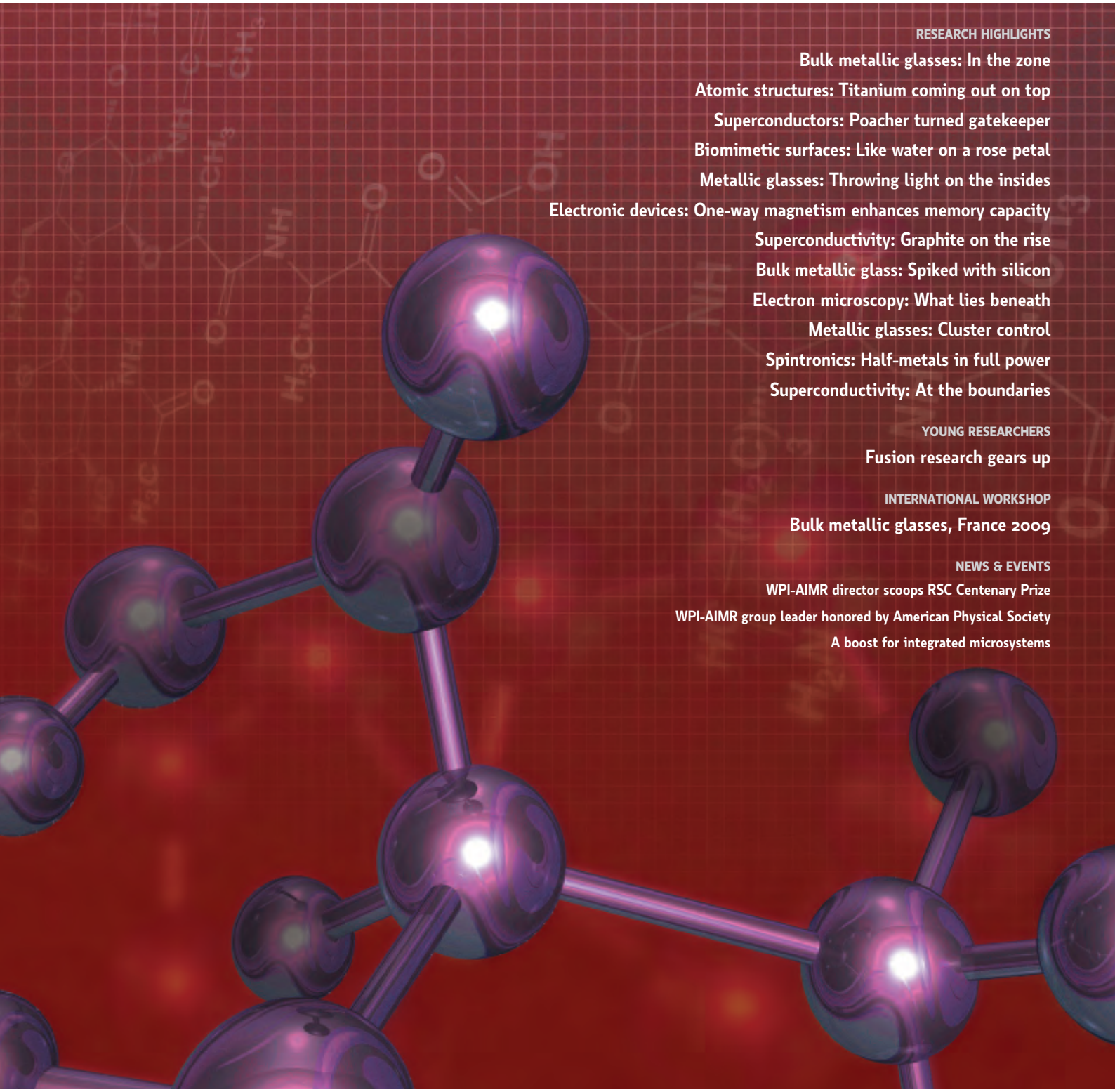
AiM Research

RESEARCH HIGHLIGHTS 2009

A publication of the WPI Advanced Institute for Materials Research



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WPI Advanced Institute for Materials Research

The Advanced Institute for Materials Research (AIMR) at Tohoku University in Sendai, Japan is one of five World Premier International (WPI) Research Centers established with the support of the Japanese Ministry of Education, Culture, Sport, Science and Technology (MEXT). Inaugurated in 2007 and coinciding with the 100th anniversary of the founding of Tohoku University, the WPI-AIMR brings together internationally renowned researchers from Japan and abroad to lead interdisciplinary collaborative research on new and innovative functional materials technologies at the forefront of materials science.

The WPI-AIMR is composed of four main divisions focusing on bulk metallic glasses, nanophysics, nanochembio and device/systems construction. Led by Chief Scientist and Institute Director Yoshinori Yamamoto and supported by an international advisory board, the WPI-AIMR promotes collaboration among its divisions toward the development of breakthrough technologies bridging such disciplines as materials science, physics, chemistry and precision, mechanical, electronics and information engineering.

The WPI-AIMR is host to over 100 leading researchers from across the world including 32 principal investigators. In addition to the research hub at Tohoku University, the WPI-AIMR collaborates with research centers in the UK, France, Germany, the US and China. Close ties with other leading international universities are maintained through its adjunct professor and associate professor programs.

AIM*Research*

AIM*Research* is a new online and print publication that highlights the scientific achievements and activities of the WPI-AIMR. First published in June 2009, AIM*Research* selects the most important papers from the wealth of research produced by WPI-AIMR scientists throughout the year, distilling the essence of the achievements into timely, concise and accessible research highlights that are easy-to-digest but retain all of the impact and importance of the original research article.

Uploaded monthly to the AIM*Research* website in both English and Japanese, AIM*Research* highlights bring the very best of WPI-AIMR research to a global audience of specialists and non-specialists alike.

AIM*Research* also publishes a range of features articles introducing other activities of the WPI-AIMR's research groups. All of the information contained on the AIM*Research* website is also available in Japanese and visitors can register for free monthly email alerts in either Japanese or English so that they can keep abreast of the latest developments and discoveries made at the WPI-AIMR.

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A material world

As institute director of the World Premier International Advanced Institute for Materials Research, it is my very great pleasure to welcome you to this print collection of research highlights published by AIM*Research* in 2009.

Materials science is becoming increasingly important year on year in terms of both pure and applied research. From a scientific and technological perspective, materials science stands at the intersect point of a whole range of different disciplines, from basic sciences such as chemistry and physics through to highly focused applications such as photonics and nanotechnology, electron microscopy, superconductor technology, materials catalysts and electronic devices. Some of this research, in the fields of bulk metallic glasses and semiconductor research, for example, or the development of materials with one-dimensional magnetic properties, is likely to have a direct impact on society in the near future. Other areas, such as advanced electron microscopy and 'spintronic' devices, hold the promise of new and better tools and techniques that will deliver the next generation of scientific advances.

Materials science then continues to change the world in which we live, now and in the future.

For a scientist in the twenty-first century, however, it is not enough simply to investigate, discover and innovate. The modern researcher must also be able to communicate the importance and relevance of their work not only to their colleagues, but also to scientists active in other fields and even to non-scientists. But this is not communication for communication's sake: greater understanding of the science stimulates even more fruitful exchange of ideas between researchers, raises the overall level of interest in science and engenders greater trust of scientists in society.

It was with this aim — sharing the fruits of our labors at the WPI-AIMR — that we created AIM*Research*.

This collection is only a snapshot of what is being published on the AIM*Research* website every month. I hope that you will visit the site in the near future and read the very latest highlights and features published by the WPI-AIMR (research.wpi-aimr.tohoku.ac.jp). While you are there, I would encourage you to register for regular, free email alerts so that you need never miss the latest information about research from the WPI-AIMR.

Yoshinori Yamamoto
Institute Director
WPI Advanced Institute for Materials Research

Bulk metallic glasses

In the zone

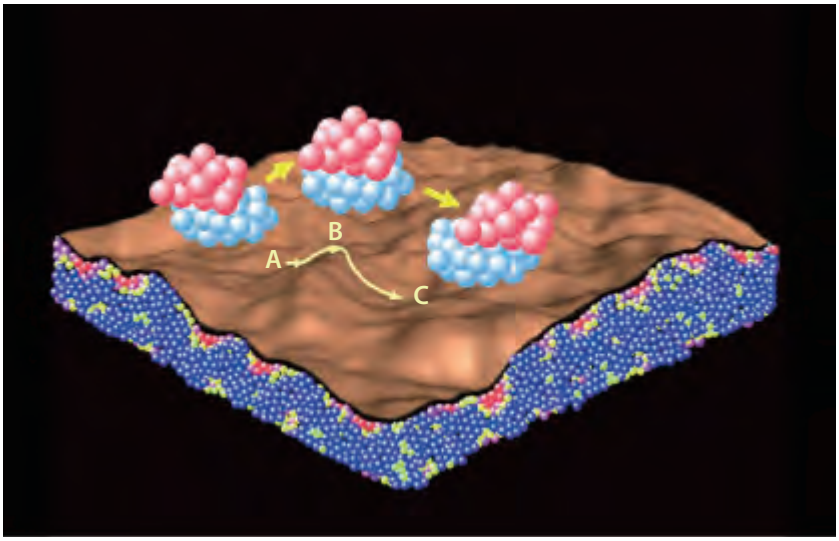
Nanoscopic shear zones have been identified as responsible for plastic flow in bulk metallic glass

Metal alloys with a glassy atomic structure, known as bulk metallic glasses (BMGs), are much stronger than normal metals and have great promise for a variety of applications. Unfortunately, they are also less ductile, making them more susceptible to fracture. To try to understand why, Mingwei Chen and colleagues from the Advanced Institute for Materials Research (AIMR) at Tohoku University[1] have conducted the first experimental characterization of shear transformation zones that arise when a BMG is subject to plastic deformation.

