from Tsukuba, Japan to the world

NIMS NOW

National Institute for Materials Science

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SPECIAL FEATURES

Materials Research Supporting Innovative Optical Technology

Fabrication Techniques for 3-Dimensional Photonic Crystals

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Photonic crystals have attracted considerable attention as optical materials which are expected to support next-generation IT technology. Photonic crystals are 2 to 3-dimensional structures with an optical wavelength-sized period (several 100 nm-several μm). Many 2-dimensional photonic crystals have been manufactured using semiconductor processing technology, and may be applied in optical integrated circuits in the not-too-distant future. On the other hand, practical application of 3-dimensional photonic crystals is desired, as these are the only type of material which is capable of realizing fundamental improvement in laser performance, but no established fabrication process is currently available. Because semiconductor processing technology is essentially a method for creating planar structures, fabrication of 3-dimensional structures is inherently difficult. Self-assembly of micro-spheres has drawn attention as a simple process, but it is difficult to realize perfect structures as designed.

The Intelligent/Smart Materials Group took up the challenge of assembling 3-dimensional photonic crystals by operating a micro-robot while observing the process with a scanning electron microscope (SEM). Parts of the photonic crystal can be easily carried on the tip of a needle because the force of gravity decreases rapidly as objects becomes smaller, while attractive forces such as electrostatic and intermolecular forces become predominant, providing adequate adhesion to the needle.

Examples of crystals assembled by this group are shown in the **figures**. **Fig. 2** is a diamond-type photonic crystal formed from spheres. Because it is known that crystal structures formed by self-assembly of micro-spheres do not manifest a large photo-emission control function, a technique in which the spheres are stacked in a diamond form was required. In **Fig. 3**, flat plates fabricated using semiconductor technology were cut from a frame (like the parts of a plastic model), and were then stacked to produce the photonic crystal shown in the photo. This large number of stacked layers is unprecedented with conventional techniques.

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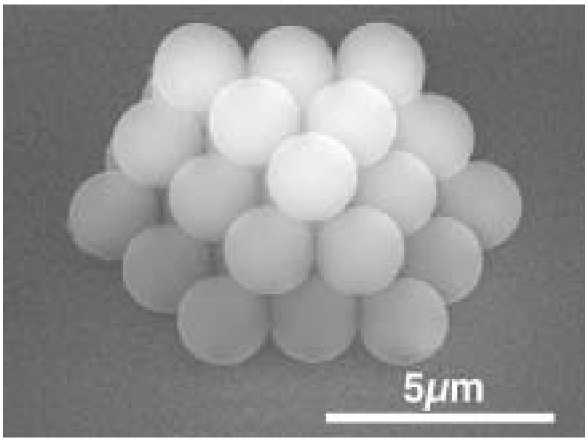

Fig. 1 3-dimensional lattice assembled using micro-robot.

NIMS NEWS

Memorandum with the Nanoscience Centre of the University of Cambridge

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In this issue

Development of Infrared Laser Wavelength Converter for Medical and Environmental Measurement

—Commercialization by NIMS-Licensed Venture Company SWING—

Kenji Kitamura
Opto-Single Crystal Group
Advanced Materials Laboratory (AML)

The Opto-Single Crystal Group has developed a wavelength converter for near-infrared applications as a high power and compact light source for medical and environmental measurements and spectrum analysis, and commercialized the device through the venture company SWING, which was licensed by NIMS to develop practical applications of research results.

Although the laser is now an indispensable basic tool in advanced science and technology, including semiconductor processes and optical telecommunications, no simple, easy-to-use laser capable of generating any desired wavelength has yet been developed. On the other hand, there is an increasingly strong need for lasers with various wavelengths in a number of fields, lending heightened importance to the development of a technology which makes it possible to convert the designated wavelength generated by easily-used lasers to other desired wavelengths.

