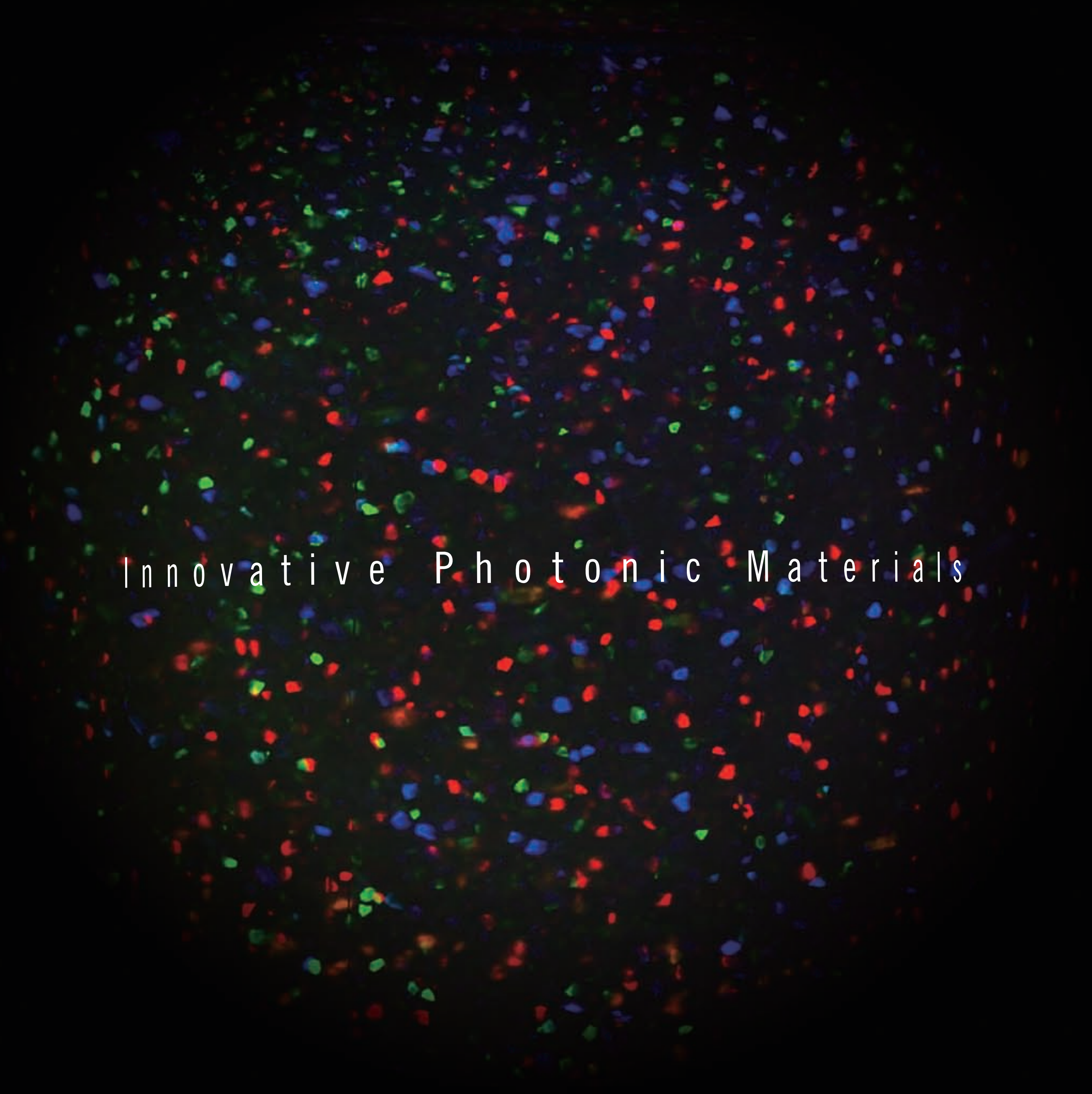
Every type of device that is now used in IT technology
is an electronic device that uses electrons.
But the fact that these devices use electrons is also a barrier.
If electrons can be replaced with photons,
higher integration, solution of heat treatment problems, cryptography, higher capacity and speed,
all these features can be dramatically improved.

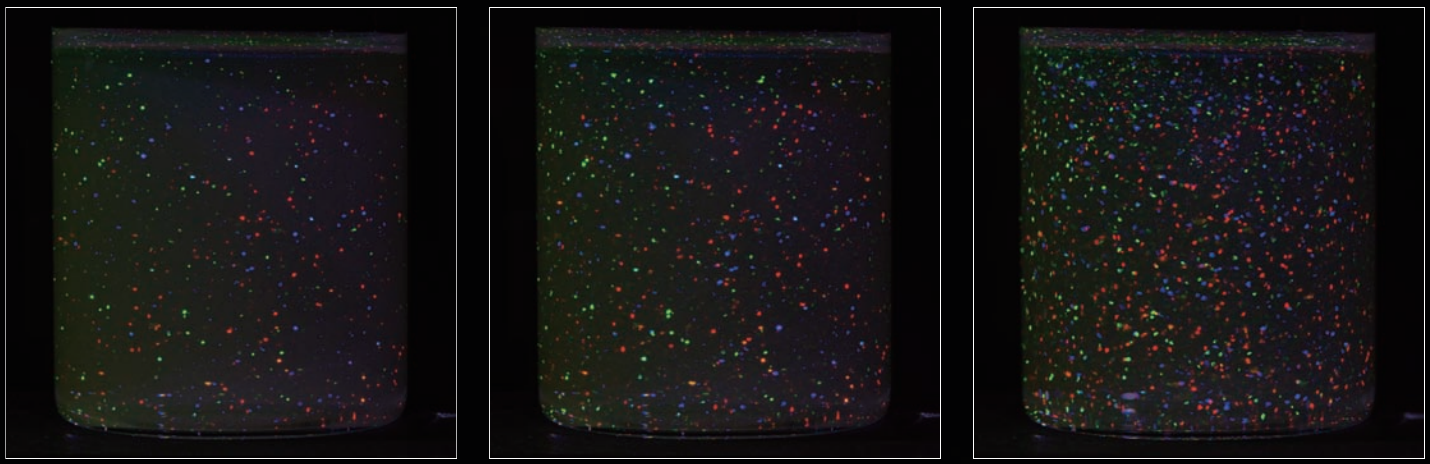
This Special Feature introduces laser and single photons and quantum dots,
that are unique NIMS advanced photonic materials.
for realizing the devices of the future.