When a conventional metal cools from its molten liquid state, its atoms arrange into well-ordered crystalline structures. This rarely results in a perfect single-crystal structure; rather, a polycrystalline matrix consisting of randomly oriented crystallites is generally formed. Owing to the weakness of the boundaries between these grains and other imperfections, the actual mechanical strength of a metal is usually much lower than the theoretical strength it would have if it were a perfect single crystal.

BMGs, on the other hand, are alloys in which the atoms have not been given time to arrange into crystallites, resulting in a non-regular structure similar to that of ceramic glass. This circumvents the problems of grain boundaries and crystal defects, making BMGs much stronger than conventional metals. However, although they are less brittle than ceramics, they are more brittle than most metals.

One of the leading explanations for this poor ductility is the emergence of 'shear transformation zones' (STZs) within a BMG. STZs are nano-scale volumes of material that undergo plastic flow (pictured), and the concentration of stress at STZs is believed to cause localized shear bands to form, leading to mechanical failure and poor ductility. Until now, the nature or even the exact size of these zones has never been characterized. To address this, Chen and his colleagues developed a new 'rate-jump nanoindentation' technique for characterizing the mechanical behavior of these structures involving the measurement and modeling of the response of a BMG to a micro-sized diamond indentor with nanoscopic resolution of force and displacement.



Schematic diagram of the activation of an STZ in a glassy material. Mechanical failure through macroscopic shear occurs by the accumulation of a critical number of activated STZs on a slip plane.

The researchers applied this approach to a variety of different BMGs, which allowed them to determine the volumes of material involved in the plastic flow of atomic clusters in an STZ, and to correlate this with the ductility of the BMG. They found that BMGs exhibiting the smallest STZ volumes were also the least ductile. This observation should allow other scientists to improve their understanding and optimize the mechanical performance of BMGs. It is also a demonstration of a powerful technique for characterizing the mechanical behavior of other non-crystalline materials. ■

1. Pan, D., Inoue, A., Sakurai, T. & Chen, M.W. Experimental characterization of shear transformation zones for plastic flow of bulk metallic glasses. *Proceedings of the National Academy of Sciences* **105**, 14769–14772 (2008).

Atomic structures

Titanium coming out on top

High-resolution electron microscopy settles the problem of the atomic structure at the surface of titania, an important catalyst material

Precise knowledge of the arrangement of atoms at the surface of a crystal is crucial for catalytic materials, which are used to initiate chemical reactions through interactions at the surface. Settling existing controversy, Yuichi Ikuhara and colleagues from the University of Tokyo in collaboration with the Advanced Institute for Materials Research (AIMR) at Tohoku University[1] have now determined the atomic arrangement at the surface of titania (TiO_2), which is an important material for catalytic processes.

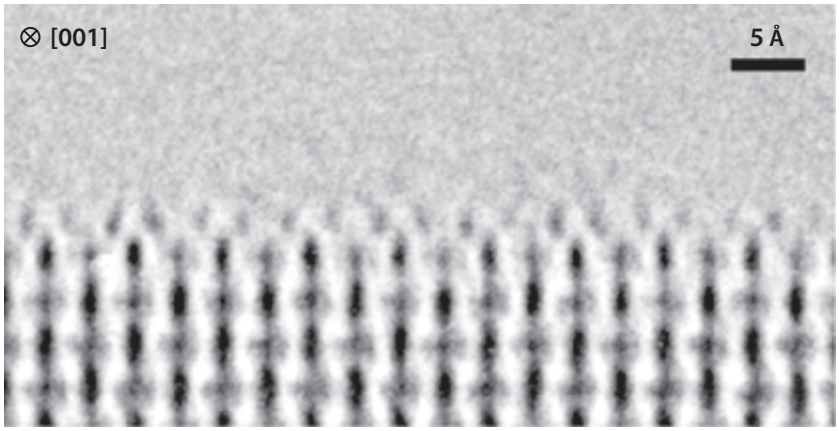
Crystalline materials are regular three-dimensional assemblies of atoms, and study of the bulk crystal structure is generally straightforward. The surface of a crystalline material, however, is notoriously difficult to study, as the disruption to the perfect crystal symmetry leads to compromises in the positions and chemical bonds of the surface atoms. "Determining the surface structure is very important for understanding the nature and the mechanism of the catalytic properties," says Ikuhara.

Although there have been many proposals for the surface structure of titania, it has remained difficult to determine the positions of top surface atoms precisely by experimental observations. The researchers were able to derive the titania surface structure for the first time through a combination of high-voltage electron microscopy (HVEM) and scanning electron microscopy techniques (pictured).

The surface structure was studied with atomic precision from two directions, and the three-dimensional image thus obtained was compared with two structures that have recently been proposed in theoretical studies. In one of the models, the outer surface is comprised predominantly of oxygen atoms, whereas in a more recent study, titanium was predicted to be located at various positions near the surface such that the surface composition is more balanced between oxygen and titanium. The experimental results clearly confirmed the latter prediction.

The findings suggest that titanium plays a more active role on the surface of titania than previously thought, which provides valuable feedback for developing a better understanding of the reaction kinetics on the surface of titania. "I believe that our findings will contribute significantly to our understanding of the surface kinetics," comments Ikuhara.

In catalytic applications, the surface of titania is often functionalized with noble metals such as gold or platinum, which act as co-catalysts. As a next step it will be important to study the structure of the interfaces between these metals and titania. "This," says Ikuhara, "will enable us to understand the origin and nature of their catalytic properties." ■



High-resolution HVEM image of a TiO_2 (110) surface observed from the [001] direction (black corresponds to Ti sites). Structural reconstruction is visible at the surface.

1. Shibata, N., Goto, A., Choi, S.-Y., Mizoguchi, T., Findlay, S.D., Yamamoto, T. & Ikuhara, Y. Direct imaging of reconstructed atoms on TiO_2 (110) surfaces. *Science* **322**, 570–573 (2009).

Superconductors

Poacher turned gatekeeper

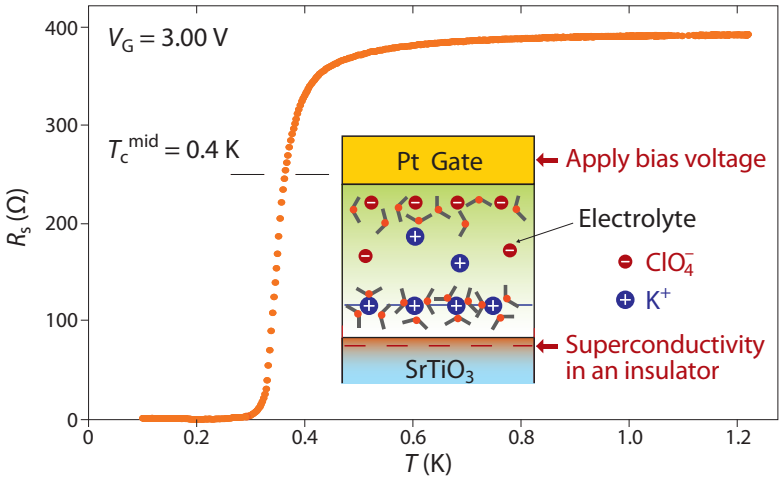
An insulating material has been converted into a superconductor using only an electrical field — without the need for chemical doping

Superconductivity, the capacity of certain materials to conduct electricity with zero resistance and therefore no loss of energy below a critical temperature, is a physical phenomenon of profound importance with numerous scientific and practical applications. Superconductivity is controlled by the density of charge carriers within a material — electrons in the case of negative charge and 'holes' for positive charge. Typically, materials are converted into superconductors by introducing impurities into the crystal lattice by chemical doping. However, such modification is often irreversible, and inevitably introduces structural disorder.

An alternative approach for making superconductors involves tuning the density of charge carriers of a material by applying an external electric field. This method has made it possible to convert metals and chemically doped insulators into superconductors, but attempts with non-doped insulators have so far been unsuccessful due to the low charge densities in these systems. Now, a team of scientists led by Masashi Kawasaki and Kazunori Ueno from the Advanced Institute for Materials Research (AIMR) at Tohoku University[1] have successfully used an electrical method to induce superconductivity in strontium titanate ($SrTiO_3$), which is better known as an insulator. "This work is the first demonstration of converting an insulating material to a superconducting one purely by an electric field. That was dreamed by people for more than 50 years," says Kawasaki.

