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No. 1

Bones and Materials

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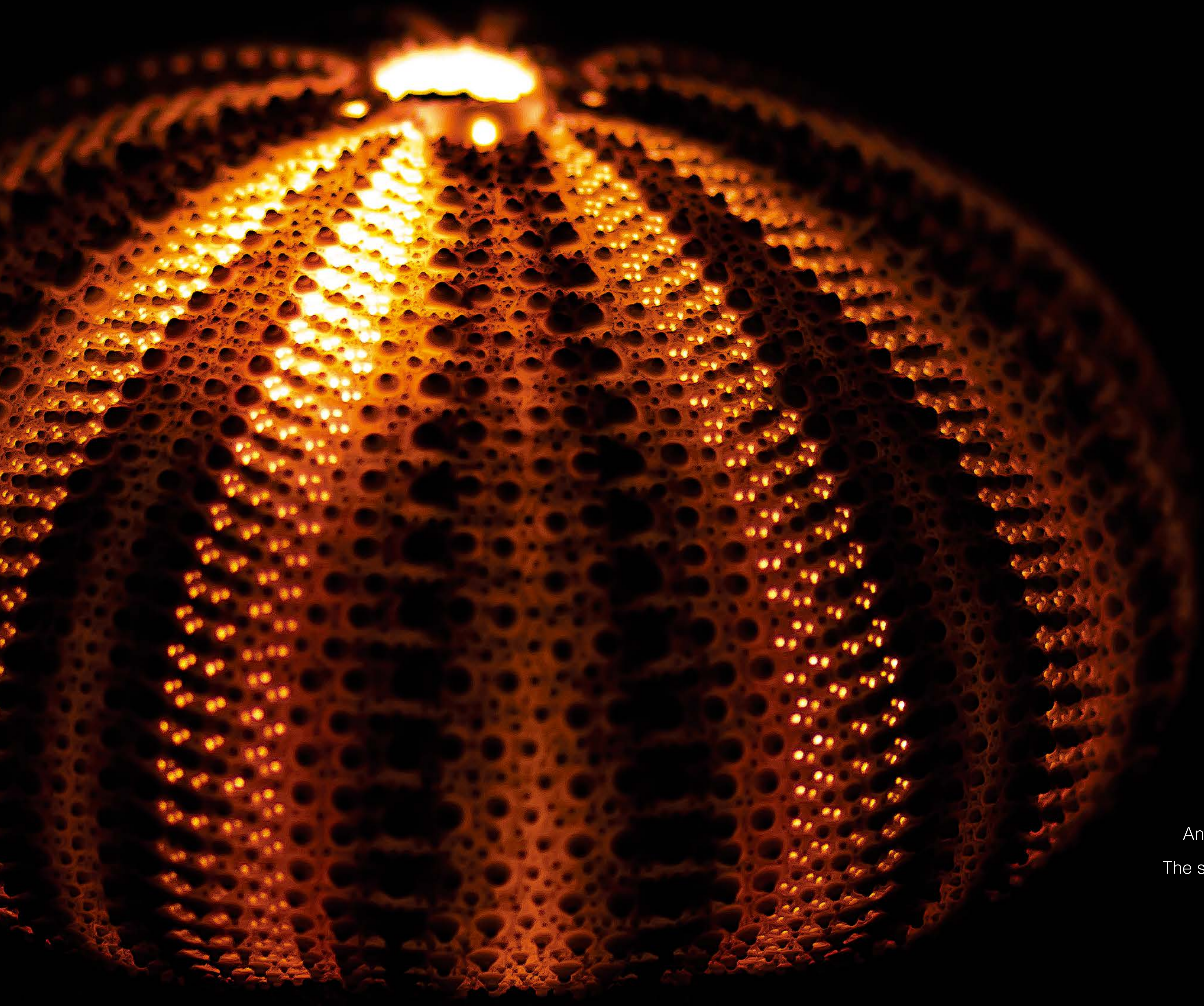


Sea urchin shell with spines and outer membranes removed.
The shell has numerous microscopic pores invisible to the naked eyes in addition to many visible pores.
Its microstructure may be uniquely useful(see p4).

Bones provide structural support to our bodies and protect our internal organs. Even when bones break or crack, they are able to heal—an amazing biological process.

However, when bones are damaged too severely, they are unable to restore themselves to their original shapes and functions. When this happens, artificial bones and bone fixation materials are used to replace missing bone and keep damaged bones in the correct position.

NIMS has been pursuing the development of materials that are more than mere bone replacements—they would enhance the innate self-healing ability of bone and naturally disappear once they have served their purpose. A NIMS researcher has been attempting to achieve this using a material derived from an unexpected organism.

Another NIMS researcher has been applying bone-related research beyond the medical field. The self-healing mechanism of bone inspired him to develop a remarkable new ceramic material that has overcome the biggest weakness of conventional ceramics: brittleness.

This NIMS NOW issue describes the latest NIMS research related to bones and materials.

Research 1

Sea urchin shells: a promising artificial bone material

Masanori Kikuchi has developed various types of artificial bone materials and is now focusing on sea urchin shell as a potential source of new material.
Sea urchin shells, which are one of huge marine wastes in Japan, have numerous pores: relatively small pores around 10 micrometers (µm) in diameter and larger pores around 200 µm in diameter.
These microscopic pores make sea urchin shells an effective bone regeneration material.

Coverage cooperation

Masanori Kikuchi

Leader of the Bioceramics Group
Research Center for Functional Materials

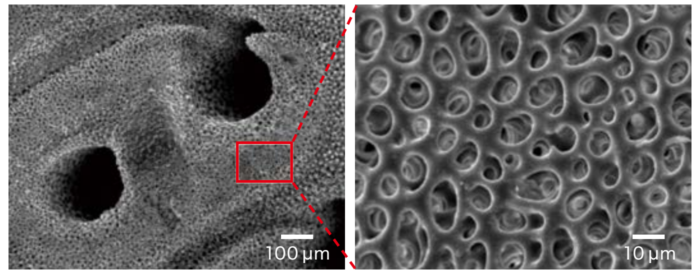


Figure 1. Microscopic pores on the surface of a sea urchin shell

Sea urchin shells have numerous tiny pores of two approximate sizes: 200 µm (left) and 10 µm (right) in diameter, as seen in these electron micrographs.