Crystallization behavior of a colloidal dispersion used as material for soft photonic crystals. Numerous colored dots are domains of growing colloidal crystals. For details, see p. 6.

Innovative Photonic Materials





Manipulating the Quantum World by Creating Sophisticated Nanostructures

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The world of quantum nanostructures

Utilizing crystal growth techniques, we are creating sophisticated semiconductor nanostructures. We also manipulate the mysterious phenomena in the quantum world that are unfolded by electrons, photons (particles of light), and other quanta, and extract novel and useful functions and properties from those phenomena. This is the target of our research.

"Quantum dots" are a representative type of nanostructure, and are fine crystals with width, height, and depth dimensions of around 10 nanometers (nm). Although 1 nanometer is 1 billionth of 1 meter, let's try to image how small 1nm actually is. The diameter of our Earth is about 12,700km. Imagine that the size of the Earth is reduced to only 1 meter. If the size of a marble ball with 1.2 cm diameter is reduced by the same ratio, it will be approximately 1nm. Compared with atoms, 1nm is the size of several to about 10 atoms.

When an electron is confined in a quantum dot, it behaves as a wave, and the energy levels of an electron undergo discretization due to the quantum size effect. This means that quantum dots respond like atoms to electric signal and incident light.

For example, using the phenomenon called the "Coulomb blockade," electrons can be put into and take out from a quantum dot one by one. This can be regarded as similar to the phenomena of electrostatic charging or ionization of atom. Light is also emitted as a result of the electronic transition between discrete levels in a quantum dot. Because each discrete level does not have width, the energy of emitted photons is identical, and light with high color purity can be obtained. This is basically the same as the principle by which gas atoms emit light in a mercury lamp or sodium vapor lamp. Moreover, if a single quantum dot can be selected, it is possible to generate a single photon. Generation of single photons by quantum dots, which has been developed rapidly in these 10 years, is being studied for application to quantum cryptography technology, which will make eavesdropping absolutely impossible.

As this suggests, semiconductor nanostructures have the potential to provide us with novel phenomena and innovative functions. The real pleasure of this research is in discovering and demonstrating these phenomena and functions, and in searching for applications as technology.

Using the providence of Nature

Well then, what are the key elements in research on quantum nanostructures? Of course, many techniques and much advanced knowledge are necessary, but the importance of fabrication techniques is especially great. How these extremely small structures are created determines the success or failure of research. Moreover, not simply small size, but also high quality and purity of the tiny crystals are demanded.

When the concept of quantum nanostructures was first proposed, experiments were carried out by traditional fabrication methods using lithography and etching. However, defects occurred in the crystals, and the hoped-for physical properties and device characteristics could not be obtained. Subsequently, a new technological trend using thin-film crystal growth techniques for the lattice-mismatched systems called self-assembled processes began around 1990, and research accelerated because this process enabled fabrication of high quality quantum dots.

During the same period, NIMS also proposed a unique self-assembly process called "droplet epitaxy" and carried out a variety of technical developments related to this technique. As the principle of the droplet epitaxy, this process utilizes the phenomenon in which, for example, hemispherical Ga droplets having a diameter and height of nanometer size form in a self-assemble manner when the constituent gallium (Ga) atoms are deposited on the surface of gallium arsenide (GaAs) substrate.

After this, crystallization proceeds as arsenic (As) is supplied to the Ga droplets, and GaAs quantum dots are formed. The self-assembly of these droplets utilizes the power of Nature, resembling the way the rainwater that falls on a lotus leaf collects to form a round water droplet.

Recently, we succeeded in fabricating new quantum dots by the droplet epitaxy. Figure 1 shows an AFM (Atomic Force Microscope) image of GaAs quantum dots which formed on a special crystallographic surface called the (111)A plane. The quantum dots take the form of regu-

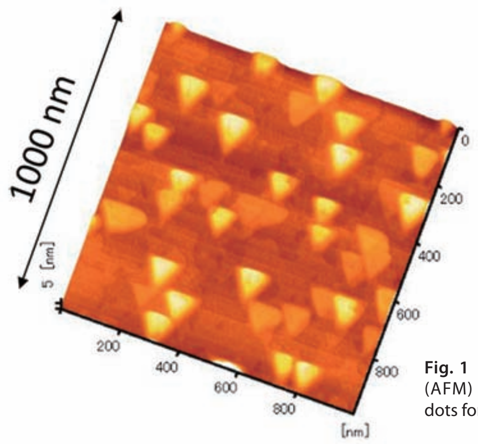

Fig. 1 Atomic force microscope (AFM) image of GaAs quantum dots formed on the (111)A plane.

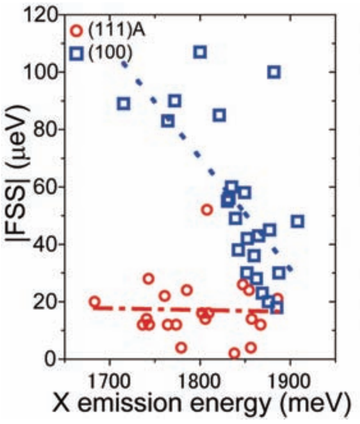

Fig. 2 Relationship between exciton (X) emission energy in a quantum dot and fine structure splitting (FSS). Small FSS is essential in the formation of entangled photon pairs. Quantum dots on a (111)A substrate can realize a small FSS in comparison with those on a (100) substrate.

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lar (equilateral) triangles because the symmetry of atomic arrangement in the (111)A plane is reflected in the quantum dot shape. These equilateral triangular crystals are automatically formed by the crystallization process when As is supplied to the Ga droplets. In other words, the providence of Nature is also at work here.

Quantum dots with excellent shape symmetry have become increasingly important in recent years. This is because the semiconductor devices that simultaneously generate two photons having a quantum correlation, which is called an "entangled photon pair," are necessary in order to realize long-distance transmission in quantum cryptography technology. Since efficient emission of these photon pairs from highly symmetric quantum dots has been predicted theoretically, the attention of researchers around the world has been focused on the NIMS droplet epitaxy method. Basic data have already been obtained, as shown in Figure 2, and demonstration of entangled photon pairs will soon be realized.