The researchers electrically doped $SrTiO_3$ using a modified electrical method inspired by electrochemical cells. Writing in *Nature Materials*, the researchers describe their work in which they constructed an 'electric double-layer transistor' field-effect device. In a conventional electrochemical cell, an electrolyte is set between two electrodes, and the application of an electrical field across the electrodes leads to charge separation as the positive and negative ions within the electrolyte migrate toward opposite electrodes. The researchers modified this technique by replacing one of the electrodes with $SrTiO_3$. When immersed in an organic electrolyte with a platinum wire electrode, the resistance of the $SrTiO_3$ declined sharply at voltages above 2.5 V, showing that the system was behaving like a conducting metal. Upon dropping the temperature to 0.4 K — near absolute zero — the normally insulating $SrTiO_3$ became a superconductor (pictured). Examination of the $SrTiO_3$ surface revealed that this transition is due to the accumulation of positive charge near the surface rather than to electrochemical reactions. Furthermore, this electrically doped $SrTiO_3$ material exhibited superconducting behavior different from that of the chemically doped samples.

"Our study provides another way to search for superconductivity, and considerably widens the choice of candidate materials for possible new superconductors," says Ueno. ■



Graph showing the abrupt disappearance of resistance (R_s) in $SrTiO_3$ as the temperature drops to 0.4 K at a gate voltage (V_G) of 3 V. Inset shows a schematic diagram of the structure of the electric double-layer transistor incorporating the $SrTiO_3$.

1. Ueno, K., Nakamura, S., Shimotani, H., Ohtomo, A., Kimura, N., Nojima, T., Aoki, H., Iwasa, Y. & Kawasaki, M. Electric-field-induced superconductivity in an insulator. *Nature Materials* **7**, 855–858 (2008).

Biomimetic surfaces

Like water on a rose petal

Metal–polymer surfaces inspired by natural systems can be made to retain or repel water droplets

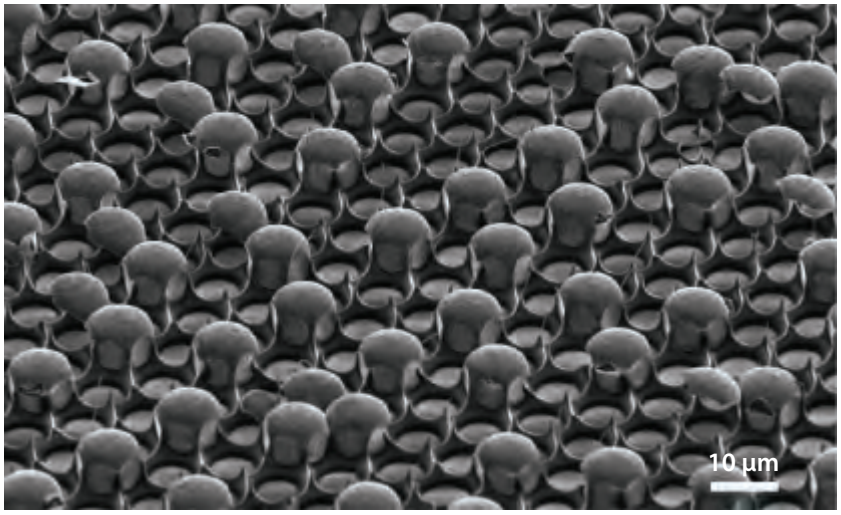
Picture a rose, in full bloom, after a rain shower. Water droplets bead up on the petals, but they do not slide off — instead, the petals grip the droplets in place, even if the flower is inverted. The secret to the water-retaining power of rose petals? A microstructured surface with both hydrophilic (water attracting) and hydrophobic (water repelling) regions.

The field of biomimetics seeks to reproduce natural technologies, such as the adhesion properties of rose petals, with synthetic materials. Now, Masatsugu Shimomura and co-workers from the Advanced Institute for Materials Research (AIMR) at Tohoku University[1] have developed a new biomimetic surface composed of self-organized metal–polymer structures, which can be made to repel or cling to water droplets.

According to Daisuke Ishii, the lead author of the study, creating a biomimetic material with adjustable wettability requires precise dimensioning of the hydrophilic and hydrophobic surface patterns. If the patterns are too large, the regions act independently, making it impossible to control water droplets. Similarly, patterns that are too small compared to the size of the droplet have little effect on the droplet's behavior.

"Our surface is composed of micrometer-sized hydrophobic–hydrophilic patterns," says Ishii. "As a result, water droplets are simultaneously repelled and adhered on our hybrid surface."

The researchers combined hydrophilic metal domes with super-hydrophobic polymer spikes to create their new biomimetic surface. "By fabricating a polymer and metal hybrid, we hoped to make a functional surface with wettability that responds to external stimuli," explains Ishii.



Scanning electron microscopy image of a biomimetic surface composed of hydrophilic metal domes and hydrophobic polymer spikes.

First, the scientists cast a thin polystyrene-based film onto a glass honeycomb-patterned template to form hexagonally ordered microcavities. This honeycomb film was then coated with nickel metal, which filled many of the cavities. By peeling off the polymer film layer, the researchers obtained a series of metal domes and empty cavities amidst an array of polymer spikes (pictured).

Ishii's team prepared a range of these biomimetic surfaces by varying the surface metal concentration. They found that altering the metal dome coverage from 0% to 25% changed the surface's properties from completely water-repellent to as water-adherent as a rose petal.

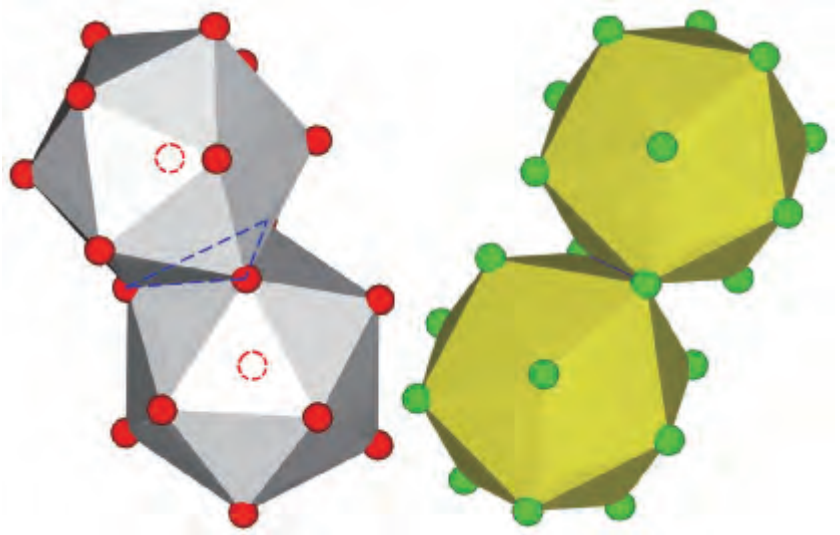
Manipulating wettability through external stimuli is the ultimate goal of the researchers. "Adhesion properties can be controlled by using the electric and magnetic energies of the metal microstructures," says Ishii. "We will demonstrate micro-droplet manipulation on the biomimetic surfaces for new micro-fluidic and lab-on-a-chip devices." ■

1. Ishii, D., Yabu, H. & Shimomura, M. Novel biomimetic surface based on a self-organized metal–polymer hybrid structure. *Chemistry of Materials* **21**, 1799–1801 (2009).

Metallic glasses

Throwing light on the insides

High-energy light reveals the hidden internal structure of metallic glass



Schematic diagram showing how the atoms in Zr–Cu metallic glass form icosahedral clusters that pack tightly together by sharing faces (left) or edges (right).

Metallic glasses, made by carefully cooling hot metal alloys so that they solidify without crystallizing, promise to revolutionize the materials industry. Thanks to an irregular, tightly packed internal arrangement of atoms, metallic glasses are moldable like plastic when heated, yet stronger than typical crystalline alloys.

Now, a team of international researchers from the Advanced Institute for Materials Research (AIMR) at Tohoku University in Japan and the Institut Polytechnique de Grenoble in France[1] has used high-energy light to probe the internal structure of a metallic glass of zirconium (Zr) and copper (Cu). The results provide a guide for producing thicker alloy glasses with enhanced functionality.

The researchers, led by Alain Yavari, used a high-energy synchrotron X-ray source to ricochet photons off atoms buried deep inside a sample of Zr–Cu metallic glass. Mathematical interpretation of the resulting X-ray diffraction signals gave a description of how pairs of Zr–Zr, Cu–Cu and Zr–Cu atoms were distributed within the glass. By taking measurements of alloys with various compositions, the scientists were able to correlate changes in glass stability with changes in the atomic structure.

According to Yavari, the Zr–Cu metallic glass is an 'ideal solid solution' — that is, because the interactions among atoms are weak, the atoms can distribute randomly within the glass.

The random distribution of atoms creates a densely packed internal structure, but it also reduces the alloy's resistance to crystallization — only very thin glasses can be cast from Zr–Cu mixtures. Recently, however, scientists found that adding a third component, aluminum (Al), to the hot alloy allowed stronger glasses to be cast at thicknesses of up to several millimeters.

In contrast to the ideal solution character of Zr–Cu, the researchers found that Zr–Cu–Al metallic glasses deviated markedly from ideal behavior. They observed that the Zr–Cu–Al glasses were comprised of finite regions of atomic order, providing the extra support needed to form thicker glasses. These ordered regions are believed to form due to attraction between the outer electrons of aluminum atoms and the larger zirconium atoms. The atoms arrange in shells resembling icosahedra, which pack together tightly in the glass (pictured). Yavari and his colleagues have previously observed the formation of such clusters in other Zr–Cu alloys.