Known laser wavelength conversion methods utilize crystals of lithium niobate ($LiNbO_3$) and lithium tantalate ($LiTaO_3$). These crystals, which are typical ferroelectric materials, possess polarity (polarization) in their atomic configurations in a designated direction. This polarization can be partially reversed by applying an electric field. If a periodic polarization reversal structure is formed, the wavelength of incident laser light can be converted with good efficiency. However, with the crystals which have long been available in the market, the field (coercive force) necessary for polarity reversal was extremely large. Thus, reversal was difficult, and the thickness of devices was limited to approximately 0.5-1 mm.

We discovered that the required coercive force can be reduced by one order of magnitude by growing single crystals while controlling disturbances (defects) in the atomic configuration in the crystal. Utilizing this effect, we succeeded in fabricating a series of thick (2-3 mm) polarization reversal devices using single crystals of $LiTaO_3$ (see **figure**).

Thick devices have a variety of advantages. For example, thicker devices passes laser light more easily and can withstand high output oscillation (average outputs of 10W are possible). In the first stage of this work, a device with a 2 mm square rod shape was developed as a standard.

The generated wavelength depends on the polarization-reversal period and operating temperature. At present, it is possible to fabricate devices with reversal periods of 20-35 microns, which convert laser light with a wavelength of 1.064 microns to wavelengths in the range of 1.4-4 microns. As each device has only one reversal period, its conversion wavelength band is limited, depending on temperature. However, it is possible to obtain arbitrary wavelengths over a wide wavelength region by combining devices with different reversal periods. As no simple laser light source was previously available for some wavelength regions, this device is expected to contribute to the development of new applications, including fields other than medicine and the environment.

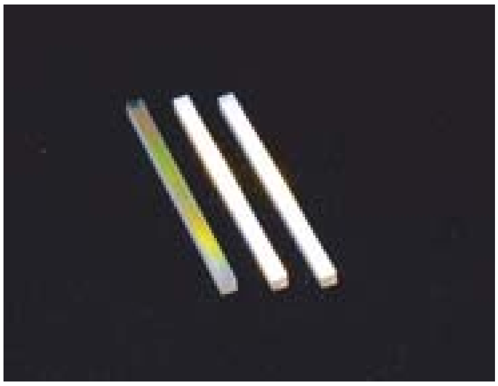

Fig. Examples of new wavelength conversion device (rod-shaped) using MgO-doped stoichiometric $LiTaO_3$ crystals. Standard size: 2 x 2 x 35L mm.

Eco-Integration —Interconnect Eco-Design and Eco-Devices—

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Eco-Device Group
Ecomaterials Center (EMC)

What are environment-friendly materials? A number of answers are possible, including non-toxic materials, materials with low environmental loads in the material creation process, easy-to-recycle materials, and materials with high resource-utilization efficiency. Although the environmental impact would perhaps be less in every case if the materials were simply not used, humankind lives in a world of man-made products, where civilization would be impossible without consuming materials.

Few products are simple substances; virtually all are produced by creating composites, assembling and integrating the result into devices of various kinds, and incorporated these into systems. Moreover, in comparison with other artifacts created during the long span of human history, modern devices are characteristically created and developed in an extremely short cycle, have very short live spans, and are produced and consumed in huge quantities. Today, we are at last beginning to deal with the environmental impact of these prod-