Nanostructures of atomic and molecular size

We are also putting great effort into another nanostructure. This is a technique in which an impurity atom having large electronegativity, called an isoelectronic impurity, is doped in a semiconductor crystal and made to behave like a quantum dot by strongly binding a few electrons and holes in the area around an isolated impurity and an impurity pair. In individual quantum dots which are fabricated by self-assembly, some fluctuations in shape and size are unavoidable. Therefore, achieving uniformity in the properties of all quantum dots is difficult, and has become a serious technical issue.

We devised a concept that makes it possible to solve the non-uniformity problems of self-assembled quantum dots by using an isolated impurity doped in a crystal, or a pair of impurities located at two neighboring lattice positions.

Figure 3 shows the microscopic PL (Photo Luminescence) image from a specimen in which nitrogen, as an isoelectronic impurity, was doped in merely one atomic plane of a gallium phosphide (GaP) crystal. Multiple bright spots with a uniform emission wavelength can be observed in the field of view.

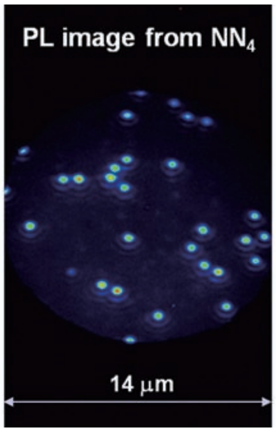
All these bright spots are photon emissions from excitons (pairs of electron and hole combined by Coulomb force) which have been captured by NN$_4$ pairs occupying the 4th neighboring lattice positions. We performed spectroscopy of one NN$_4$ pair, and demonstrated for the first time in the world that single photons are generated one by one each time excitons recombine and are extinguished. This experiment proved that excitons which are constrained by individual impurity pairs display a behavior similar to that of excitons confined in quantum dots.

The distance between the atoms in a NN$_4$ pair is approximately 0.77 nm. This is one order smaller than the size of self-assembled dots. Although NN$_4$ are formed stochastically, because all NN$_4$ have the same atomic arrangement, their emission wavelength coincides and is uniform. We are now engaged in research with the aim of expanding this technique to other materials systems, such as GaAs and others of direct band-gap structures.

Surface research supporting nanostructure fabrication techniques

A deep understanding and systemization of knowledge of the elementary processes of crystal growth not only has scientific value, but is also useful in fabricating new nanostructures. From this viewpoint, we perform structural analyses of semiconductor surface by STM (Scanning Tunneling Microscopy) and RHEED (Reflection High-Energy Electron Diffraction) and are also investigating the mechanism of crystal growth at the atomic level, including issues such as surface reconstruction and the dynamics of adsorbed atoms.

Figure 4 shows an STM image of the GaAs (001) surface on which 0.1-0.2 monolayers of nitrogen (N) atoms were adsorbed. The reconstructed surface structure with a distinctive (3x3) periodicity formed by adsorption of N atoms was revealed. To obtain information on the occupied sites of N atoms, RHEED and XPS (X-ray Photoelectron Spectroscopy) measurements were also performed. Utilizing this kind of basic data, the development of new nanostructure formation techniques can be improved and advanced efficiently.



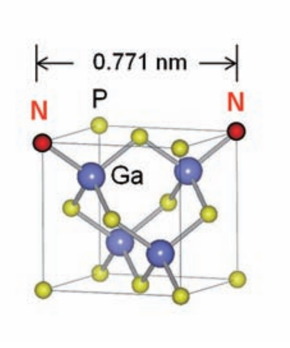


Fig. 3 (left) Photoluminescence (PL) image from the δ-doped layer of N in GaP, and (right) the unit crystal lattice of GaP and atomic arrangement of NN$_4$ pair.

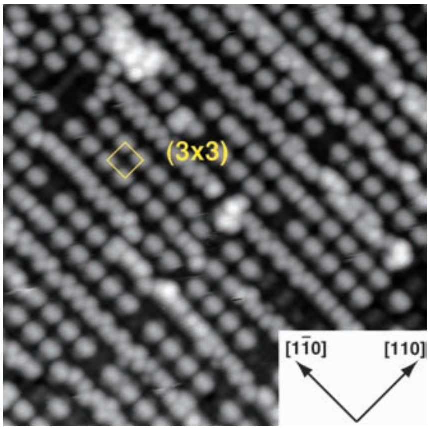


Fig. 4 Scanning tunneling microscopy (STM) image of a GaAs (001) surface on which nitrogen was adsorbed.

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Creation and Application of Soft Photonic Materials

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What does "soft" mean in photonic crystals?

The purpose of our research is to create and develop applications for soft photonic materials utilizing novel optical effects which are possible by producing fine structures from the nano size to the micron size. Here, "soft" mainly means that the materials are flexible, but at the same time, it also includes the meanings of the "soft" property of the synthesis process (soft chemistry resource-saving and energy-saving techniques are used) or the "soft" nature of the field of application (product fields that are more familiar and friendly).

Colloidal photonic crystals

Although a wide variety of photonic materials exist, the materials of interest to us are mainly the periodic structures of fine particles called "colloidal photonic crystals." Materials in which a periodic structure of a small scale on the order of the wavelength of light is formed by combining substances with different refractive indexes are generally called "photonic crystals." Colloidal photonic crystals are one type of such photonic crystals, but are called "colloidal" because the unit of the periodic structure is a colloidal particle (particle of nano to micron size).

Because photonic crystals are expected to manifest various special optical effects, such as a light confinement effect, light amplification, extreme reduction of the speed of light, and unique refracting properties, development of materials with the potential for practical application is desired. With general photonic crystals, expensive equipment is frequently necessary in order to fabricate the tiny structures of the crystals. In contrast, colloidal photonic crystals can be produced at a comparatively low cost because their periodic structure is readily formed by self-assembly of fine particles. Thus, when considering practical application, colloidal photonic crystals have the advantage of being suitable for industrial mass production.

Soft photonic crystals

Our aim is to realize soft materials, in which the material itself can be deformed easily, by selecting a flexible material such as a polymer gel or elastomer as the parent phase that fixes the periodic structure of fine particles in the fabrication of colloidal photonic crystals. The significance of creating these soft materials is that the properties of the material are easily changed by deformation. Figure 1 shows a schematic diagram of a soft photonic material. Since the parent phase which is embedded between the particles is a flexible material, the entire crystal is easily deformed by stress, that is, by compression or tension. This deformation changes the spacing between the particles and the symmetry of the array, which control the optical characteristics of photonic crystals. This means that soft photonic crystals are materials whose optical properties can be changed easily by applying stress.