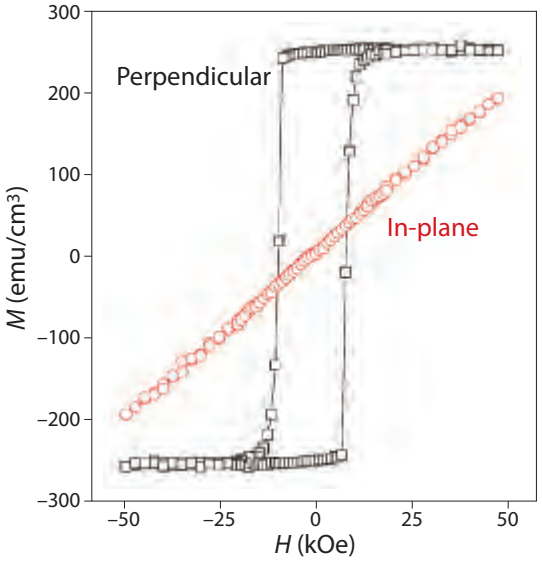
The use of synchrotron light, Yavari says, was highly advantageous for analyzing the Zr–Cu–Al metallic glasses. Whereas conventional X-ray beams are completely absorbed at the surface of the material, light produced by a synchrotron has sufficient energy and intensity to penetrate into even thick samples, providing a deeper understanding of the unique internal structure of metallic glasses. ■

1. Georgarakis, K., Yavari, A.R., Louzguine-Luzgin, D.V., Antonowicz, J., Stoica, M., Li, Y., Satta, M., LeMoulec, A., Vaughan, G. & Inoue, A. Atomic structure of Zr–Cu glassy alloys and detection of deviations from ideal solution behavior with Al addition by X-ray diffraction using synchrotron light in transmission. *Applied Physics Letters* **94**, 191912 (2009).

Electronic devices

One-way magnetism enhances memory capacity

A thin alloy film with one-dimensional magnetic properties could pave the way for higher capacities of nonvolatile memory



Graph showing the magnetization (M) of thin $Mn_{2.5}Ga$ films versus the applied magnetic field (H). When the field is applied perpendicular to the film (black), the film quickly reaches a maximum (saturation) magnetization, but when the field is applied in the plane of the film (red), the magnetization cannot be saturated. This 'perpendicular magnetic anisotropy' could be ideal for magnetic data storage and spintronic applications.

Magnetic random access memory (MRAM) consists of submicron-sized elements — magnetic tunnel junctions (MTJs) — that can be 'written' into one of two different magnetization states representing individual bits of information ('0' and '1'). The obvious way to increase memory capacity is to make these MTJs smaller, but this can also make them less stable.

Now, Feng Wu, Terunobu Miyazaki and co-workers at the Advanced Institute for Materials Research (AIMR) and the Department of Applied Physics at Tohoku University[1] have developed a thin alloy film that could improve the stability of high-capacity MRAM by restricting the magnetization of MTJ memory layers to just one direction. The film could also have applications in spintronic devices, which exploit the intrinsic spin of electrons as well as their charge.

"Making smaller MTJs to support higher memory capacity has been a successful approach," says Wu. "Today, however, MTJs have become so small that further shrinkage would cause the magnetization of the individual MTJs to be unstable and flip spontaneously. So the memory would erase itself."

One way of getting round this problem is to use a material with perpendicular magnetic anisotropy (PMA). Such materials show a preference for magnetization in only one direction — perpendicular to the film. In PMA films, the memory bits are therefore more stable than usual against small, random energy fluctuations from the environment. What's more, MRAM based on PMA films with large spin polarization can be accessed faster than those based on existing small-spin-polarized PMA films because the MTJs have 'giant' tunnel magnetoresistance. "MRAM containing MTJs with a PMA memory layer is the most likely candidate for the next generation of universal memory," says Wu.

Wu's team fabricated their new PMA film from an alloy of manganese and gallium ($Mn_{2.5}Ga$). They deposited one atomic layer at a time using a magnetron sputtering technique, which allowed the atoms to form a well-ordered tetragonal crystal structure. Interestingly, the alloy exhibits ferromagnetism even though its constituent metals do not.

"In our alloy, the distance between manganese atoms is much larger than that in manganese metal," says Wu. "Thus, ferromagnetic properties can be found. Our alloy is also predicted to have large spin polarization."

The researchers found that the $Mn_{2.5}Ga$ film only became magnetized when a magnetic field was applied at right angles to the film, indicating strong PMA (pictured). The large spin polarization of this PMA film makes it ideal for MRAM and spintronic devices.

"Now, we are fabricating MTJs using this material as a memory layer, which is crucial for the realization of gigabit-class MRAM," says Wu. ■

1. Wu, F., Mizukami, S., Watanabe, D., Naganuma, H., Oogane, M., Ando, Y. & Miyazaki, T. Epitaxial $Mn_{2.5}Ga$ thin films with giant perpendicular magnetic anisotropy for spintronic devices. *Applied Physics Letters* **94**, 122503 (2009).

Superconductivity

Graphite on the rise

High-resolution spectroscopy experiments reveal important clues toward the understanding of superconductivity in graphite compounds

The discovery of superconductivity at unusually high temperatures in the graphite intercalation compounds C_6Yb and C_6Ca has spurred intense efforts to understand the nature of superconductivity in these materials. Researchers from the Advanced Institute for Materials Research (AIMR) and the Department of Physics at Tohoku University[1] have now contributed an important clue to the origin of superconductivity in graphite compounds by determining the size and nature of the tell-tale gap in the superconducting energy spectrum.

C_6Ca (pictured left) is part of a larger family of layered materials in which atoms such as calcium are intercalated between graphite sheets. Some of these graphite intercalation compounds were found to be superconductive more than 40 years ago. However, the recently discovered C_6Ca is special, as it remains superconductive to much higher temperatures, up to 11.5 K.

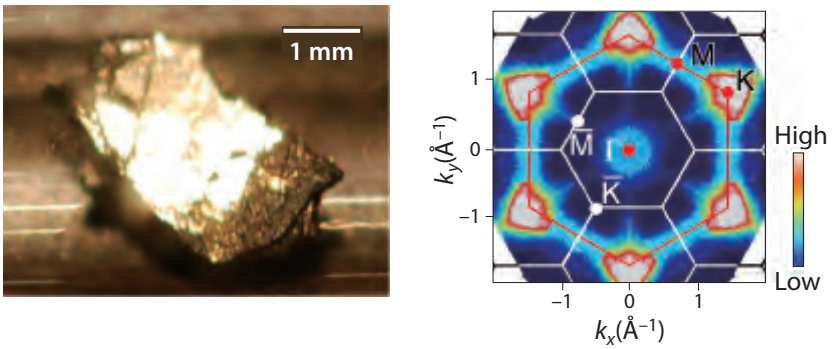
To unravel the origin of this behavior, the researchers compared the electronic states of C_6Ca (pictured right) with those of regular graphite. They measured the small differences between these compounds using a special high-resolution photoemission spectrometer at Tohoku University. "The energy resolution of our spectrometer is world-leading and essential to observe the superconducting gap," comments Takashi Takahashi, who led the research team.

The high-resolution experiments uncovered important differences between graphite and C_6Ca. In particular, the experiments revealed not only the energetic states associated with the carbon atoms in the graphite layers, but also those of the calcium intercalation layers. The researchers were thus able to observe the changes in the interlayer energy states as the material was cooled to below the superconducting onset temperature.

The theoretical expectation was that the onset of superconductivity could be observed by the opening of a gap in the measured energy states. Indeed, this is what the researchers observed. However, the gap was seen only for the electronic states of the calcium interlayers — not for the in-plane states of the graphite sheets.

These findings provide clear evidence of the important role of the interlayer. The calcium atoms 'donate' electrons to the graphite layers, but the experiments also suggest that this strong coupling between the calcium electrons and the carbon atoms could explain the higher superconducting temperature of C_6Ca.

The importance of these findings extends beyond the graphite intercalation compounds. The results may also provide important clues toward the understanding of other layered systems, such as the high-temperature cuprate superconductors. In addition, says Takahashi, "the knowledge we obtained may eventually also lead to the discovery of new superconductors with even higher transition temperatures." ■



Photograph of a C_6Ca crystal (left) and electronic states of superconducting C_6Ca as imaged by high-resolution photoemission spectroscopy (right).

1. Sugawara, K., Sato, T. & Takahashi, T. Fermi-surface-dependent superconducting gap in C_6Ca. *Nature Physics* **5**, 40–43 (2009).

Bulk metallic glass

Spiked with silicon

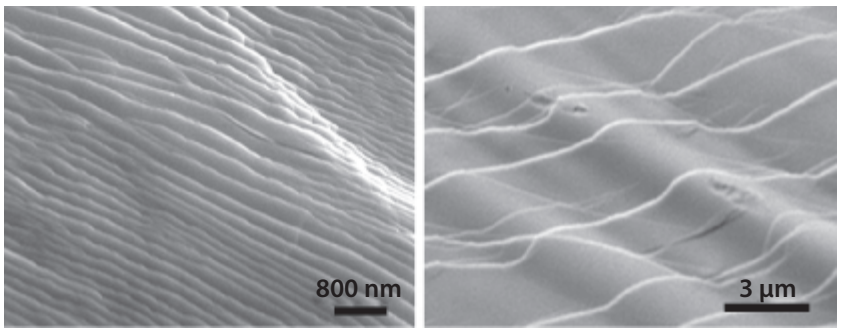
The incorporation of small amounts of silicon into a metallic glass enhances ductility without inhibiting its glass-forming ability

Bulk metallic glasses (BMGs) are metal alloys that have been cooled such that they solidify without crystallizing to form an ordered lattice. Unlike conventional metals, they soften and flow readily at moderate temperatures, allowing them to be cast or molded into intricate shapes. This unique processability, and their high strength, wear and corrosion resistance, make these materials attractive for application in biomedical and microelectromechanical devices.