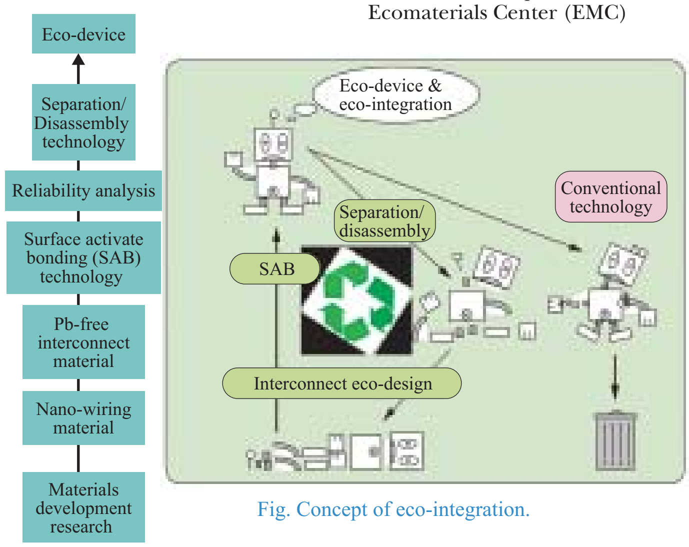

Fig. Concept of eco-integration.

Research on Terahertz Oscillator Using Natural Crystal Structure

Takeshi Hatano
Yoshihiko Takano
Nano Quantum Electronics Group
Nanomaterials Laboratory (NML)

Electromagnetic waves in the terahertz (THz: 10^{12}/sec) band lie between the radio wave and far infrared bands. As no practical oscillation source exists in this region, it can be called an unexplored frequency band. In the field of electronics, THz is positioned three orders of magnitude above the existing gigahertz (GHz: 10^9) range, while in optics, it corresponds to the excitation energy for molecule vibration and rotation. Considering this, the THz band has high latent potential for advanced information technology and medicine, which utilizes biotech and other technologies.

Three-layer stacked devices called Josephson junctions, which consist of a superconductor/insulator/superconductor, are used in radio astronomy and other fields as high frequency receivers, but because their emission power is low, at one-billionth of a watt, this type of device has not been applied practically as an oscillator. In crystals of oxide high temperature (high-Tc) superconductors, superconductor/insulator atomic layers are stacked repeatedly at a cycle of 1-2 nm, creating a system of Josephson junction array called an intrinsic Jospehson junction, or IJJ in short. In the present research, we are developing a high power THz band oscillator based on this structure by producing a stacked element structure extending to several hundred layers. Because the superconducting transition temperature of high-Tc superconductors is high and their superconducting energy gap is large, operation in a higher THz band than with conventional metal superconductors is expected.

The **figure** shows a natural IJJ with a bismuth-based single crystal structure (**left** in **figure**), the IJJ obtained by a micro-processing technique using focused ion beam etching (**center**), and the structure of the hybrid device, including the peripheral circuitry (**right**).

Because this field is unexplored frequeny range, it is necessary to develop not only devices, but also techniques for transferring radio waves and a total system technology, including a measurement and evaluation system.

We have synthesized bismuth- and yttrium-based high-Tc superconducting single crystal whiskers and thin films, and have fabricated IJJ from these materials by micro-processing techniques and investigated their basic electromagnetic properties. Using these structures, we have also designed and examined an oscillation device consisting of an integrated antenna and resonator for verifying its novel characteristics.