The change in optical properties due to stress can be experienced most directly in the color change that occurs when tension is applied to a soft photonic material. Because photonic crystals have a microscopic periodic structure, they strongly reflect light of a certain wavelength, which is determined by their period. This phenomenon is termed "Bragg reflection." As a result, color due to Bragg reflection can be

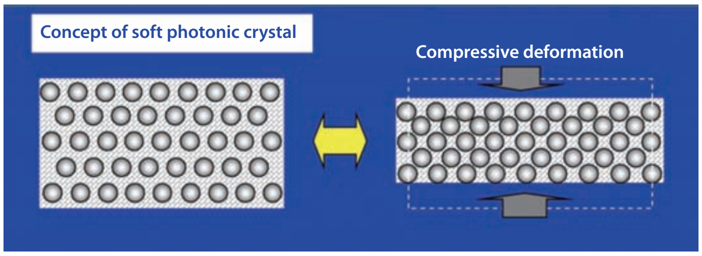

Fig. 1 Schematic diagram explaining the concept of soft photonic crystals. Because the spacing of the particles and the symmetry of the array structure change when stress (in this case, compressive stress) is applied to the material, optical properties can be changed by applying stress.

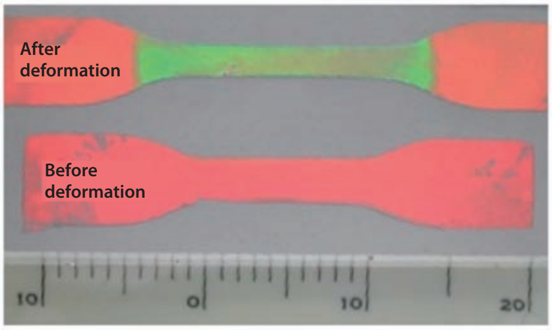

Fig. 2 Color change of a colloidal photonic crystal due to tensile deformation. Deformation changes the distance between the particles, and as a result, the color caused by Bragg reflection also changes.

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observed even in materials which are intrinsically colorless. Figure 2 shows the change from red to green in a red colloidal photonic crystal when tension is applied. The spacing of the array of fine particles contained in the crystal changes depending on tension, and accompanying this change, the optical properties of the crystal also change. One of our targets is to develop a process for producing this type of soft photonic crystal with a large surface area while also maintaining high quality.

Tunable microlasers using soft photonic crystals

Although the development of large-area soft photonic crystals is currently progressing, we can already produce comparatively small crystals of several millimeter to centimeter size (although these have been considered large in this field until now). We introduce the results of development of a laser device as an advanced application using this type of material.

Photonic crystals generally display a phenomenon in which the speed of light of a certain wavelength (wavelength very close to the Bragg reflection wavelength) is extremely reduced, and this phenomenon enables to generate the laser action. We fabricated a soft colloidal photonic crystal containing an added fluorescent dye and succeeded in producing laser action by exciting the crystal with short wavelength light. We also succeeded in continuously changing the wavelength of laser color from red to orange by compressive deformation of this colloidal photonic crystal. In other words, this is a tunable laser. Since the thickness of the material necessary for laser action is only 0.1mm, we succeeded in realizing a tunable microlaser by using this soft photonic crystal. Figure 3 shows the emission spectrum when the wavelength of laser oscillation is shifted, and Figure 4 shows the color change of the laser spot when the wavelength is shifted.

Utilizing the special features of structural color

This article has introduced an advanced laser device as an application of soft photonic crystals, but several other more familiar applications are also conceivable. The simplest application is use of the color produced by photonic crystals. The color of photonic crystals is not due to a dye, but rather originates from the microscopic periodic structure contained in the crystal. Color that originates from the structure of a material, like that of photonic crystals, is called "structural color." Soft photonic crystals are materials in which this structural color is easily changed by deformation. Taking advantage of this feature, we are studying use of soft photonic crystals in unique decorations and displays. We are also studying application of the change in optical properties depending on deformation as a technique for sensing strain. If soft photonic crystals can be obtained at a low cost, a wide variety of applied products may soon be part of our daily lives.

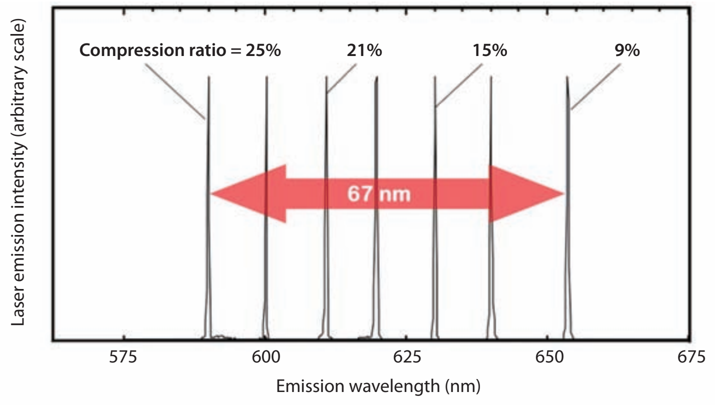

Fig. 3 Change of laser oscillation wavelength using a soft colloidal photonic crystal. The laser wavelength shifts continuously under compressive deformation, realizing a tunable laser.

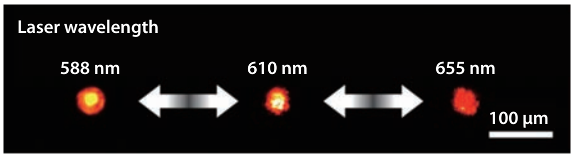

Fig. 4 Color change of laser spot when the laser wavelength is shifted by compression.