Despite being stronger and more wear-resistant than conventional metals, some metallic glasses are also brittle. Now, Na Chen from Tohoku University's Advanced Institute for Materials Research (AIMR) and collaborators[1] have introduced small amounts of silicon (Si) into a metallic glass combining palladium (Pd), nickel (Ni) and phosphorus (P) to create an alloy with enhanced glass-forming ability and ductility.

Noting that an exceptionally ductile metallic glass of Pd–Si had been developed previously[2], and that binary alloys of palladium or nickel with either silicon or phosphorous form similar phases on cooling, the researchers expected that the addition of silicon could also improve the ductility of the ternary Pd–Ni–P alloy without significantly affecting its glass-forming ability.

To produce their alloy, the team sealed well-defined compositions of high-purity metal powders in quartz tubes under high vacuum, and melted the mixtures homogeneously at 1,323 K. They then cooled the tubes in water to solidify the Pd–Ni–Si–P ingots. Finally, they melted the ingots and cast the alloy into 2 mm-diameter cylinders.



Scanning electron microscopy images showing wavy nanometer- and micrometer-sized steps induced by a propagating crack during failure.

Chen and her colleagues found that, under compression, the Pd–Ni–Si–P alloy could tolerate three times as much strain as the original Pd–Ni–P alloy before breaking. The broken Pd–Ni–Si–P surfaces displayed wavy nanometer- and micrometer-sized steps (pictured). "These steps are usually observed on the fracture surface of brittle materials," explains Chen. "But in the case of the Pd–Ni–Si–P metallic glass, the nanoscale and microscale wavy steps were formed at the final stage of the fracture."

The researchers showed that Pd–Ni–P displays two crystallization stages at different temperatures. When they added as little as 5% silicon, however, only one of those stages remained. They therefore suggest that the addition of silicon to Pd–Ni–P traps the metals in a liquid-like arrangement where the atoms bind loosely to each other.

"Compared to metallic additives, silicon is a much smaller atom, and thus has a large atomic size difference with the main constituents, palladium and nickel, which favors the formation of a non-periodic dense packing structure and suppresses crystallization," explains Chen.

The researchers are currently focusing on developing other ductile and biocompatible BMGs and plan to use these high-performance, durable materials to manufacture small devices for microelectromechanical systems. ■

1. Chen, N., Louzguine-Luzgin, D.V., Xie, G.Q., Wada, T. & Inoue, A. Influence of minor Si addition on the glass-forming ability and mechanical properties of $Pd_{40}Ni_{40}P_{20}$ alloy. *Acta Materialia* **57**, 2775 (2009).
2. Yao, K.F., Ruan, F., Yang, Y.Q. & Chen, N. Superductile bulk metallic glass. *Applied Physics Letters* **88**, 122106 (2006).

Electron microscopy

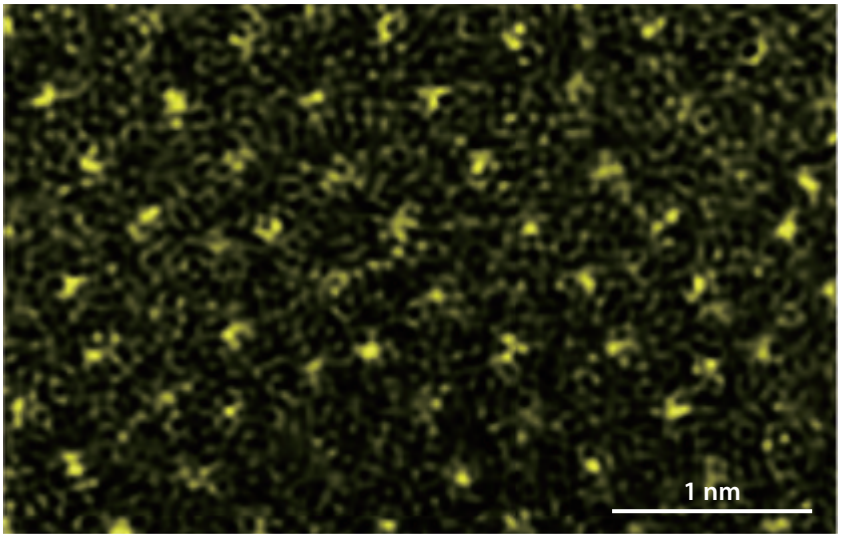
What lies beneath

A technique for imaging impurity atoms at a buried interface provides a useful tool for understanding the behavior of polycrystalline materials

The composition and structure of the interfaces between crystallites in a polycrystalline material play an important role in determining the material's properties and behavior. In electronic devices and microcomputer circuits, it is often the electronic properties of these interfaces, rather than those of the bulk materials, that form the basis for device operation. One way of controlling the characteristics of the interfaces is to add small amounts of impurities as 'dopants'.

As the size of devices and material structures approaches nanometer scales, the influence of interfaces and dopant atoms becomes ever more significant. However, because dopant atoms are usually buried within the bulk material, it is difficult to obtain accurate information about their distribution at an interface, or the structure of the surrounding material. To address this issue, Yuichi Ikuhara from the Advanced Institute for Materials Research (AIMR) at Tohoku University and colleagues from the University of Tokyo[1] have developed a technique that uses an electron microscope to image the location and local structure of individual dopant atoms within a buried interface.

To demonstrate their approach, the researchers first doped an alumina surface with a low concentration of yttrium, which is known to strengthen the boundary between alumina crystals. This surface was then buried under a second alumina layer, added directly onto the first layer by diffusion bonding. The sample was subsequently imaged using a scanning transmission electron microscope — but in a slightly different way to how electron microscope images are usually taken.



Scanning transmission electron microscopy image of the interface between two yttrium-doped aluminum-oxide crystals showing the distribution and structural ordering of yttrium atoms (yellow spots). Individual yttrium atoms are 0.3–0.5 nm apart.

Electron microscopy of crystalline materials is commonly carried out by directing an electron beam along one of the sample's 'strong channeling axes' — particular directions in a crystal along which electrons can travel easily. This procedure usually improves the clarity of the images obtained, but can also conceal the presence of impurities. Instead, Ikuhara and his colleagues imaged their sample at an angle from these axes, which enabled them to obtain clear, high-contrast images of the yttrium atoms at the buried interface (pictured).

The ability to collect atomic-scale information about interfacial make-up and structure should enable researchers to better understand, and therefore better control, the doping of material interfaces. This in turn should help them to more easily engineer and optimize the properties of polycrystalline materials and the devices that rely on the behavior of the interfaces among crystallites. ■

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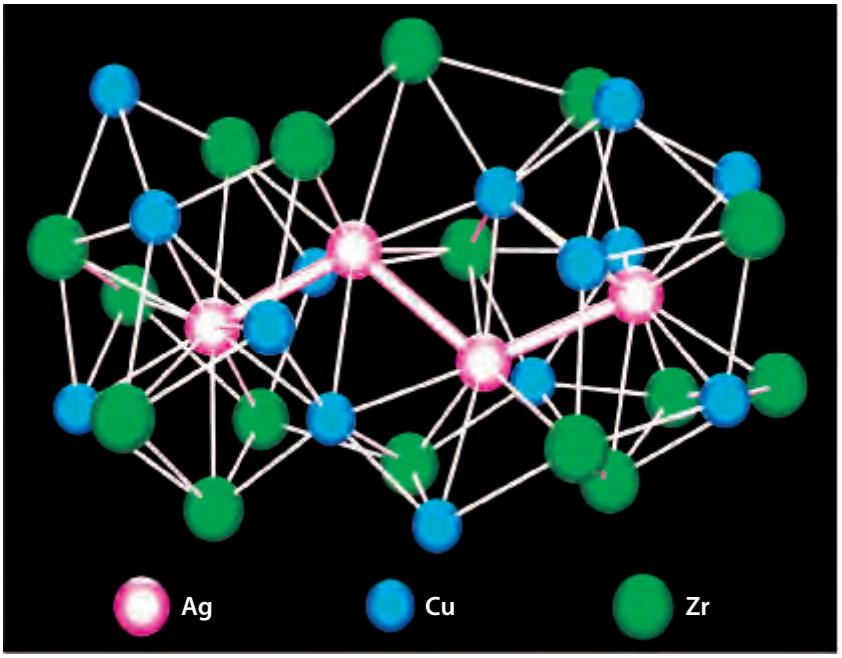
Metallic glasses

Cluster control

Atomic-scale heterogeneity makes a better metallic glass



The atomic configuration in a Cu–Zr–Ag metallic glass. Clusters centered by sliver atoms link together sharing the surrounding shell atoms.