Sea urchin shells are first crushed into 1 to 2 mm pieces and then phosphatized.

Bones are regenerated continuously

When people lose bone fragments as a result of injury or bone tumor extraction, they normally undergo autogenous bone grafting, in which the bone defect is filled with bones transplanted from their own ilium or fibula. This technique is effective and has a low risk of rejection because it is patient's own bone. However, the technique also has drawbacks: it damages healthy tissues and cannot be used for large bone defect due to the limitation in grafting amount of bone.

Artificial bones are used to resolve these issues. Metals used as artificial bones remain in the body as foreign objects. However, recently developed artificial bone void fillers are biologically resorbed with bone regeneration and reducing the stress on patients as well as potential risks by remaining of foreign bodies. Masanori Kikuchi has been researching and developing such patient-friendly artificial bone void fillers.

"Many people believe that bones are static once they are formed," Kikuchi said. "In reality, they are continuously replaced. Effective use of this natural process may allow implanted artificial bone void fillers to be replaced by regenerated bones." A bone is mainly made of collagen, an organic substance, and apatite, an inorganic substance composed of phosphate and calcium. Osteoclasts resorb old bone and osteoblasts form new bone. These processes occur continuously.

"An ideal approach to artificial bone implantation is to drive the eventual replacement of implanted artificial bones with a patient's own bones as they regenerate," Kikuchi said. "Tiny pores play a vital role in this process."

Vast quantity of larger and smaller pores

Pores in artificial bones are capable of serving as scaffolds for osteoclasts and osteoblasts as they resorb old bone and form new bone. Highly porous artificial bones (porosity is a proportion of empty space in a material relative to its volume) facilitate the growth of new bones. Moreover, previous studies said that artificial bones with pores of two different sizes can accelerate bone regeneration.

If an artificial bone only has large pores, bone cells will enter and clog them, preventing body fluids from flowing into them and cutting off oxygen and nutrient supply to the cells. While, presence of smaller pores, in which the bone cells cannot invade, in artificial bone void fillers allows oxygen and nutrients delivery to the cells and make accelerate bone regeneration. In fact, human bones have numerous larger and smaller pores.

"Efforts are being made to develop highly porous artificial bones with both larger and smaller pores," Kikuchi said. "However, the fabrication process is complicated, slowing these efforts. Moreover, high porosity reduces the strength of artificial bones. Some researchers are addressing this issue by filling small pores with resin, but this approach defeats the purpose of using a porous material. Under these circumstances, I found an ideal artificial bone material."

Converting waste into an effective material

In addition to working at NIMS, Kikuchi has been serving as a Guest Professor at Hokkaido University Graduate School since 2011.

"In casual conversations with students, I learned that sea urchin shell waste had created a considerable problem in Hokkaido," Kikuchi said. "After the edible part of a sea urchin is removed, its shell is discarded as waste. I heard that enormous amounts of sea urchin shells have piled up."

Hokkaido area of Japan solely produces 8,500 tons of sea urchin shell waste annually and expends significant resources on its disposal.

"The sea urchin issue made me think about a sea urchin shell's microstructure," Kikuchi said. "I knew about this because it had been studied in biomimetics, a discipline which seeks to apply biological structures and functions to materials development. I had a flash of inspiration: it might be possible to process sea urchin shells into an ideal artificial bone material."

Having spiny shells, sea urchins belong to the animal phylum Echinodermata. Removing a sea urchin's spines and skin exposes its endoskeleton or shell. The shell has numerous interconnected small pores, some approximately 10 µm in diameter and other approximately 200 µm in diameter, in addition to pores which are visible to the naked eye (Figure 1). Bone cells are approximately 100 µm in size, allowing them to enter the larger pores but not the smaller ones. Sea urchin shells therefore naturally possess a microstructure which is difficult for humans to create and perfect for artificial bone void fillers.

Processing sea urchin shells into artificial bones

Sea urchins are soaked in a bleach solution for several to remove spines and skin. The sea urchin shells thus obtained are composed of calcium carbonate containing a large amount of magnesium. The calcium carbonate in the shells needs to be converted into calcium phosphate—a major bone component—if they are to be used as an artificial bone material.

Kikuchi succeeded in making this conversion while preserving a shell's microstructure using a technique called a hydrothermal treatment. He then discovered another advantage of using sea urchin shells.

"When the hydrothermal treatment is applied to sea urchin shells, a calcium phosphate composite containing apatite is produced," Kikuchi said. "I found that the composite contains a large amount of β-tricalcium phosphate. Previous research has demonstrated that composite materials containing β-tricalcium phosphate and apatite are capable of promoting bone regeneration, indicating that they are favorable artificial bone materials."

The chemical composition of sea urchin shells is the reason that a large quantity of β-tricalcium phosphate was produced. Magnesium in the shells inhibits the growth of apatite crystals during the hydrothermal treatment and stabilize β-tricalcium phosphate formation.

Spherical sea urchin shells cannot be directly used as artificial bones. Kikuchi therefore crushed the shells into one-to-two-millimeter (mm) pieces and phosphatized; then finally assembling them into blocks using gelatin or collagen as a binder (photo adjacent to the title on p. 4). He cultured osteoblast-like cells in the block and observed that the cells migrated into the center of the block and multiplied there. He also confirmed that these cells upregulated osteogenic genes (Figure 2).

"The results of the cell culture experiment indicated that sea urchin shells are a promising artificial bone material. I plan to carry out animal testing in order to closely study the processes by which bone cells enter larger pores by supporting of smaller pores," Kikuchi said enthusiastically.