Creation and Application of Nanostructures for Radiation Field Control

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Ultrathin light-wave manipulation devices employing metamaterials

In order to manipulate light waves in desired ways, it is needed to create media suitable for individual purpose. Since 2000, great progress has been achieved in metamaterials that are emerging field on artificial electromagnetic wave media. In the studies these years, NIMS has demonstrated ultrathin devices that use subwavelength optical paths to manipulate the fundamental components, the polarization vector and phase, of light waves.[1)]

Figure 1 shows an actual ultrathin polarizer. Polarizer is one of the most basic optical devices. While commercially-available polarizers have optical paths of several 100 µm to centimeter order, the optical path in this metamaterial polarizer (3 layer structure) is a mere 250 nm. This device realizes equal or better polarizer performance, even though its thickness was reduced to 1/1000 to 1/100,000 of the ordinary ones. Our group has also shown systematic miniaturization of wave plates and circular dichroic devices [NOTE)] that control phase of light.

The relationship between ultimately small materials and light

We are also working toward elucidation of the optical phenomena in ultimately small materials, such as atomic scale and nano scale materials, which are the constituents of electromagnetic wave media, and are pursuing research that should contribute to the creation of new material functions. For example, we are investigating the behavior of light using the atomic level low-dimensional structures which are formed by self-assembly on the surface of crystals and the nanoantenna structures fabricated by lithography.

Our aim is to create plasmon resonance over a wide region from the infrared to the visible regions, as well as electric field amplification, and to apply these phenomena to detection of trace-level biomolecules in solutions, high efficiency energy conversion devices, etc. (Fig. 2).

Infrared scanning device using plasmonic metamaterial

A new plasmonic metamaterial was fabricated, in which an infrared scanning device for ultra-compact, low-cost laser/radar use was designed with a metal/dielectric laminated nanohole structure.

A flat prism is realized by gradually changing the hole shape at the surface, and a beam is scanned by controlling the light output direction.

Using electron beam lithography and the dry etching technique, we fabricated an infrared beam scanning device by nanofabrication techniques with high nanoscale accuracy and high speed. The holes were filled with a liquid crystal, enabling dynamic control by an external electromagnetic field. This work confirmed the principle of the infrared scanning device (Fig. 3).

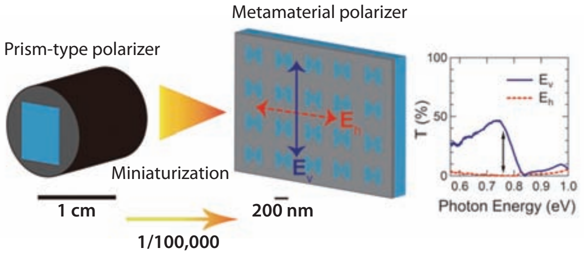

Fig. 1 Extreme miniaturization of a polarization control device: From the bulk device (left) to the metamaterial device (right). Gray and pale blue denote a metal (silver) and a transparent insulator, respectively. The measured polarized-light transmittance spectra are shown at the right.

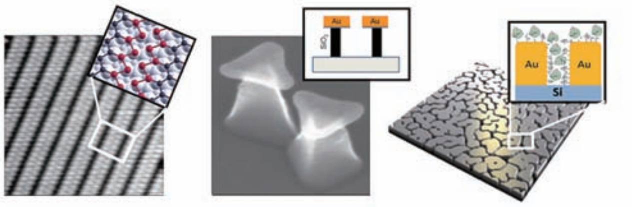

Fig. 2 (left) Gold atomic wire structure on a Si single crystal surface, (center) antenna structure fabricated by lithography, and (right) a nanogap structure grown in a solution.

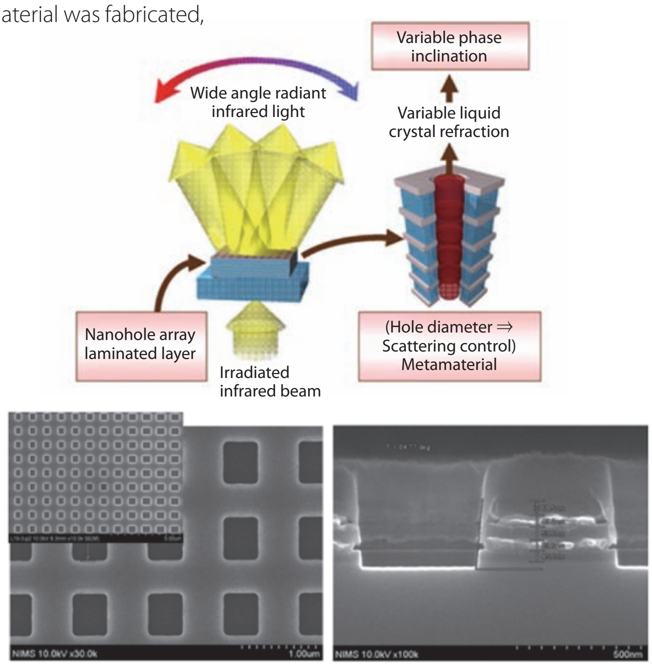

Fig. 3 Schematic diagram of the infrared beam scanning device and SEM images of the processed shape.

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1) M. Iwanaga, Sci. Technol. Adv. Mater. 13, 053002 (2012). [Review]

circular dichroism: Phenomenon that difference in absorption occurs in 3-dimensional structures when right-handed and left-handed circularly polarized light illuminates.

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Research on Coherence-Controlled Light Source by Nano Polarity Control
Coherence-Designed Low Noise Light Source

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What is possible with nano polarity control?

Wavelength control and phase control utilizing nonlinear optical effects are techniques for controlling the radiation field of light. Thanks to the impressive growth of dielectric polarization-reversal technology, progress can now be seen in nonlinear optics by polarity control.1)

Although energy conversion and phase control are possible by spatial inversion of the polarity of materials, nonlinear optical devices in which polarity is controlled with nanometer accuracy are necessary for precise frequency and phase control.

A completely new degree of freedom in radiation field control is obtained by polarity-controlled wavelength conversion. Because this technology allows us to design the amplitude, wavelength, and phase of light after wavelength conversion by applying various modulations to the polarity structure (Fig. 1), tunable lasers with features suited to individual applications are possible.

What are the potential applications of nano polarity control?

Like the revolution in lighting caused by LEDs, lasers are continuing to open doors in displays. Since laser displays have a variety of outstanding features, such as high brightness, high efficiency, and a focus-free property (focal point extending to infinity), application to large screen cinema and outdoor sinage is expected.

Although examples of practical application can already be seen in some projectors and televisions, reduction of speckle noise* is a difficult issue in laser displays. However, if low coherence design can be achieved by expanding the wavelength bandwidth of the light source, light sources with reduced speckle noise will be possible (Fig. 2)2).