Solid metals usually exist as well-ordered crystals, but in recent years researchers have also produced stiff, strong, disordered metal alloys known as bulk metallic glasses (BMGs). However, it remains unclear exactly why certain combinations of metals form BMGs more readily than others.

Now, Takeshi Fujita, Mingwei Chen and co-workers at Tohoku University's Advanced Institute for Materials Research (AIMR) and the Miyagi National College of Technology in Natori[1] have observed that when more than two types of metals are combined, their atoms may arrange in different types of clusters that aid the formation of a BMG. "Bulk metallic glass is a new type of high-strength material for engineering," explains Chen. "It is also very easy to fabricate into various nanostructures in a supercooled liquid state."

The team's latest work was prompted by experiments showing that a two-metal alloy is more likely to form a BMG structure when small amounts of a third metal are added. However, it had so far remained difficult to scrutinize the structure of a multi-component BMG.

Fujita, Chen and their colleagues were able to examine the atomic structure of copper–zirconium (Cu–Zr) alloy samples containing varying amounts of added silver through the use of extended X-ray absorption fine structure (EXAFS) spectroscopy at the incredibly powerful SPring-8 synchrotron radiation facility in Hyogo, Japan.

"Without the advanced synchrotron source, we could not have detected the atomic structure of these disordered solids," says Chen. "Our colleagues in Natori helped us to interpret the EXAFS spectra. I think multidisciplinary collaborations are very important in today's cutting-edge research."

By combining their X-ray spectra with computer simulations, the researchers concluded that the atoms in their copper–zirconium–silver (Cu–Zr–Ag) BMG arranged themselves into two main types of structure: clusters with silver atoms at the center surrounded by a shell rich in zirconium, and clusters rich in copper throughout (pictured). The atomic-scale heterogeneity favors glass formation.

These two types of clusters were seen in both the supercooled liquid and the solid glass state. Moreover, the fact that the clusters are close to the ideal sizes for efficient packing means that they represent an important step in glass formation. Different to conventional atomic clusters, the clusters in metallic glasses are not individually isolated. Instead, they always share 'overlap' atoms with neighboring clusters to form a dense and connected packing.

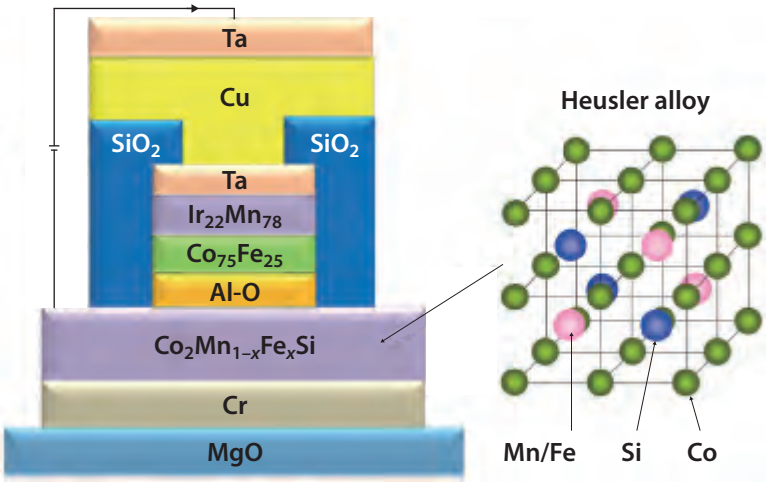
The findings highlight the importance of structural heterogeneity in forming amorphous solids. More generally, the results challenge the traditional notion that an atom in a solid usually prefers to be surrounded by atoms of different types. ■

1. Fujita, T., Konno, K., Zhang, W., Kumar, V., Matsuura, M., Inoue, A., Sakurai, T. & Chen, M.W. Atomic-scale heterogeneity of a multicomponent bulk metallic glass with excellent glass forming ability. *Physics Review Letters* **103**, 075502 (2009).

Spintronics

Half-metals in full power

The spintronic performance of half-metal Heusler alloys can be enhanced by composition engineering



Schematic representation of the magnetic tunnel junction device used in the experiment (left), and a schematic illustration of the crystal structure of the Heusler alloy (right).

Controlling electron spin, in addition to the use of electrons as a charge carrier, may one day lead to a new generation of advanced electronic devices. For example, we can envisage transistors based on currents with a well-defined spin orientation, or logic devices in which the magnetization is controlled through electrical currents.

Essential for the development of such 'spintronic' devices are materials with suitable magnetic properties, such as a high degree of spin polarization and a high Curie temperature (T_C) — the temperature above which the material ceases to be a ferromagnet. These criteria are satisfied by several intermetallic compounds with a specific crystal structure known as Heusler alloys. Terunobu Miyazaki and colleagues at the Advanced Institute for Materials Research (AIMR) and the Department of Applied Physics at Tohoku University[1] have now constructed high-performance devices based on Heusler alloys with the composition $Co_2Fe_xMn_{1-x}Si$.

The iron-free alloy Co_2MnSi has a high T_C (985 K) and is a half-metal; that is, a material in which electrons are conducting if their spin is one direction, and non-conducting if the spin is in the opposite direction, which is ideal for the injection of spin-polarized electrons. The manganese-free alloy Co_2FeSi, on the other hand, has an even higher T_C (1,150 K), but its status as a half-metal is ambiguous. The team from Tohoku University showed that certain mixtures of these two alloys, with a mixed iron/manganese composition, have a Curie temperature higher than 985 K but retain the half-metal character of Co_2MnSi.

The team studied magnetic tunnel junctions consisting of two magnetic electrodes and a tunneling barrier, where one of the electrodes was made of the $Co_2Fe_xMn_{1-x}Si$ Heusler alloy (pictured). They looked at how the tunnel magnetoresistance (TMR) — the resistance due to electrons tunneling from the $Co_2Fe_xMn_{1-x}Si$ through the barrier in a magnetic field — changed when they varied the amounts of iron and manganese in the alloy. The TMR first increased with the addition of iron, from 67% at $x = 0$ to a maximum of 75% for compositions between $x = 0.4$ and $x = 0.6$, but then dropped to 46% at $x = 1$. The researchers suggest that the high iron content (high x) causes the compound to stop being a half-metal and the tunneling electrons to become less polarized.

The team also measured the 'Gilbert damping constant' of their $Co_2Fe_xMn_{1-x}Si$ compounds. This parameter, related to the relaxation of magnetization, should be low for materials used in magnetization switching. They obtained the minimum value for the alloy with a composition of $x = 0.4$, which also indicates that the material with this iron content is still a half-metal.

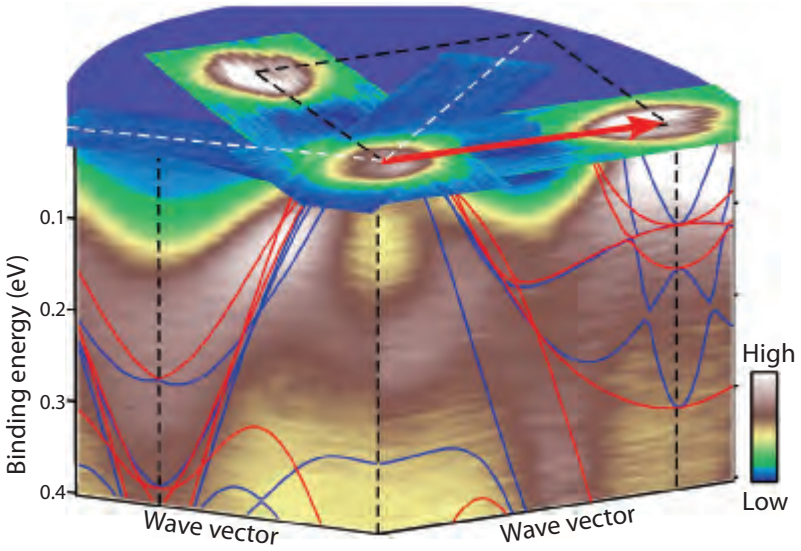
Shigemi Mizukami from the research team explains that "engineering of the half-metallicity and damping properties for these alloys is required for actual device design." In his view, the results of their work on $Co_2Fe_xMn_{1-x}Si$ will stimulate further experimentation to obtain Heusler alloys with even higher spin-polarization and lower damping in the near future. ■

1. Kubota, T., Tsunegi, S., Oogane, M., Mizukami, S., Miyazaki, T., Naganuma, H., & Ando, Y. Half-metallicity and Gilbert damping constant in $Co_2Fe_xMn_{1-x}Si$ Heusler alloys depending on the film composition. *Applied Physics Letters* **94**, 122504 (2009).

Superconductivity

At the boundaries

The properties of a new class of superconductors are determined by the energy distribution of electrons



Fermi surfaces for an iron-pnictide superconductor. The color gradient shows photoemission measurements, and the solid red and blue lines indicate the calculated Fermi surfaces. The strongly interacting parts of the Fermi surfaces are indicated by a red arrow.

The physical characteristics of superconductors, such as the disappearance of electrical resistivity at very low temperature, are well known. Yet when it comes to the fundamental mechanism that drives such behavior, particularly for the recently discovered class of 'high-temperature' superconductors, many open questions remain. Researchers from Tohoku University's Advanced Institute for Materials Research (AIMR) along with international collaborators[1] have now revealed the significant role of interactions between electrons at different electronic states in the superconducting properties of the iron-based 'pnictide' superconductors.