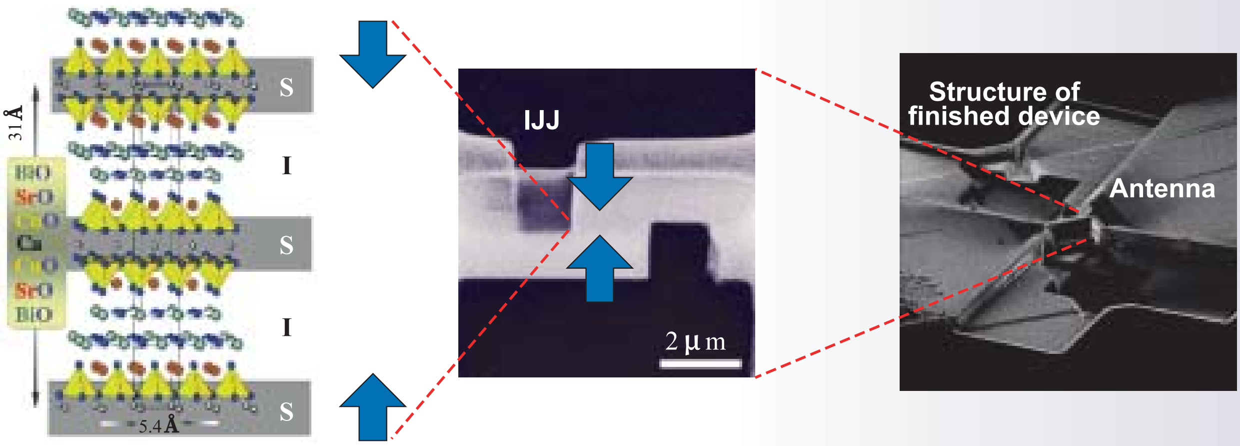

Fig. Crystal structure of high-Tc superconductor (left), intrinsic Josephson junction fabricated by focused ion beam etching (center), and structure of finished device, including peripheral circuitry (right) .

ucts, in particular, by recognizing the need to incorporate environment-friendly features in products from the design stage, in other words, eco-design.

The requirements placed on materials are not limited to the basic material function. Materials must also satisfy environmental conditions such as size and shape and display maximum performance, and they are a key element in deciding the life cycle of devices. Because materials determine the device life cycle, the eco-design of any device must begin from an understanding of its materials.

Eco-integration does not consider materials only from the viewpoint of basic material functions, as mentioned above. Rather, it is a general name for a method of realizing high system performance and environmental performance by high-level integration of materials (see **figure**).

As a concrete method for achieving this goal, the Eco-Device Group is engaged in research on interconnect eco-design as a design procedure for eco-materials for interconnect and bonding of materials, including separation and dismantling of interconnets. Concrete examples include lead-freeinterconnect materials, Fullerene nano-whiskers for high density wiring/high performance devices, material integration methods utilizing surface activated bonding (SAB) of solids at room temperature, and separation methods for interconnect.

While remaining deeply rooted in materials science, the development of methods of interconnect eco-design and device eco-integration is an extremely promising direction for new materials research.

A NIMS-sponsored international workshop on "Progress in Nb-based Superconductors" was held February 2-3 with a total of 70 participants from Japan, the United States, the United Kingdom, Switzerland, Korea, China, Germany, and Russia. In addition to spirited discussions, the poster session also attracted considerable interest among participants, making this an extremely significant workshop.

International Workshop on "Progress in Nb-based Superconductors"

Development of Quantum Dots Applicable to Optical Telecommunications Band

—Aiming at a Single-Photon Emission Device for Quantum IT—

Yoshiki Sakuma
Optoelectronic Nanomaterials Group
Nanomaterials Laboratory (NML)

Computers, the internet, and other IT technologies are indispensable to modern life. However, in the near future, limits on information processing capacity and information leaks in telecommunications are expected to become serious problems at the individual and national levels.

Recent years have seen the beginnings of research and development of a new technology called "quantum IT," which has the potential to solve these problems. Ordinary visible light actually consists of groups of huge numbers of particles called photons. In conventional optical telecommunications, information is transmitted by controlling the amount of these photon groups. In contrast, quantum IT is a radically new technology in which information is assigned to individual light particles by arbitrarily manipulating the properties of photons using the principles of quantum mechanics. Although this will enable high speed, high volume transmission, and will also make it possible to construct extremely safe networks in which private, business, and government information is not threatened by eavesdropping, realizing the actual technology is no simple matter, and will require R&D on new materials and devices. The key to success in this effort is single photon devices for generation/detection of individual photons and a material technology for forming quantum dots, which are the basis for such a device.