This research concerns light sources for laser displays. Advanced laser light sources can be realized by low coherence design by using this nano polarity control technique.

Porarity-controlled wavelength conversion devices

For low coherence wavelength conversion to the visible light region, we are investigating polarity-controlled wavelength conversion devices, in which polarity is controlled with nano accuracy.

In this research, first, an electrode structure is formed by microexposure on stoichiometric lithium tantalate (Mg : SLT), which is an oxide ferroelectric, using a high conductivity metal. Next, a high electric field is applied to this electrode structure under a vacuum, and polarization reversal is performed. Because ions adsorbed on the surface are removed under the vacuum, large field contrast is possible when the field is applied. This is an advantage in micropolarization reversal formation.

Figure 3 shows the results of polarization reversal using a nano-accuracy periodic electrode. This figure shows a differential interference microscope image of a device with a period of 4.6 μm that converts the 405 nm wavelength of a gallium-nitride (GaN)-based semiconductor laser to the green 530 nm band. Sufficient uniformity for wavelength conversion was realized across a length of 20 nm at a polarization reversal ratio of 0.5, which gives the maximum efficiency. Here, a nano-accuracy structure could be secured at the macro scale, and more than 4000 domains are ordered and arranged.

As illustrated by this example, a new degree of freedom, polarization reversal provided by materials science, opens the way to innovative photonic materials.

References
1) Miyazawa and Kurimura, eds., "Fundamentals and Applications of Polarization-Reversed Devices," (Optronics Co., Ltd., 2006)
2) Kuroda, Yamamoto, and Kurimura, eds., "Commentary: Laser Displays," (Optronics Co., Ltd., 2006)

Speckle noise: Noise with a speckled pattern that appears when coherent laser light irradiates an object.

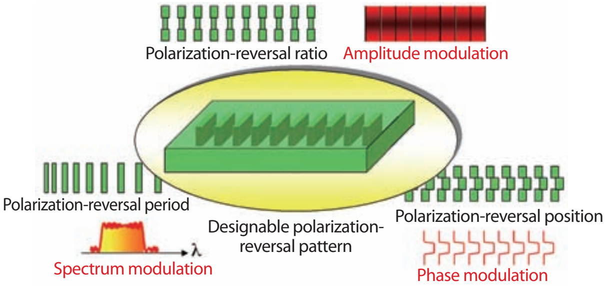

Fig. 1 Polarity-controlled nonlinear optical device : designable modulation in amplitude, wavelength, and phase of light.

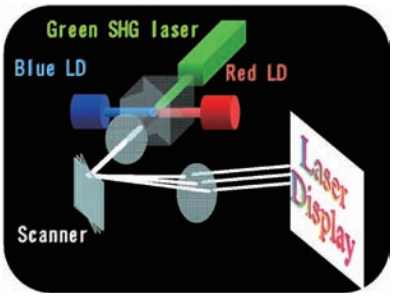

Fig. 2 Display using laser: Focus-free (focal point extends to infinity).

Fig. 3 Nonlinear optical device for polarity control which generates green light by wavelength conversion.

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Research on Innovative Waveguide Structures

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Kazuaki Sakoda

Aiming at innovative optical waveguides

In this subtheme, we are carrying out both experimental research and theoretical research with the aim of pioneering novel optical waveguide mechanisms utilizing nanostructures. Among achievements in this research, this article introduces recent results in connection with polariton nanofibers and optical Dirac cones.

Light propagation with low bending loss in nanofibers

In the course of exploratory research before the start of this project, we discovered that assemblies of thiacyanine dye form nanofibers. As shown in Figure 1, the thiacyanine molecules emit fluorescence when one point on the nanofiber is optically excited with a focused laser beam, and this light propagates through the nanofiber and is emitted from both ends.

Although the nanofiber includes a bend with a bending radius of about 4 microns, the microscope photograph shows that fluorescence propagates to the two ends with virtually no leakage from this bend.

We also succeeded in forming a Bragg reflector by electron beam processing of the fiber surface, and realized a Mach-Zehnder interferometer combining multiple nanofibers.1) These results are expected to contribute to the realization of micro-optical circuits and application to optical interconnects between semiconductor chips, etc.

The extremely small bending loss observed with this nanofiber is impossible to realize with conventional optical fibers that utilize refractive index guiding. Theoretical analysis revealed that a unique exciton polariton (wave in which electronic polarization of thiacyanine and a light wave form a complete whole), which reflects the structural anisotropy of the thiacyanine molecule, is responsible for light propagation in the nanofiber. 2)

Optical Dirac cones and zero refractive index

As already introduced elsewhere in this Special Feature, in our project research, we realized unique optical properties by fabricating photonic crystals and metamaterials with a regular arrangement having a period on the order of the wavelength of light, and are now developing various applications. We have also made important theoretical discoveries in connection with these materials.

The basic nature of light propagation in photonic crystals and metamaterials is determined by the relationship (dispersion relation) between frequency (ω) and wave number (k). If the frequency range near ω= 0, which is not important for applications, is excluded, the dispersion relation around k = 0 is normally flat (horizontal). This means light forms a standing wave and does not propagate in any direction.

However, if the frequencies of two light waves with different spatial symmetries can be made to coincide by skillfully designing a photonic crystal, we found that it is possible to realize a conical dispersion relation called an optical Dirac cone, as illustrated in Figure 2. 3)

At the Dirac point (ω_D), the light wave is a travelling wave, and it also has the unique property of displaying an effective refractive index of 0. Using this phenomenon, development of directional antennas, light waveguides with no bending loss or scattering loss, and other devices is expected.

1) K. Takazawa et al., Phys. Rev. Lett. 105. (2010) .067401; Appl. Phys. Lett. 99. (2011) 253302; Adv. Mater. 23. (2011) 3659; Adv. Func. Mater. 23. (2013) 839.

2) H. Takeda and K. Sakoda, Phys. Rev. B 86. (2012) 205319.