The use of sea urchin shells as an artificial bone material is expected to be profitable for local communities as their disposal has been costly. If this material is proven effective, its use may ease the distress experienced by bone disease patients and its production may help revitalize local areas. (by Shino Suzuki, PhotonCreate)

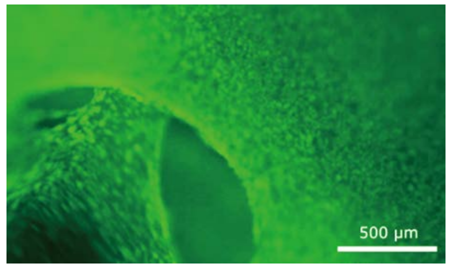


Figure 2. Culturing osteoblast-like cells

Osteoblast-like cells were cultured for 21 days in a block composed of sea urchin shells. Cultured cells in the center of the block were then stained, allowing live cells to glow green and dead cells to glow red. Virtually no dead cells were found on day 21, indicating that these cells are facilitating new bone growth.

Focus

Development of a filter capable of removing harmful ions using sea urchin shell microstructure

In addition to the artificial bone material, Kikuchi is also considering developing a fluoride ion filter using sea urchin shells. Flouride has been used to treat the surfaces of semiconductors and glasses, but is harmful to humans when ingested as drinking water.

Techniques for removing fluoride ions from industrial wastewater already exist. Calcium chloride can be added to wastewater, causing fluoride ions in the water to bond with calcium and precipitate out as calcium fluoride sediment which can then be collected. However, this treatment alone is not capable of reducing fluoride ion concentrations to within the legally mandated environmental limit. Consequently, DCPD* powder, a type of calcium phosphate, is added to the wastewater, causing the remaining fluoride ions to bond with calcium phosphate and precipitate out as fluorapatite (FAp) particles. The FAp particles can be then collected.

This DCPD powder technique is inefficient, however. First, FAp particles form very slowly; thus pre-treatment to form apatite nuclei on DCPD particles is necessary. In addition, the phosphate produced during this removal process needs to be removed by adding large amounts of calcium carbonate to the wastewater. This additional treatment increases the volume of wastewater that needs to be filtered by several times. As a result, the amount of waste to be collected also increases.

To resolve this issue, Kikuchi considered using sea urchin shells in place of DCPD powder. "First, sea urchin shells are treated so that some of the calcium carbonate in them is converted into calcium phosphate while a certain proportion remains unchanged," Kikuchi said. Calcium carbonate has the ability to accelerate chemical reactions leading to FAp particle formation. It is also capable of removing excess phosphate produced during the removal process.

Because they have so many microscopic pores, sea urchin shells have large surface areas. For this reason, the shells only need to be crushed into coarse 1 to 2 mm granules to increase their surface area. The use of sea urchin shell granules causes fluoride ions to form FAp particles 20 µm in size which precipitate out within five minutes. These granules can then be easily separated from the FAp particles and recovered for reuse. The FAp particles can also be collected and used for certain purposes.

The experimental use of shell granules has demonstrated their capacity for removing fluoride ions quickly and efficiently. In addition, the use of shell granules resolved another issue associated with the use of DPFC powder. The formation of FAp particles by the action of DPFC powder yields excessive amounts of phosphate ions, whereas the formation of FAp particles by the action of shell granules was found not to do so.

Contamination of groundwater and well water with high concentrations of fluoride ions is a common problem in India, Southeast Asia and China. Kikuchi has therefore been considering the application of this technique overseas.

*DCPD: calcium hydrogen phosphate dihydrate

Research 2

Bone fixation devices capable of disappearing within the body after the bones are healed

An ideal bone fixation material would keep broken bones firmly in position and disappear after they are healed. The use of such a material would eliminate the need for a second surgery to remove it after bones have healed, significantly reducing patient distress.
The strength, biodegradability and bioabsorbability of magnesium (Mg) make it a promising bone fixation material. However, Mg alloys often dissolve too rapidly—before broken bones fully heal—presenting a problem.
Sachiko Hiromoto has been attempting to resolve this issue by coating the surfaces of Mg alloys.

Coverage cooperation

Sachiko Hiromoto
Principal Researcher
Corrosion Property Group
Research Center for Structural Materials

Fixation of broken bones during new bone growth

Some of you may have experienced wearing a cast after breaking a bone. Casts are used to keep broken bones in position and prevent them from moving out of place. Bones regenerate continuously, and the gap between two broken bones is filled by new bone growth, allowing them to reconnect within several months. Reconnection of misaligned broken bones may cause pain and other aftereffects. For this reason, fixation is a critical process in broken bone treatment.

Broken bones that cannot be aligned externally or fixed using a cast are surgically treated by first aligning them and then reconnecting them using bone fixation materials, such as plates and screws. Titanium (Ti) alloys and stainless steel are conventionally used as bone fixation materials as they are strong and resistant to corrosion. Although they can firmly fix broken bones, these foreign objects need to be removed by a second surgery causing significant patient distress.