Semiconductor quantum dots are nanostructures with artificially-created atom-like properties, which make it possible to generate individual photons by confining negative electrons and positive holes in an extremely small region of several tens of nm or less. Although quantum dots have already been created with many material systems, none has shown satisfactory luminescence in the 1.3-1.55 µm wavelength band, which is essential to fiber-optic telecommunications. Focusing on indium arsenide (InAs) crystals grown on an indium phosphide (InP) substrate using MOCVD technology, our group and a private company jointly developed a quantum dot fabrication technology called the 2-step capping layer process which enables emission wavelength control (**insert** in **Fig. 1**). **Fig. 1** shows an atomic force microscope (AFM) image and photoluminescence (PL) spectra. Normally, the height of quantum dots is 5-10 nm, but with the 2-step capping process, we succeeded in producing dots with heights of less than 2 nm. As a result, it was possible to fabricate extremely high quality quantum dots which have shown strong luminescence more than 10 times greater than that of conventional QDs over the entire telecommunications wavelength band from 1.3 µm to 1.55 µm. Using a technique called the micro-PL spectroscopy, we investigated the optical properties of individual quantum dots of different heights and succeeded for the first time in observing the atom-like emission from the discrete energy levels, as illustrated in **Fig. 2**. In the future, we plan to develop a technique for efficiently producing single photons from a quantum dot and implement it in the prototype devices.

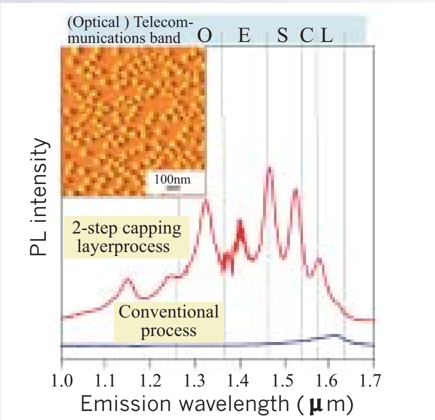

Fig. 1 Emission spectra of InAs quantum dots ensemble on InP (100) substrate at 10K. (Upper left, Atomic force microscope (AFM) image of InAs quantum dots formed on InP(100) substrate by MOCVD method)

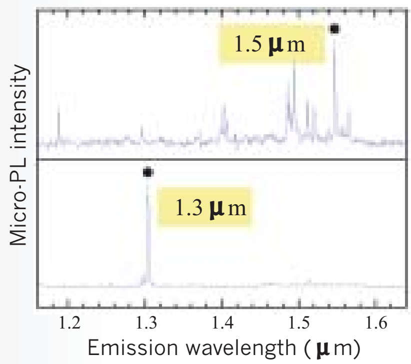

Fig. 2 Spectra of individual InAs quantum dots by micro-PL spectroscopy.

For further information, please visit: http://www.nims.go.jp/clsnom/english/e_index.html

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Fabrication Techniques for 3-Dimensional Photonic Crystals

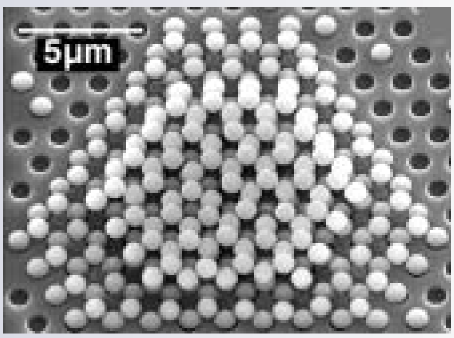

Fig. 2 Diamond-type photonic crystal of silica spheres (Joint research with Unidad Asociada CSIS-UPV (Spain)).

Because these newly developed techniques make it possible to create high-accuracy 3-dimensional crystals under complete control, though realizable scale is limited, they are playing a unique role in trial manufacture in advance of other techniques, and in basic research on photonic crystals, including systematic research on the relationship between structure and optical properties. Although still in the initial stage, we have also demonstrated the possibility of automatic assembly by image recognition. As suggested in this report, we believe that a proper division of roles between micro-processing techniques and assembly will be the key to practical application of 3-dimensional photonic crystals.