The iron-pnictide superconductors, discovered just last year, share many commonalities with the closely related and well-known copper oxide-based superconductors (the 'cuprates'). Both material classes have a complex two-dimensional layered structure that forms the basis for their superconductivity, and both begin to superconduct at relatively high temperatures (near 50 K).

The high-energy electrons responsible for superconductivity fill certain energy states at the top of what is known as the 'conduction band'. These states can be plotted in three dimensions as a 'Fermi surface' that describes the crystal's electronic properties in relation to the symmetry of the crystal lattice and the occupation of various energy levels. Fermi surfaces can be a single object, such as a sphere, or an arrangement of small unconnected shapes.

Using an ultrahigh-resolution photoemission spectrometer at Tohoku University, which allowed the electronic states to be resolved in fine detail, the researchers studied the relationships among the individual parts of the complex arrangement of Fermi surfaces in a pnictide superconductor (pictured). They observed that the interaction between small Fermi surfaces — called nesting — is strong for this class of superconductors. "Our study has definitely established that Fermi surface nesting is an essential and universal feature for superconductivity in the pnictides," explains Takashi Takahashi, who led the research team.

Pnictide superconductors with strong interactions were found to have a higher superconducting transition temperature than those exhibiting weak interactions. The researchers also found that Fermi surface nesting plays a much stronger role in the pnictides than the cuprate superconductors, even though the underlying mechanisms of superconductivity are related.

According to Takahashi, based on this discovery of important differences between pnictides and cuprates, further studies of samples with different crystal structures are needed to determine precisely which electronic states lead to strong nesting and high transition temperatures. Ultimately, he adds, "by searching for new superconductors in which the Fermi surface nesting condition is well satisfied, we may able to find superconductors with higher transition temperatures." ■

1. Terashima, K., Sekiba, Y., Bowen, J. H., Nakayama, K., Kawahara, T., Sato, T., Richard, P., Xu, Y.-M., Li, L.J., Cao, G. H., Xu, Z.-A., Ding, H. & Takahashi, T. Fermi surface nesting induced strong pairing in iron-based superconductors. *Proceedings of the National Academy of Sciences* **106**, 7330–7333 (2009).

YOUNG RESEARCHERS

Fusion research gears up

The unconstrained research environment of the WPI-AIMR prompts young researchers to avidly seek collaborators from different groups, leading to one interesting project idea after another.

Every Friday evening, dozens of students, researchers and principal investigators flock into the lobby of the WPI-AIMR's brand-new research building. Younger researchers especially look forward to the regular gathering as a great opportunity to mingle and chat freely with colleagues of any rank over coffee and cookies, where conversations can lead to new ideas and even joint projects.

The weekly 'Tea Time', a kind of informal event still unusual at Japanese research institutes and universities, is the latest example of an undertaking by the WPI-AIMR to provide young researchers with an unconstrained and stimulating environment to allow their potential to bloom. The WPI-AIMR's endeavors have already begun to show fruit in the form of spontaneous and creative research activities, and more than 25 'fusion research' projects have been created at the institute of 120 researchers since the first call for proposals was issued in March 2009. Fusion research is designed to encourage interdisciplinary interaction and collaboration among researchers with different backgrounds in an effort to spur synergies that could pave the way for new materials science.

Yu-Ching Lin, assistant professor, Device/System Group

Attractive research environment

"Fusion research is one of the main reasons I came here," says Yu-Ching Lin, an assistant professor of the Device/System Group specialized in microelectromechanical systems (MEMSs). Before the WPI-AIMR was established, the Taiwanese researcher spent time at the Tohoku University School of Engineering, and later at the Fraunhofer Research Institution for Electronic Nano Systems in Chemnitz, Germany. Having studied practical and theoretical engineering, Lin reached a point where she felt the need to learn the basic materials science required to invent novel MEMS devices. Around that time, her supervisor, Thomas Gessner, director of the Fraunhofer ENAS who now concurrently serves as a principal investigator at the WPI-AIMR, recommended that she apply for her current position, and she jumped on the opportunity.

When Lin joined the WPI-AIMR in November 2008, she knew almost no-one. But the turning point arrived four months later when the WPI-AIMR held a week-long workshop. Lin had discussions with many researchers and found three eager collaborators from the Bulk Metallic Glasses Group — Na Chen, Deng Pan and Dmitri Louzguine. In April 2009, they submitted a proposal for a fusion research project and launched a project aimed at applying bulk metallic glasses (BMGs) for MEMS device fabrication.

Applying metallic glasses for MEMS

MEMS devices are micrometer-sized sensors or actuators having electrical and mechanical elements mounted on a single board, and have origins in semiconductor technology with key emphases on materials, fabrication and device design. Historically, every introduction of an innovative material, such as polymers, silicon carbide, piezoelectrics and carbon nanotubes, has become a landmark event in the creation of a new realm of MEMS applications. "We believe now is the time for metallic glasses," says Chen, a research associate, citing BMG's unusual strength and formability.

Na Chen, research associate, Bulk Metallic Glasses Group

When using conventional materials, lithography is employed to transfer patterns for MEMS devices. In addition to conventional fabrication techniques, however, the high formability and durability of metallic glasses could potentially allow such microscale parts to instead be cast using a mold, considerably simplifying the fabrication process. There is strong demand for a new MEMS fabrication scheme, but BMGs have been largely overlooked by engineers for use as MEMS parts. Lin's team is now developing MEMS-compatible micro/nano fabrication methods for metallic glasses and investigating how to integrate BMG

Taro Hitosugi, associate professor, Nanophysics Group

molding structures into MEMS devices.

But substantive technological challenges lie ahead, as metallic glasses have residual stress and poor adhesion to the silicon and silicon oxide used in complementary technologies. The team has tested a number of BMGs, and has found that parameters such as pressure and temperature are very important in the fabrication process. "By combining optimization of fabrication parameters and good selection of suitable BMG materials, we believe we can solve this bottleneck," Lin says. Lin is also involved in another fusion research project formed by four principal investigators to examine the use of BMG as a novel bonding material for MEMS bonding technology. "Young people like me can be at the center of even 'PI-level' fusion research. That is really encouraging," say Lin.

Making the most of the WPI-AIMR

The WPI-AIMR philosophy has also attracted young Japanese scientists like Taro Hitosugi. When appointed as an associate professor of the Nanophysics Group, he was impressed with the institute's generous support for the construction of an ideal laboratory at his own discretion. As a researcher of surface and interface physics, his work relies heavily on scanning tunneling microscopy (STM), which is extremely sensitive to noise and vibration. To shield his instruments from such interference, Hitosugi was allowed to cut out the laboratory floor, drill piles down into the bedrock, and pour 80 metric tons of concrete. The chamber is shielded with special double walls, each of which is 40 cm thick; but the combined effect is equivalent to 10 meters of concrete, says Hitosugi. "We have the best laboratory for STM in Japan, and the lab is one of the best in the world," he says. "I'd like to take advantage of the WPI-AIMR as much as possible."

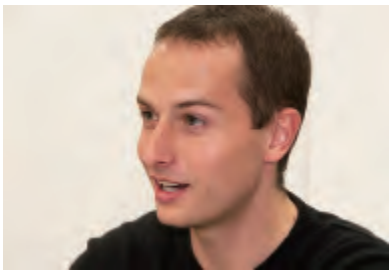
Daisuke Hojo, assistant professor, NanoChemBio Group

Like the weekly Tea Time, Hitosugi finds that fascinating projects are often conceived through casual interactions with Japanese and overseas colleagues. One day in 2009, Hitosugi dropped by the laboratory of Tadafumi Adschiri, principal investigator of the NanoChemBio Group and a specialist of novel nanostructural synthesis technologies. As their conversation developed from one topic to another, an idea for possible fusion research came up and Hitosugi was introduced to Daisuke Hojo, an assistant professor of the Adschiri laboratory.

Shigemi Mizukami, assistant professor, Device/System Group

One aspect of Hitosugi's research is to produce nanoscale thin oxide films that show interesting physical properties such as superconductivity, and to investigate their electronic structures and functions at interfaces using STM. Hojo, on the other hand, synthesizes nanoparticles of metal oxides and bonds them with organic molecules in supercritical water. Usually, nanoparticles easily stick together, but Hojo's synthesis allows nanoparticles to be dispersed uniformly in a solvent, making them easier to handle. These two researchers thought of combining their 'dry' and 'wet' processes to create innovative nanoparticles that acquire an anisotropic hetero-interface, which is impossible to achieve using wet processes only. "This is an unusual idea, but we can pursue maverick research here," Hojo says. The new product could contribute to improve the properties of nanoparticles in applications such as semiconductors and catalysts, he adds.

A different fusion research project is underway between Hitosugi and Shigemi Mizukami, an assistant professor



Marco Haubold, GI[3] laboratory student, Device/System Group

specialized in spintronics — electronics utilizing the spin of electrons — in the Device/System Group. Their project is ambitiously aimed at changing the magnetic properties of a rechargeable battery by controlling lithium ions instead of electrons as in conventional systems. "I didn't know ions behave so interestingly. We could change the paradigm of the battery system," Mizukami says. The lithium-ion batteries in electric vehicles currently take about five hours to recharge. If the interaction between lithium-ion-diffusion and magnetism can be successfully controlled, however, lithium-ion batteries could be recharged much faster by applying a magnetic field to control the lithium ions.