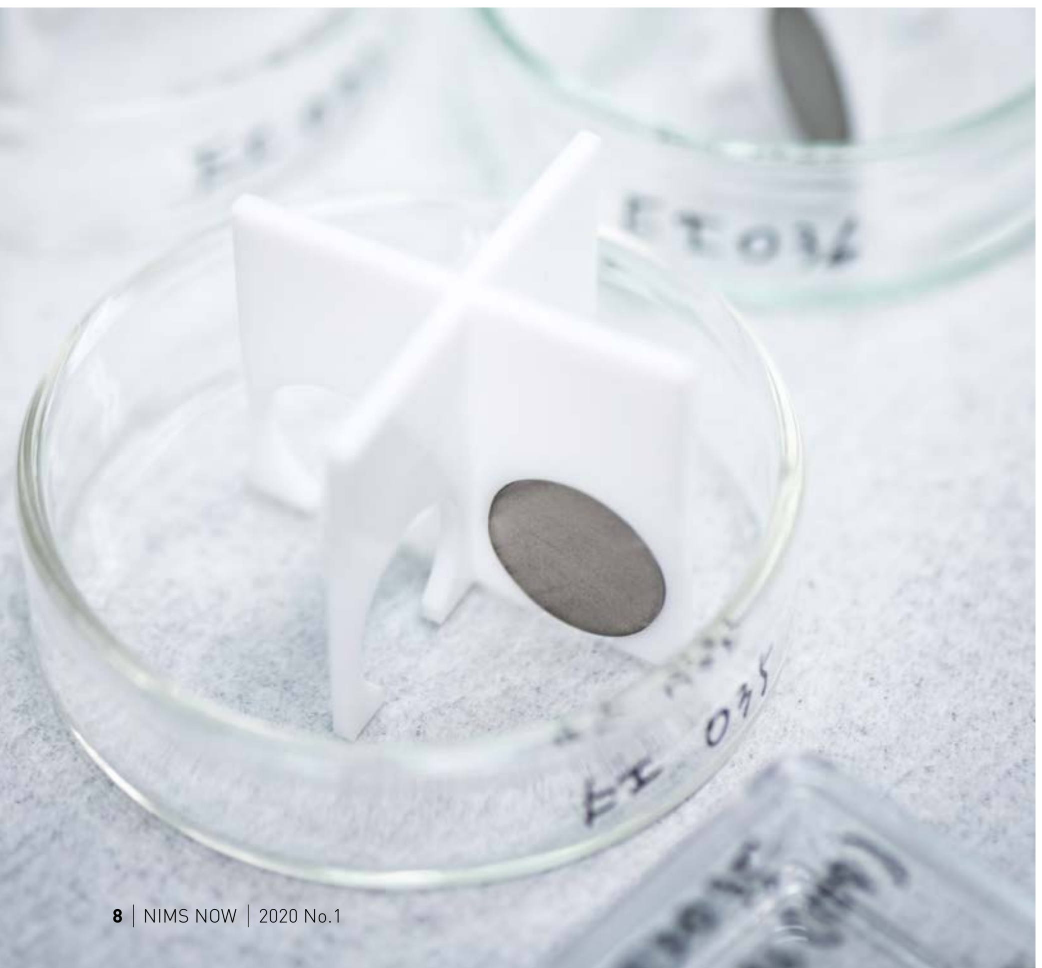
Materials dissolved and absorbed in the body

"Bone fixation materials that could fix broken bones, dissolve when they are healed, and then be absorbed by the body--such materials would be very beneficial." said Sachiko Hiromoto who has been studying the effects of corrosion on metal surfaces. Similar to the manner in which iron corrodes with rusting and weakening as a result of atmospheric exposure, metals implanted in the body corrode in response to chemical reactions.

Bioabsorbable materials are materials capable of dissolving and being absorbed by the body. Among these materials, bioabsorbable metals began to attract attention around 2000. A bone fixation material composed of a polylactic acid polymer has been in practical use. However, the low strength of the polymer has limited its use to certain parts of the body. In such a situation, Mg alloys are promising bioabsorbable materials for bone fixation. Although they are lower in strength than Ti alloys, Mg alloys are lighter and exhibit a low elastic modulus similar to that of bone. In addition, Mg is a biologically essential chemical element and is biocompatible.

One important issue has been found with the use of Mg alloys as bone fixation materials, however. "Once implanted, Mg alloys immediately start dissolving and are unable to fix broken bones in the intended position until they heal," Hiromoto explained.

For Mg alloys to function as effective bone fixation materials, Mg dissolution in the body needs to be slowed. Many researchers have been trying to achieve this by coating the surfaces of Mg alloys with materials intended to reduce body fluid permeation.



Round plates composed of a Mg alloy in a petri dish. Hiromoto placed them in a plastic holder and then immersed it in a coating solution to make coated Mg alloys (photo on p. 7).

Slowing Mg alloy dissolution

While a variety of coating materials have been tested, Hiromoto has been focusing on "hydroxyapatite" (HAp), a type of calcium phosphate. HAp is a major bone component and is therefore highly biocompatible. There was an issue with the use of HAp, however. Coating with a simple immersion process is preferable for bone fixation materials as they are complex in shape. However, no one had succeeded in coating the surfaces of Mg alloys with HAp in a solution using a single process.

"It was known that Mg alloys could be coated with HAp through multistep chemical reactions," Hiromoto said. "However, developing the simplest possible techniques was a major policy of my work."

Hiromoto attempted to form an HAp layer on the surface of Mg alloys by immersing the alloys in a solution in which phosphate and complex, calcium-containing metal molecules were dissolved. The problem with this approach was that Mg ions released from the Mg alloys into the solution and bonded with phosphate ions. This prevented a desirable chemical reaction—the bonding of phosphate ions and calcium (Ca) ions to form HAp. Hiromoto thought that this problem could be solved by adding extra Ca ions to the solution in advance.

"I went back to the basics of the chemistry—my academic background—and revisited the theory of chemical kinetics, which states that the rate of a chemical reaction is proportional to the concentration of the reactants," Hiromoto said. "Assuming that the concentration of reactant A is higher than that of reactant B, a reaction with A will proceed faster and yield a greater amount of reaction products than a reaction with B. Based on this principle, I managed to develop a coating solution rich in Ca ions. It was a difficult challenge, but I finally succeeded in coating Mg alloys with an HAp layer in solution via a single process."

Hiromoto then implanted HAp-coated Mg alloys into rat femora in a joint project with the Kagoshima University Faculty of Dentistry and the National Institute of Advanced Industrial Science and Technology. The HAp-coated Mg alloys were found to dissolve more slowly in the body and promoted the formation of new bone (Figure).

Replacement of both coating materials and Mg alloys with bone

Although the expected results were obtained, Hiromoto was left with one concern: the HAp coating remained even four months after implantation in rat femora. Mg alloys are expected to dissolve and be replaced with bone within four months, making it desirable for a coating material to have been completely absorbed by the body within that timeframe.