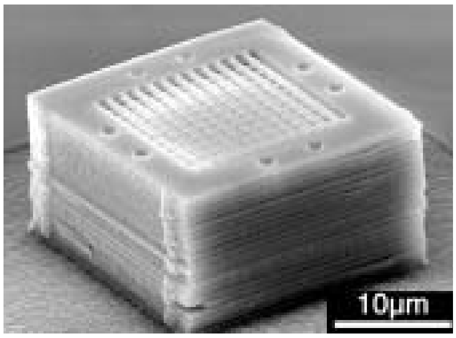

Fig. 3 3-dimensional photonic crystal produced using semiconductor process (Joint research with RIKEN and Yokohama National University) .

For further information, please visit: http://www.nims.go.jp/Smart/eng/index_e.html

Non-linear Optical Glass and Crystals

—Steps toward Practical Use of the Third-order Non-linear Optical Effect—

Hideo Kimura
Piezo Crystals Group
Materials Engineering Laboratory (MEL)

Lasers are used in processing and telecommunications. Although laser beam can be generated with various materials, the most general technologies at present are the semiconductor laser which employs semiconductors, and solid-state lasers which employ various oxide crystals. Information on CD and DVD discs can be read and write with these devices.

Unlike ordinary beam, the high intensity of incident laser beam causes an interaction with electrons in solids. This phenomenon, called the non-linear optical effect, makes it possible to shorten the light wavelength by one-half (second-order) or one-third (third-order effect). The second-order effect can only be used with crystals, but the third-order effect can be used with both crystals and amorphous substances such as glass.

While the second-order effect is mainly used in laser wavelength modulation, more complex uses are also possible with the third-order effect. For example, it is possible to make incident light striking a mirror reflect back in the direction of incidence. Normally, the angle of reflection is decided by the angle of incidence. The third-order effect is also important in optical telecommunications. As one example, when used in an optical circuit switch, the third-order effect enables laser light switching. However, because the wavelength is shortened, the material used at that wavelength must have adequate transparency. In other words, the material must be transparent even at short wavelengths, and it must have a large tertiary non-linear optical constant. To date, it had been thought that the third-order non-linear optical constant is larger in materials with large refractive indexes. However, transparency in the short wavelength region decreases as the refractive index increases. Moreover, fabrication of materials with high refractive indexes is also a problem.

The Functional Fundamentals Group succeeded in increasing the third-order non-linear optical constant of glass materials with satisfactory transparency even at short wavelengths by combining atoms of different sizes so as to increase the amount of electron displacement (**Fig. 1**). We also developed a new fabrication process for this glass material (**Fig. 2**), and are presently investigating methods of achieving higher performance.

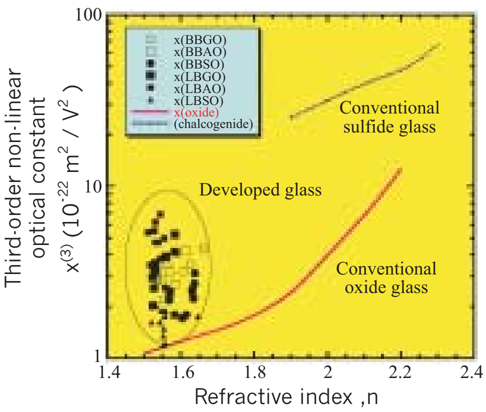

Fig. 1 Newly-developed glass with large third-order non-linear optical constant vs. refractive index (in comparison with conventional glasses).