3) K. Sakoda, Opt. Express 20. (2012) 3898; ibid. 20. (2012)9925; ibid. 22. (2012) 25181

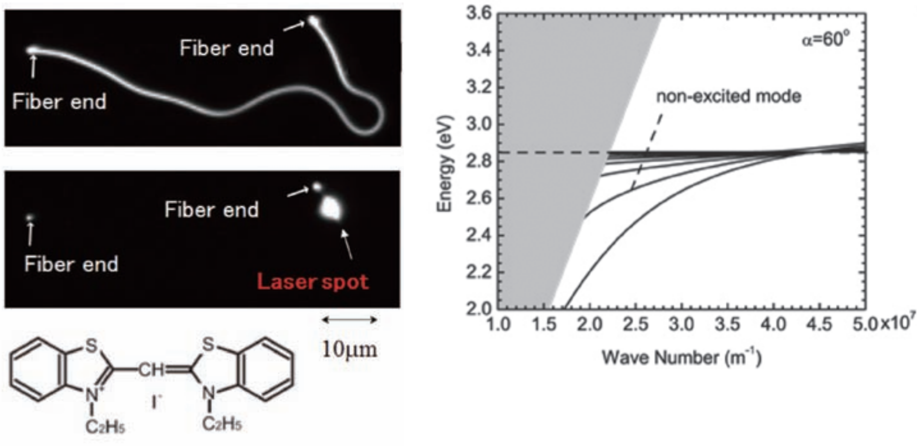

Fig. 1 (upper left) Micrographs of the newly-developed polariton nanofiber and propagation of fluorescence in the nanofiber under laser excitation, (lower left) chemical structure, and (right) graph showing the dispersion relation.

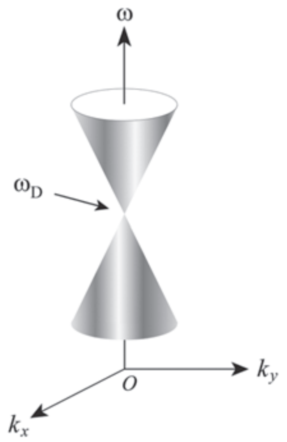

Fig. 2 Dirac cone showing the dispersion relation of light.

Hiroyuki Takeda Ph.D. (Engineering) Completed the doctoral course at the Osaka University Graduate School of Engineering in 2004. After working as a postdoctoral researcher at the University of Toronto, he joined NIMS as a postdoctoral researcher in the NIMS International Center for Young Scientists (ICYS) in 2010. Since 2013, he has been a postdoctoral researcher in the Photonic Materials Unit. / **Tetsuyuki Ochiai** Ph.D. (Science) Completed the doctoral course at the Hokkaido University Graduate School of Science in 1997. Prior to joining NIMS as a Senior Researcher in the NIMS Quantum Dot Center in 2006, he was a researcher at the Japan Science and Technology Corporation (now Japan Science and Technology Agency), the Autonomous University of Madrid, and Chiba University. He has been a Senior Researcher in the Photonic Materials Unit since 2011. / **Ken Takazawa** Ph.D. (Science) Completed the doctoral course at the Waseda University Graduate School of Science in 1996. He is concurrently a Researcher in the NIMS High Magnetic Field Station. / **Kazuaki Sakoda** Ph.D. (Engineering) Completed the master's course at the University of Tokyo Graduate School of Engineering in 1982. Prior to joining NIMS as a Senior Researcher in 2002, he was a researcher at the Toray Industries Electronic and Information Materials Research Laboratory and an Associate Professor of the Hokkaido University Research Institute for Electronic Science. He was appointed Director of the NIMS Quantum Dot Center in 2007 and has been Unit Director of the Photonic Materials Unit since 2011.

Millimeter-level Visual Detection of Location of Cesium

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Taizo Mori

Principal Investigator,
Unit Director, Supermolecules Unit,
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The distribution of cesium can't be determined immediately

The accident at the Fukushima No. 1 Nuclear Power Plant following the Great East Japan Earthquake of 2011 released large amounts of radioactive substances, which contaminated an extensive area beginning with Fukushima Prefecture. Today, more than 2 years have passed, but contamination of the soil, water, and ocean is still a concern. Radioactive cesium is a particular worry, as it has a long half-life of approximately 30 years. Radioactive cesium can be detected by radiation measurement and further detailed analysis. However, where large amounts of cesium are distributed in an area where radiation is detected cannot be determined immediately, and the presence of this "invisible devil" is a source of anxiety.

Wouldn't it be good if it were possible to see the existence of cesium with the naked eye? In answer to this question, we developed a visual detection method using the properties of cesium itself, rather than the conventional method of radiation detection.[1)] The new method enables determination of the presence of cesium with submillimeter accuracy. If used in combination with the conventional radiation detection method, it is possible to identify the location where cesium is actually present in an area where contamination is suspected, and remove cesium with high efficiency (Fig. 1).

Development of a supermolecular material fluorescent probe

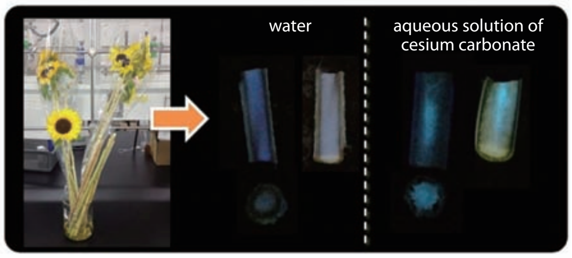
As a fluorescent probe for visualization of cesium by fluorescence, we developed a "supermolecular material" in which a nitrobenzene group is connected to a fluorescence-emitting phenol derivative by an ethylene glycol chain. The fluorescent probe emits blue-green fluorescence when irradiated with ultraviolet light in the presence of cesium ions. In the fluorescent probe, the ethylene glycol chain selectively captures cesium ions, and the probe fluorescence change from blue to blue-green as a result of the electrostatic interaction of the captured cesium ions with the phenol part. Because the size of other ions is not compatible with the probe, ions other than cesium do not trigger a similar change in fluorescence, and the probe continues to display the normal blue fluorescence.

This fluorescent probe enables visualization of the distribution of cesium ions in solids and on the surface of objects with high spatial resolution. It is also possible to confirm the behavior of cesium ions in soil, foods, and living organisms by fluorescent. The new probe will allow researchers to track cesium in fluorescence experiments using safe, non-radioactive cesium when investigating the process of dispersion and accumulation of cesium ions. Moreover, its use is not limited to visual inspection. If an analyzer is used, fluorescence emissions can be detected with extremely high sensitivity. Thus, the probe is expected to provide an effective tool for answering the question of where cesium accumulates in living organisms and foods.