"The HAp coating greatly enhances the function of the bone fixation material by accelerating bone bonding to Mg alloy surfaces," Hiromoto said. "The HAp coating will eventually fragment and be absorbed by the body. However, in order to accelerate the complete bone healing, including thorough absorption of the bone fixation material and its coating, it is preferable for a coating material to be absorbed more quickly and in greater synchrony with bone healing."

To put this idea into practice, Hiromoto chose a new coating material, carbonated apatite (CAp), a type of calcium phosphate like HAp but with a slightly different chemical composition.

"Bones are continuously regenerated through the absorption of old bone by osteoclasts and the formation of new bone by osteoblasts," Hiromoto explained. "CAp is known to be absorbed by osteoclasts during this bone remodeling cycle. Therefore, CAp is presumably capable of facilitating new bone growth and more rapid absorption by the body when used as a coating material. I hope to develop CAp-coated Mg alloys able to firmly fix broken bones and completely dissolve when the bones are healed. My research goal is to bring such an ideal material into reality."

A German manufacturer recently developed Mg alloy bone screws and Mg alloy stents to be used to expand blood vessels. These products have been certified for sale as medical devices in Europe (CE marked). Nearly 90% of the bone fixation materials and artificial joints made of Ti alloys and stainless steel currently used in Japan are imported from overseas. If this trend continues, we may also rely on imports for Mg alloy medical devices. Hiromoto warns that Japan's medical spending on the purchase of foreign products may continue to increase. Development of Japanese-made bioabsorbable bone fixation materials is vital to breaking dependence on foreign products.

"Achieving practical application of medical equipment is an extremely strenuous process, requiring many tests and procedures. Even so, I would like to pursue practical application of the HAp and CAp coating materials while cooperating with medical institutions and manufacturers. I would like to lead this effort as a NIMS researcher," Hiromoto said calmly but resolutely.

(by Shino Suzuki, PhotonCreate)

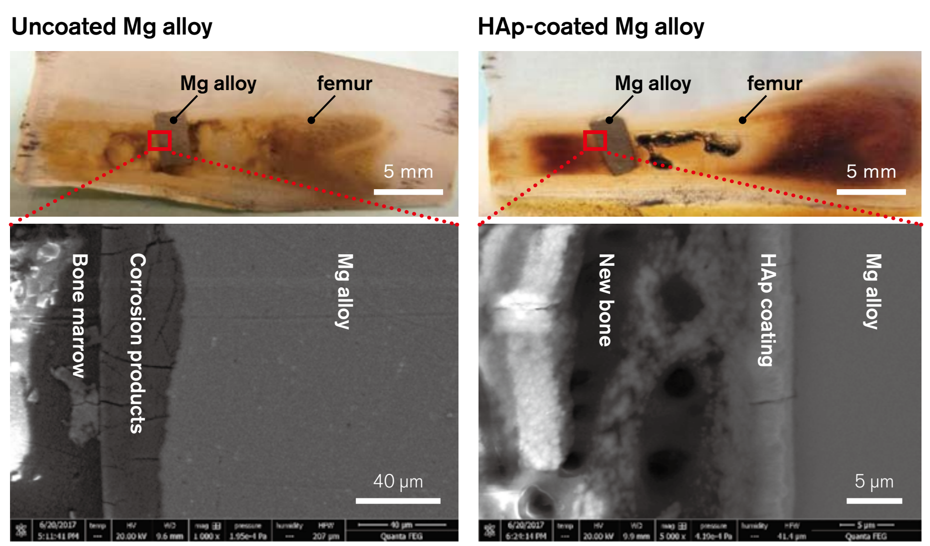


Figure. Experimental implantation of an Mg alloy in a rat femur

Longitudinal sections of a rat femur fixed in resin, with an implanted Mg alloy (Upper photos). SEM observation of the interface between the uncoated Mg alloy and the bone tissue, showing the development of corrosion products on the surface of the biodegrading Mg alloy. No new bone formed (Lower left). On the other hand, newly formed bone was observed on the surface of a Hap-coated Mg alloy (Lower right).

Research 3

Self-healing ceramics recovering naturally like bone

Broken bones gradually heal spontaneously.
Structural materials able to self-heal similarly would greatly reduce the need for repair and replacement.
Toshio Osada has been studying ceramic materials with such a self-healing function since college.
Osada and his colleagues at NIMS, Toru Hara and Masanori Mitome,
have been working collaboratively to understand the mechanisms of self-healing ceramics
and improve their design.

Compensating for the weakness of ceramics

Relatively minor wounds and broken bones heal naturally because the human body possesses the capability to heal itself. All materials are destined to break eventually. If they have the ability to repair breakage themselves the same as the human body's mechanisms, their durability and safety would be greatly improved. Osada has been researching and developing amazing materials called "self-healing ceramics."

Ceramics are hard, but this characteristic makes them brittle and susceptible to cracking on impact. If ceramics can be made capable of self-repairing cracks, thereby compensating for their brittleness, they may become appropriate for a much wider range of applications.

Issues of self-healing ceramics

"Kotoji Ando, Professor Emeritus at Yokohama National University, discovered self-healing ceramics in 1995," Osada said. "I joined the Ando lab as a senior at the university in 2003 and saw self-healing ceramics for the first time."

After completing his Ph.D., Osada carried out superalloy research for about two-and-a-half years. He then became a faculty member at Yokohama National University in January 2012. This was when he decided to seriously commit himself to the research and development of self-healing ceramics.

Self-healing ceramics have been conceived as a potentially effective material for aircraft engine turbine blades. Their self-healing function activates only at extremely high temperatures (above 1,000°C). Cracks in turbine blades produced from self-healing ceramics designed to operate at these high temperatures could be self-repaired during flight.

"Although this sounds theoretically promising, many issues have been identified," Osada said. "Two issues are particularly challenging. First, it takes the ceramics 1,000 hours to self-repair cracks when the engine operates at 1,000°C. Second, turbine blades are exposed to a wide range of temperatures, from 1,500°C on the front side to 600°C on the reverse side."