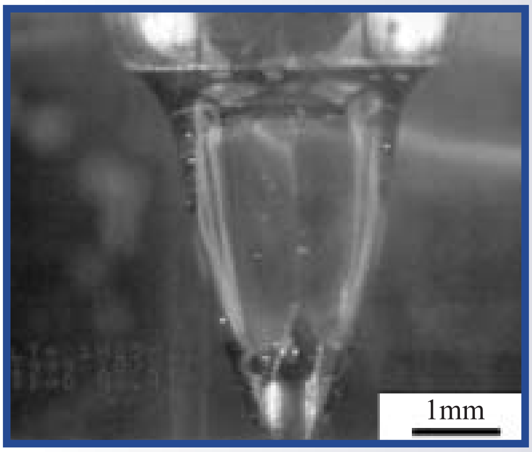

Fig. 2 Glass material fabricated by new process.

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Memorandum with the Nanoscience Centre of the University of Cambridge

An agreement between the Nanomaterials Laboratory (NML), NIMS and the Nanoscience Centre of the University of Cambridge, UK, was signed by Dr. M. Aono and Prof. M. Welland in a ceremony held at NIMS on the 29th January 2004. This agreement will strengthen the long-standing collaboration between Dr. Aono and Prof. Welland and in particular will allow for the sharing of both facilities and researchers.

The combined effort of the two laboratories will effectively combine a leading European nanoscience activity with its Japanese equivalent so that over 300 researchers will be able to combine their knowledge and experience in nanoscience. A major bilateral meeting is planned for the summer this year where research students from Cambridge and NIMS will come together in Tsukuba to talk about their work and to stimulate future joint projects.

Information about the Nanoscience Centre at Cambridge can be found at www.nanoscience.cam.ac.uk

Creation of Environment-friendly Pb-free High-performance Piezoelectrics with Colossal Field-induced Strain

As part of a New Research Promotion Program of the Japan Science and Technology Agency (JST), a group lead by Senior Researcher Dr. Xiaobing Ren of the Materials Physics Group, Materials Engineering Laboratory (MEL) discovered what is being termed a "colossal" electrostrictive strain effect (electric-field-induced shape-change) based on a novel mechanism and developed an environment-friendly material which does not use the toxic substance lead. Dr. Ren's discovery is another "world's first" for NIMS researchers.

In comparison with the electrostrictive effect of materials widely used in the past, the effect with this new mechanism is of a different order of magnitude, being approximately 40 times stronger than that of the best conventional materials at low voltage. The new material is expected to find application in a wide range of fields, including sensors, acuators, and other devices based on electro-mechanical energy conversion. These research results were also published online by the English science journal Nature Materials on January 12.

Job Opportunities

The National Institute for Materials Science (NIMS) is seeking outstanding scientists with a strong challenging spirit to pursue original and innovative research in materials science. NIMS warmly welcomes applications from persons who are interested in working at NIMS.

• Available Fields

- Nanostructured magnetic materials
- Composite materials
- High temperature alloys
- Nanotechnology/nanoscience towards information technology
- Bio-nanotechnology
- Interactions between biomaterials and cells
- High quality new conductive polymers
- Photocatalysts
- Fullerene-based new carbon materials
- Magnetic processing of polymeric materials (using high magnetic field)
- General (any field of materials science)

• Eligibility

In principle, persons 35 years old or under who have a Ph.D degrees (including persons who expect to receive a degree by start of employment) are eligible.

Other qualifications, including expert knowledge and experience, are specified by each field.

For more details, please see our homepage: http://www.nims.go.jp/eng/employment/index.html

• Application Deadline

Applications must be received by NIMS on or before Monday, May 31, 2004.

Applications in the field of "Any field of materials Science" are accepted at any time (not subject to deadline).

• Contact

For inquiries, please contact the Search Committee, Integrated Strategy Office by e-mail: search2004@nims.go.jp

Shidarezakura (Weeping Cherry)
March 21

Spring has come to Japan!

The cherry blossom (sakura) is Japan's most beloved flower in spring. People celebrate this season with blossom viewing (hanami) parties under the trees. Sakura has been deeply rooted in Japanese culture and used in place name, food, art etc. Sakura Site, one of the three research sites of NIMS, is named after the place name of the area.

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