1) T. Mori, M. Akamatsu, K. Okamoto, M. Sumita, Y. Tateyama, H. Sakai, J. P. Hill, M. Abe and K. Ariga, Sci. Technol. Adv. Mater., 14. (2013) 015002.

Cesium in soil is detected visually and removed.

Visualization of cesium particles on filter paper.



Visualization of the distribution of cesium in sunflower stems.

Fig. 1 (top) Visualization of cesium in soil and on filter paper, (bottom) visualization of the distribution of cesium in sunflower stems.

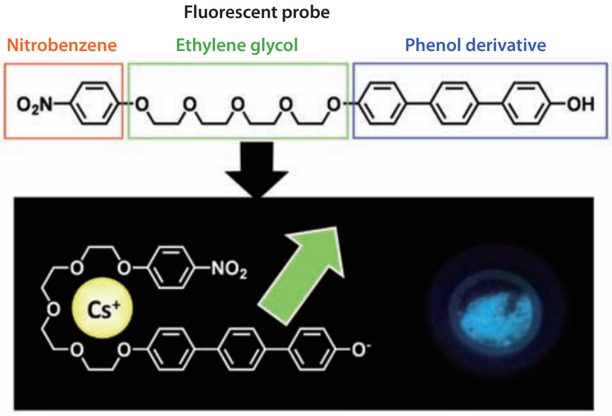


Fig. 2 When cesium is captured on the fluorescent probe, the probe emits blue-green fluorescent light under ultraviolet irradiation.

Taizo Mori (photo, left) Ph.D. (Engineering) Completed the doctoral course at the Kyoto University Graduate School of Engineering, Department of Polymer Chemistry in 2009. Joined NIMS as a postdoctoral researcher in the same year. Has been a JSPS Fellow since April 2013. **/ Katsuhiko Ariga** Ph.D. (Eng.) Prior to joining NIMS in 2004, he was affiliated with Tokyo Institute of Technology, the University of Texas, the Japan Science and Technology Agency (JST), the Nara Institute of Science and Technology, etc. He has been a MANA Principal Investigator since 2007. In 2010, he was selected by Japan's National Institute of Science and Technology Policy as a recipient of the NISTEP Award for "Researchers with Nice Step."He has been admitted as a Fellow of the Royal Society of Chemistry (2013).

NIMS NEWS

1 NIMS Open House FY2013 – "Mysteries of Materials"

NIMS held Open House Events on April 17 and 21. These events were held in conjunction with the 54th Science and Technology Week of the Ministry of Education, Culture, Sports, Science and Technology (MEXT). The events received a large number of visitors, with total participation for the 2 days exceeding 1,400 persons.

On April 17, NIMS opened its facilities to the public at the Sengen, Namiki, and Sakura Sites. This event featured introductions of research and demonstration experiments in more than 50 areas, such as "Superconductivity, diamonds, and cloud chamber experiment," "See yourself in an electron microscope," "Nanoscale world: Looking at the nanostructures of surfaces," and "Can a magnet float water?" Many visitors expressed surprise at the mysterious properties and usefulness of everyday materials. Also, Dr. Naoe Hosoda of the Hybrid Materials Unit presented a lecture on "Nanotechnology Learning from Living Things" for local residents at Namiki Site.

On April 21, a total of 8 events were held at the Sengen Site. These included "Handmade foundation," "Pewtercraft (making medals using tin)," and "Original keyholder stamped in metal sheet." As this Open House was held on a Sunday, a large number of family groups turned out for these events.

Superconductivity experiment at the Sengen Site.

Challenging making a tin medal.

2 Announcement of Winner of the NIMS Award 2013 and Holding of Award Ceremony and Award-Winning Lecture at the NIMS Conference 2013

NIMS will be holding the NIMS Conference 2013 from July 1 to 3, at Tsukuba International Congress Center. NIMS Conference is an international conference where the world's top researchers gather each year to discuss various issues from the perspective of materials science and nanotechnology and present recent research achievements. This year's conference is a commemorative event marking the 10th in the series.

The theme of this year's NIMS Conference is "Structure Control of Atomic/Molecular Thin Films and Their Applications." Spirited discussions are expected on recent achievements and the future outlook for the basic/generic technologies that will support the emerging ubiquitous computing society, such as electronic devices, electronics, and related technologies, as represented by semiconductor integrated circuits.

Also, at the conference, the NIMS Award will be presented to a researcher who has made distinguished achievements in science and technology related to materials, as well as a valuable contribution to the development of NIMS. In line with this theme, candidates were nominated from among the world's leading scientist in each country, and an impartial final selection was made by a committee of neutral experts. As a result, Prof. Hideo Hosono of Tokyo Institute of Technology was selected as this year's winner of the NIMS Award. Following the Award Ceremony at the NIMS Conference, Prof. Hosono will deliver the Award-Winning Lecture.

■Outline of NIMS Conference

Date: July 1 (Monday) to July 3 (Wednesday)
(The NIMS Award Ceremony and Award-Winning Lecture will be held on July 1).
Venue: Tsukuba International Congress Center, Tsukuba Epochal
http://www.nims.go.jp/nimsconf/2013/index.html (English)

Hello from NIMS

Dear NIMS NOW readers,

I came to NIMS, Japan in January 2011 as a postdoctoral researcher right after earning my PhD in Electrochemistry from Anna University, Chennai, India. I quite enjoyed my life in Tsukuba. NIMS has provided a vibrant international atmosphere with a great support system. I enjoyed my research in NIMS all the time. I am able to realize my own ideas, use excellent and world class facilities and communicate with many brilliant researchers. It has been an enriching experience professionally and personally to be associated with NIMS. I have been always inspired by Japanese culture and hospitality. This April my family (wife and 6 and 3 year old sons) came to Tsukuba. My children enjoyed the quiet nature of Tsukuba with a lot of parks. We have visited many places like Ushiku Daibutshu, Ueno Park, Asakusa temple, Disneyland etc. and had some unique experiences. My days at NIMS will be an unforgettable experience throughout my life.

My boys under wisteria flower at Tsukuba.

My family at Ushiku Daibutsu.

Xavier Josephraj (India)
January 2011-present
Postdoctoral Researcher; Element strategy Materials Center

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cover image: Opal film coating equipment

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