1,000 hours is an impractically long time if the goal is to for cracks to self-repair during a single flight. Moreover, given that cracks may form in any part of a turbine blade, the materials need be capable of self-repairing at a wider range of temperatures. Osada began an in-depth analysis of existing self-healing ceramics with these issues in mind.

Investigating the mysteries of self-healing ceramics using powerful analytical tools

Self-healing ceramics are produced by first mixing alumina (i.e., aluminum oxide, Al_2O_3)—a base material—with a small amount of silicon carbide (SiC) and then firing the mixture to allow it to solidify. If a crack forms in the ceramic, air enters the ceramic's interior and a chemical reaction occurs between atmospheric oxygen and SiC, yielding silicon dioxide (SiO_2). It had been thought that this SiO_2 is the self-healing agent that fills cracks. However, there were still many mysteries left in this process.

"I have heard Professor Ando say, 'When cracked self-healing ceramics are heated to about 1,200°C, a liquid-like substance appears. I am not sure what it is,'" Osada said. "So my initial interest was to identify this liquid material. I consulted with two experts at NIMS," he said, referring to Toru Hara and Masanori Mitome.

Hara is an expert in analyzing materials' macrostructures and compositions. Hara has developed outstanding analytical techniques by making original modifications to electron microscopes. When he was asked by Osada to analyze self-healing ceramics, he used a special type of electron microscope called FIB-SEM. This device allows electron scanning microscope (SEM) observation of a sample material while its surface is being etched by a focused ion beam (FIB). This technique produces successive cross-sectional images of the sample's microstructure. Hara attempted to visualize the detailed process in which SiO_2 fills a crack. At that time, he and a collaborating manufacturer had just finished developing a new type of FIB-SEM capable of producing a three-dimensional, high-precision image of a microstructure using a series of cross-sectional images.

"The resulting 3D microstructure images clearly showed tracks through which a liquid material had run (Figure 1)," Hara said excitedly.

The next objective was to identify the chemical elements constituting the liquid material and to determine its movement. To continue the quest, Hara passed the torch to Mitome, who specializes in the analysis of crystalline structures using transmission electron microscopes (TEMs). Mitome closely analyzed the cracked regions in a ceramic material using a TEM, based on the 3D microstructure images by Hara. A TEM enables observation of atomic arrangements at a resolution of 0.2 nanometers (nm) or higher.

"I closely observed the boundary between the base material (alumina) and a crack and found the presence of crystals composed of SiO_2 and alumina called mullite (Figure 2)," Mitome said.

Mitome's findings convinced Osada that he had finally identified the liquid material that forms at approximately 1,200°C. He became very excited.

"The liquid turned out to be a 'supercooled melt' which forms when SiO_2 comes into contact with alumina."

A supercooled melt is a material that is in a fluid state despite being at a temperature below its melting point. Because the melting point of SiO_2 is around 1,700°C, it is not normally found in a liquid state at 1,200°C. However, Mitome's analysis found that when the base material (alumina)—previously thought to be irrelevant to the self-healing reaction—melts, it reacts with SiO_2, yielding the supercooled melt.

Self-healed ceramics were further confirmed to be as strong as or stronger than uncracked ceramics. After thoroughly studying the self-healing mechanisms of existing ceramics, Osada moved on to the next step: developing higher-performance self-healing ceramics.

Speeding up the self-healing process by 60,000 times!

Osada's rediscovery of the importance of the analytical aspect of research inspired him to transfer from Yokohama National University to NIMS in 2013. His first project at NIMS was to search for materials that enable the formation of a supercooled melt at lower temperatures, a process required to accelerate self-healing.

In 2015, Osada identified a promising material—manganese oxide (MnO)—using a mathematical technique called thermodynamic equilibrium calculation.

"I created self-healing ceramic samples in which alumina was mixed with approximately 1% MnO," Osada said. "When the ceramic samples in which cracks were created in advance were heated to about 1,000°C, they self-repaired the cracks in just one minute."

Osada used the bodily fluid network found in human bones as a model (Figure 3 on p. 14) when preparing the samples. The Bodily fluid network facilitates efficient transport of materials needed for broken bones to heal. Osada envisioned a material design in which MnO is three-dimensionally distributed across the base material similar to the bodily fluid network. He hypothesized that this widespread MnO distribution would allow MnO-derived undercooled melts to also be distributed widely when they form, making them available for efficient self-repair. He adjusted the ceramic firing temperatures to test this hypothesis.

"The test produced positive results as expected. However, I was very surprised by the fact that the ceramics I created self-healed 60,000 times faster than conventional self-healing ceramics," Osada said.

Osada then wanted to verify whether the hypothesized self-healing process had actually occurred in the ceramics. He asked Hara to conduct another analysis.

Coverage cooperation

Toshio Osada (at left in the photo and p. 11)
Principal Researcher
Superalloys and High Temperature Materials Group
Research Center for Structural Materials

Toru Hara (right)
Director of the Structural Materials Analysis Station
Leader of the Microstructure Analysis Technology Group
Research Center for Structural Materials

Masanori Mitome (middle)
Deputy Managing Director of the Center for Nanotechnology Platform
Chief Researcher, Nanotubes Group
International Center for Materials Nanoarchitectonics (WPI-MANA)

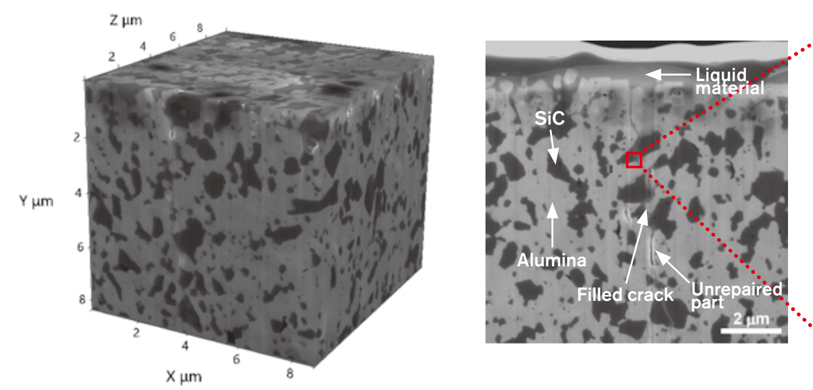


Figure 1. 3D images of a self-healing ceramic microstructure produced by FIB-SEM

(Left) Microstructures on the periphery of cracks were analyzed and visualized as 3D images using an FIB-SEM. (Right) A cross-sectional image showing a crack that has been filled with a liquid material.