Enhanced breadth as a researcher

The WPI-AIMR is not only generating spontaneous collaborations but also prompting young foreign talents to join the institute thanks in part to an incentive called the 'Global Intellectual Incubation and Integration Laboratory Project', dubbed 'GI[3]'. Marco Haubold, a student of the Chemnitz University of Technology in Germany, spent five months at the WPI-AIMR to finish his diploma thesis. Like Lin, he primarily studied the theoretical aspects of MEMS materials, so he wanted to gain some experimental experience as well as discover the essence of interdisciplinary research. "After one month, I realized it would be very hard to take the responsibility for both theoretical and practical investigation," Haubold says. "But that's the challenge I wanted, and I am now feeling more competent." Haubold returned to Germany in December, but another student Frank Roscher has recently arrived — also from Germany — with the intent of enhancing his breadth of vision to become a more able materials researcher. "In addition to the superb research environment at the WPI-AIMR, Sendai is a very comfortable place for research and living. Yes, I'd like to come back again," Haubold adds. ■

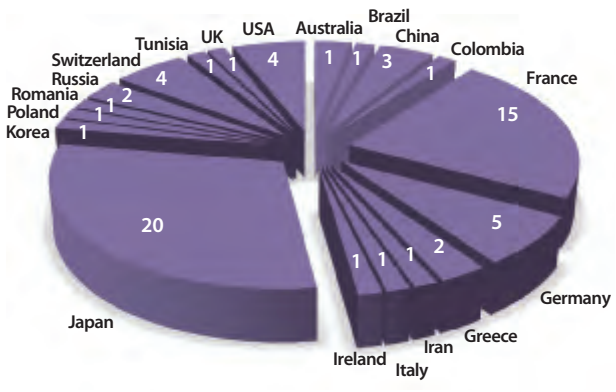
INTERNATIONAL WORKSHOP

Bulk metallic glasses, France 2009

In August 2009, Tohoku University's WPI-AIMR hosted an international workshop on bulk metallic glasses in Grenoble, France. Attended by 70 researchers from 20 countries, the workshop was a great success thanks to facilitation by Alain Reza Yavari, a professor of the Institut Polytechnique de Grenoble and a principal investigator at the WPI-AIMR.

In August, Tohoku University's Advanced Institute for Materials Research hosted an international workshop on bulk metallic glasses (BMGs) at the Maison du Tourism in Grenoble, France. The workshop, attended by 70 researchers from 20 countries, was a great success thanks to facilitation by Alain Reza Yavari, a professor of the Institut Polytechnique de Grenoble who concurrently holds the position of principal investigator at the WPI-AIMR.

The topics of the 52 oral presentations and 13 posters varied from basic research to application with a focus on the mechanical properties of BMGs. Many researchers reported their attempts to unveil the origin of BMG's strengths compared to crystals. The central topic was the 'shear bands' that arise when a BMG is subject to plastic deformation. Individual presentations included the analysis of atomic bonding using synchrotron diffraction, observation of BMGs by scanning electron microscopy, and simulations of atomic bonding in BMGs. In particular, there were active discussions on cooperative phenomena, such as shear transformation zones and microscopic formation of shear bands in BMGs.



The 2009 BMG workshop was attended by 70 participants from 20 countries

Understanding of the mechanical properties is the basis of all applications of BMGs, and elucidation of shear band phenomena is key. In the past, the primary feature of single-crystal silicon for semiconductors was dislocation: for BMGs, it is shear bands. To enhance the degree of freedom for processing, it is desirable to enhance the temperature range of supercooling just before vitrification, that is, to freely control the glass-transition point. To this end, the number of elements forming high-quality BMGs and the elemental ratio are important factors.

Researchers are making progress in discovering the compositions that form BMGs and unveiling the guiding principle. Starting from the eutectic phase diagram of three elements, and using the atomic radius and electro-negativity as guides, participants in the discussions consolidated their ideas by sharing their experiments results.

At the end of the workshop, Yavari moderated comprehensive discussions by all the participants. Akihisa Inoue, president of Tohoku University, took part in the discussions and outlined the WPI-AIMR's objectives and organizational structure. Inoue reminded participants to be mindful of the critical evaluation of high-quality research results, interdisciplinary or 'fusion' research, and the application of research outcomes by the WPI-AIMR, while expressing his resolve to make WPI-AIMR more global and attract a greater number of distinctive young researchers.

The University of Cambridge professor A. L. Greer pointed out that sustainability will be an important concept when proceeding with applications. He added that BMGs could be applied for maintaining the environment, for clean air and water and energy-saving technologies using BMGs in magnetic applications, medicine and micro-devices. ■

August 29, 2009

In Grenoble, Hiroshi Komatsu, professor emeritus of Tohoku University

WPI-AIMR director scoops RSC Centenary Prize

Yoshinori Yamamoto, institute director of the WPI-AIMR, was selected as one of the recipients of the 2009 RSC Centenary Prize by the Royal Society of Chemistry (RSC), the foremost organization for chemists in the United Kingdom. Yamamoto, who pronounced himself "surprised and delighted" at winning the award, is only the seventh Japanese-born researcher to be honored in this way.

The award, which was made in recognition of Yamamoto's "innovative contributions to methodology in organic synthesis" and comes with a specially minted medal and a £5,000 prize, was presented at a ceremony in Birmingham, UK in November 2009. The award also provides for the winners to undertake a lecture tour of leading academic institutions in the UK, which subsequently saw Yamamoto visiting York University, Queen's University Belfast and Durham University.

Formerly the RSC Centenary Lectureship, the Centenary Prize was inaugurated in 1947 to commemorate the centenary of the Chemical Society, one of the forerunner institutions that make up the RSC, and is awarded annually to three researchers from outside the UK for outstanding contributions to the chemical sciences. The RSC Centenary Prize is one of the most prestigious awards given by the UK chemical community and its list of previous recipients resembles a chemistry Hall of Fame with such legendary figures as Henry Taube, Jean-Marie Lehn, R. Bruce Merrifield and E. O. Fischer among the ranks of awardees. The 156 winners of the Centenary Prize to date include 31 Nobel laureates, among them Herbert C. Brown, who was honored with the RSC Centenary Lectureship in 1955 and who was mentor to Yamamoto when the latter was a postdoctoral researcher at Purdue University from 1970 to 1972. ■

WPI-AIMR group leader honored by American Physical Society

Terunobu Miyazaki, group leader of the WPI-AIMR Device/System Group, was awarded the 2009 Oliver E. Buckley Condensed Matter Prize for "pioneering work in the field of spin-dependent tunneling and for the application of these phenomena to the field of magnetoelectronics" by the American Physical Society (APS). Miyazaki shared the award with three researchers from the Massachusetts Institute of Technology. The ceremony was held on March 16, 2009 in Pittsburgh, Pennsylvania, USA where a prize of US$10,000 and certificates were presented to the recipients by then APS President Cherry A. Murray.

The Buckley Prize has been presented annually to outstanding researchers by the APS since 1953 to recognize important contributions to the advancement of knowledge in condensed matter physics. Previous recipients of the award include Nobel prize winners William Shockley, John Bardeen and Ivar Giaever as well as others.

Last year was a very rewarding one for Miyazaki, who was also recognized by the Japan Society of Applied Physics (JSAP) with the ninth JSAP Outstanding Achievement Award for "pioneering research on room-temperature tunnel magneto-resistive devices." Miyazaki, a professor at the WPI-AIMR since November 2007, is involved in work centering on the investigation of magnetism and magnetic materials. He is currently a member of the Spintronics Nonvolatile Device Project funded by the New Energy and Industrial Technology Development Organization of Japan. ■

A boost for integrated microsystems

The work of WPI-AIMR principal investigator Masayoshi Esashi received a sizeable boost when he was chosen as a leading researcher in the "Funding Program for World-Leading Innovative R&D on Science and Technology" in July 2009. The funding, part of a multi-billion dollar fund administered by the Japan Society for the Promotion of Science, is intended to support the development of key technologies of international importance over 3–5 years and comes from the Japanese government's fiscal stimulus package announced in early 2009.

Easahi's work is based on nano-technology and heterogeneous integration aimed at the development of cost-effective and flexible technologies for semiconductor integrated circuits. These technologies are required by industry for the development and manufacturing of advanced electronic devices. It is anticipated that the research carried out with the support of this grant will lead to discoveries that will maintain Japan's position as a leading manufacturer of integrated circuit technology for cellular phones and other related devices. ■

2010 WPI-AIMR Annual Workshop

25–27 March 2010
Tohoku University, Sendai, Japan

Following on from the highly successful 2009 workshop, this event will discuss a range of current topics in materials science including bulk metallic glasses, nanophysics, nanochembio and device/systems. The workshop will also include a number of parallel and plenary sessions as well as a poster session for younger researchers. Invited plenary speakers include Zhaomin Hou (RIKEN), Akihisa Inoue (Tohoku), Kohzo Ito (Tokyo), Jörg F. Löffler (ETH), Yoshio Nishi (Stanford), H. Eugene Stanley (Boston) and Jing Zhu (Tsinghua).

Further details are available from:
www.wpi-aimr.tohoku.ac.jp/workshop/

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