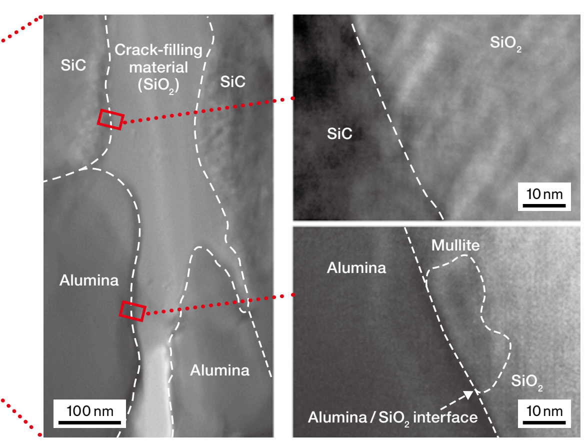


Figure 2. Identifying the liquid material using a TEM

Detailed observation of the boundary between the base material (alumina) and a crack found the presence of mullite crystals composed of SiO_2 and alumina at the boundary.

Self-healing ceramic specimen

"This time, I used a scanning transmission electron microscope (STEM) that had the world's highest analytical efficiency at the time," Hara said. "This analysis successfully visualized the presence of trace amounts of MnO distributed three-dimensionally in the boundaries between alumina particles (Figure 3). This verified that Dr. Osada's hypothesis was correct."

Analytical technologies and support offered by NIMS enabled the breakthrough

NIMS' analytical capabilities have developed over the course of many years. Osada greatly appreciated the contributions these capabilities made to the success of his research.

"The timing of Dr. Osada's request for the analysis of a very challenging sample was fortunate because I had just pulled together all of the necessary resources," said Mitome with a smile. He has been supporting Osada for nearly a decade.

Osada began conducting joint research with Hara and Mitome in 2012, the year in which the Center for Nanotechnology Platform was founded at NIMS. This Center was established as part of the MEXT Nanotechnology Platform Japan program, an initiative which aimed to support researchers in industry, academia and the public sector by making Japan's advanced research facilities accessible to them.

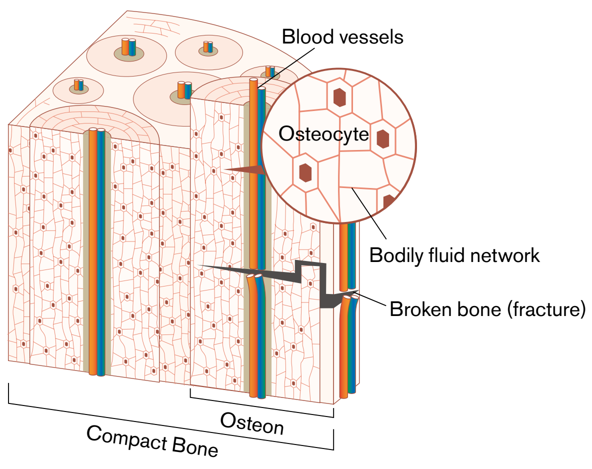
"When I was just starting my career as a university faculty member, this program made it easier for me to ask Dr. Hara and Dr. Mitome to perform analyses for me using NIMS' high-performance equipment," Osada said. "They also gave me detailed advice on various issues, such as the type of material sample I should prepare in order to generate the data I wanted. I am really thankful for their kind support."

Hara, who is also affiliated with the Center for Nanotechnology Platform, commented on his collaboration with Osada. "The analysis was so challenging that it brought out my best work in the use of sophisticated equipment and techniques. I very much enjoyed it."

Osada is now working to put the newly developed self-healing ceramic into practical use by addressing its many issues remaining. For example, structural materials are required to meet international standards for strength and longevity. Because no standard for strength currently exists for materials with self-healing capabilities, new international standards need to be established. Aircraft engine materials understandably require particularly high standards for strength.

"I am challenging to achieving the practical use of the self-healing ceramic as an aircraft engine material in addition to pursuing its application in other fields," Osada said. He plans to continue his research on self-healing ceramics in the hope of achieving their widespread use.

(by Kumi Yamada)



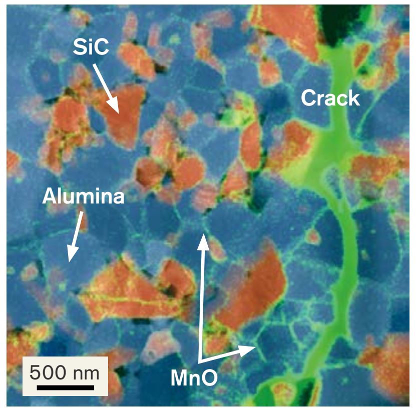
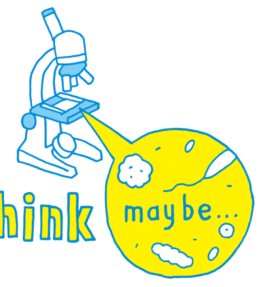


Figure 3. Bone structure (left), which inspired the microstructure design of the self-healing ceramic, and a network of MnO (right)

The bodily fluid network which allows efficient transport of materials needed for broken bones to heal inspired the design of the self-healing ceramic microstructure into which MnO was incorporated. The ceramic was deliberately cracked and heated to observe under STEM. As expected, MnO (green) flowed into the spaces between alumina particles, forming a network.

Science is even more amazing than you think maybe...



50th anniversary of the Kenjiro Takayanagi Prize for scientific TV programs

Text by Akio Etori
Illustration by Joe Okada (vision track)

Nobel Prize winner Dr. Leo Esaki recently stated that the continuous process of discovery makes science unique among all of the activities in which our society engages.

Science has been advancing at an increasingly accelerating pace. Since the dawn of the 21st century, a number of significant scientific achievements have been made, including the discovery of gravitational waves, the development of genome editing techniques, the capturing of the first image of a black hole and groundbreaking battery improvements. These feats would have been unimaginable in pre-modern times. The huge impact of the information revolution—including the advent of the internet—has dramatically changed our lives.

Advances in science have been made possible by often underappreciated but in reality immensely powerful tools: visualization technologies capable of enabling us to see invisible phenomena.

The invention of the electron microscope has enabled us to explore the submicroscopic world. Advanced electron microscopes today that resulted from a series of many improvements are even capable of directly capturing images of molecules and atoms.

The latest type of telescope based on new principles and was developed through international collaboration involving a large number of scientists. This telescope has been playing a significant role in the exploration of space beyond our solar system and in the analysis and historical study of the entire universe.

When we witnessed the fusion between sperm and egg cells for the first time, we were captivated by this mysterious phenomenon that is the essence of life.

When Apollo 11 landed on the surface of the moon and Commander Neil Armstrong left the first human footprint in the Sea of Tranquility, more than 800 million people around the world viewed the event on televisions with astonishment and joy.

The giant squid had been thought impossible to observe alive. When its giant tentacles suddenly appeared in front of a special camera placed on the abyssal seafloor, we gasped in surprise.

Other great scientific achievements—including the discovery of carbon nanotubes by Dr. Sumio Iijima , the creation of iPS cells by Dr. Shinya Yamanaka and the discovery of DNA by Watson and Crick decades earlier—were also made possible by the use of visualization technologies.

For many years, television broadcasting has played a major role in widely communicating these scientific milestones and their significance to the public.

The glorious history of Japanese TV broadcasting began when Dr. Kenjiro Takayanagi—referred to as "the father of Japanese television"—succeeded in transmitting an image of the Japanese katakana character "イ" via a cathode ray tube TV. TVs have since improved considerably in image resolution and vividness. TV continues to broadcast many intellectually stimulating programs, including fascinating scientific programs that popularize great scientific achievements like those mentioned above using visually stunning images.

The Kenjiro Takayanagi Prize for scientific TV programs was founded in 1971 by a group of volunteers keenly interested in honoring excellence in scientific TV programming. 2020 marks the prize's 50th anniversary. Prize winners are announced annually on January 20, the date of Dr. Takayanagi's death. Three programs earned best program awards this year.

I have been serving as a judge for this prize since its first year and have been truly impressed by the many excellent programs that have been produced over the years. Although this is not a high-profile prize, I sometimes hear that winning it has encouraged TV program producers to create even better programs. I'm delighted by this and have no doubt that many people have learned the joy and significance of science from these programs.

In commemoration of the 50th anniversary of this prize, I would like to express my sincere thanks to those who have contributed to the advancement of visualization technologies and the creation of intriguing scientific TV programs.

Akio Etori: Born in 1934. Science journalist. After graduating from College of Arts and Sciences, the University of Tokyo, he produced mainly science programs as a television producer and director at Nihon Educational Television (current TV Asahi) and TV Tokyo, after which he became the editor in chief of the science magazine Nikkei Science. Successively he held posts including director of Nikkei Science Inc., executive director of Mita Press Inc., visiting professor of the Research Center for Advanced Science and Technology, the University of Tokyo, and director of the Japan Science Foundation.

*This column will be the last in this long-running NIMS NOW series. We would like to thank all of our readers.

NIMS NEWS

1 9 NIMS members recognized as "Highly Cited Researchers 2019"

※Listed in alphabetical order

Clarivate Analytics selected 9 NIMS members as its "Highly Cited Researchers 2019."

"Highly Cited Researchers" are authors of scientific papers that are in the top 1% in number of citations in a given research field based on Clarivate Analytics' Essential Science Indicators database.


Katsuhiko Ariga


Yoshio Bando


Dmitri Golberg


Jonathan Hill


Ashraful Islam


Takashi Taniguchi


Kenji Watanabe


Yusuke Yamauchi


Jinhua Ye

2 NIMS signed Memorandum of Understanding (MoU) with Indian Institute of Technology, Hyderabad (IITH)

Director of IITH, Prof. B.S. Murty visited NIMS accompanied by representatives of the university and signed inter-institutional MoU, which is aiming to strengthen and promote research collaboration between IITH and NIMS.

IIT is the highest ranking university of engineering and research in India. Hyderabad in paticular is a new university established in 2008. IITH is known for its strength in advanced research on AI, IoT, Computer Science and so on.

IITH is specially supported by Japan International Cooperation Agency (JICA) , and IITH has been building a strong relationship especially with Japan. IITH and NIMS will discuss further cooperation and signing an agreement for accepting students at NIMS.


Signing Ceremony of MoU.

Hello from NIMS

Hello! My name is Shanmugavel from India. During my Ph.D. period, I had a chance to visit NIMS as an international joint graduate school fellow from Anna University, India. At that time, I faced the 2011 Tohoku earthquake and received much support from JISTEC staffs. I will never forget the days at Tsukuba festival and Tsuchiura fireworks. Currently, I' m working as an ICYS research fellow, and my research field is bioimaging and drug delivery using nontoxic and water-soluble quantum dots. I realized the freedom of research at NIMS in several situations, particularly in my JSPS and ICYS period. I feel the research facility of NIMS is the international leader and also friendly to everyone. As a scientist, my dream is developing novel two-photon fluorescence absorption and emission quantum dots for deep tissue imaging without altering the original structure of proteins in the blood.


Cruise ride around the Tokyo Bay


Shanmugavel Chinnathambi
(India)
ICYS Research Fellow

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editorial design by Barbazio Inc.
on the cover: Sea urchin shell spines and outer membranes removed.

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