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AIMR Magazine

Advanced Institute for Materials Research

01
March 2013

[Feature articles]

The Potential of Spintronics Unlocked by Ferromagnetic Semiconductors

Advanced Institute for Materials Research,
Tohoku University
Fumihiro Matsukura and **Hideo Ohno**

[A Friendly Discussion]

—— The Goals of an Endeavor to Lead the World ——

"Collaboration between Mathematics and Materials Science"

Yasumasa Nishiura × Shigefumi Mori

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Advanced Institute for Materials Research (AIMR), Tohoku University

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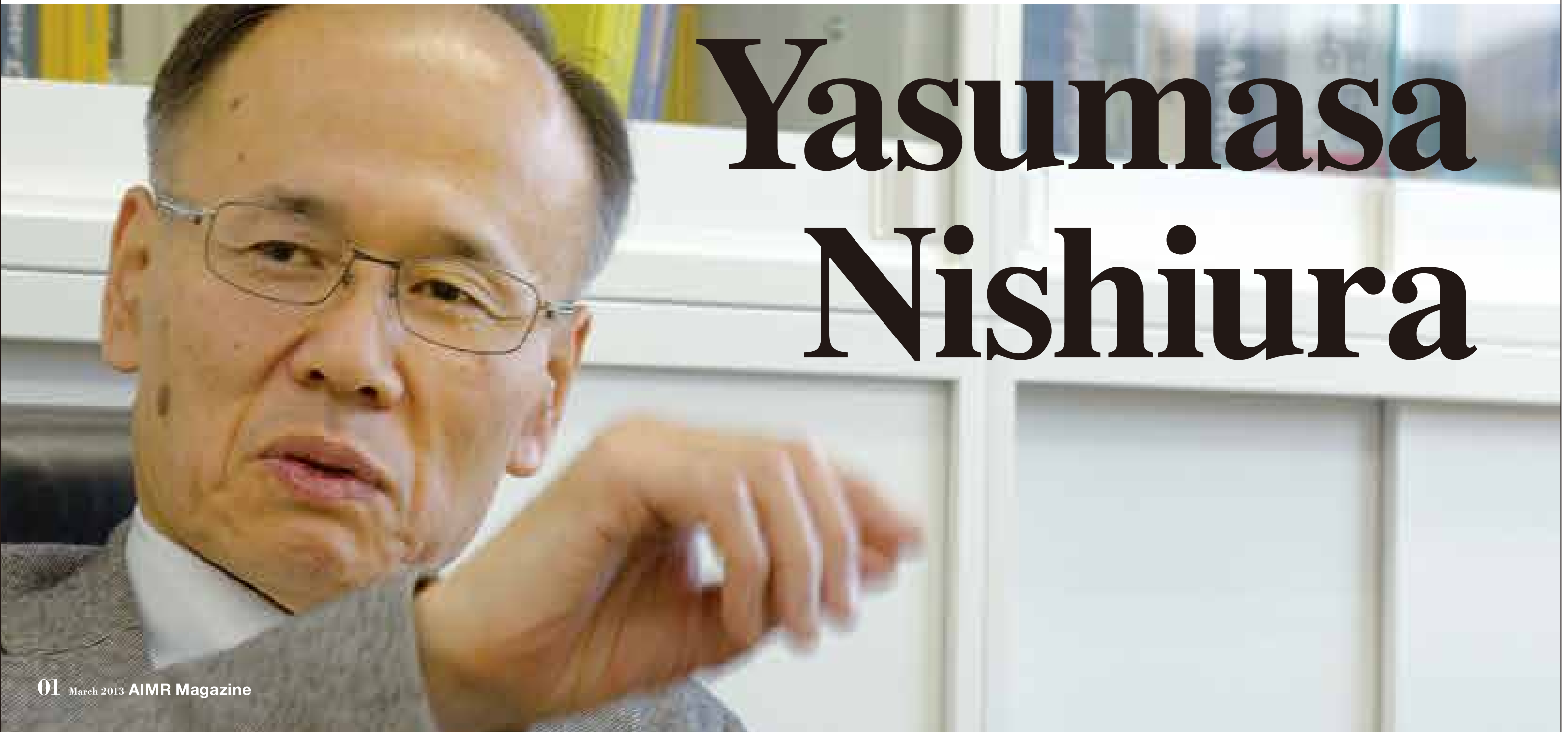
Shigefumi Mori

The Goals of an Endeavor to Lead the World ——

“Collaboration between Mathematics and Materials Science”

AIMR is taking on the challenges of an unprecedented initiative in the world; to apply “mathematical” perspectives to “materials science” to achieve breakthroughs. What is the meaning of the application of mathematics to research processes ranging from carrying out experiments at the microscopic level, to creating materials at the macro level? We found out what this extremely unique collaborative research hoped to achieve, from a mathematician’s perspective.

text by Atsumi Takebayashi, photographs by Yasufumi Nakamichi



Yasumasa Nishiura

The Job of a Mathematician Is to Continue Thinking about Unsolvable Problems

Nishiura: AIMR has set out to collaborate with materials science based on a belief in the possibilities of mathematics. However, a general statement about the possibilities of mathematics says nothing of its specific direction, and to begin with, mathematical researchers are not concerned about applying the results of their research to anything useful. So, what is your opinion of mathematics?

Mori: The way in which mathematics differs from other sciences is the fact that it basically has no restrictions whatsoever. For example, with experiments that require a variety of equipment, the extent of research is determined by the budget, but in mathematics even the most difficult problem can be attacked by a mathematician without being restricted by the size of research fund.

Nishiura: I guess it’s true that the essence of mathematics is such that individuals work on themes that they become interested in, and ponder on it to the limit of their imagination.

Mori: Mathematics is all about thinking, so easily solvable problems are not at all interesting. One of the greatest mathematicians of the 20th century, André Weil, once said that mathematical ideas only come to those who can devote themselves for a long time to research without any ideas. I think genuine mathematics is all about thinking forever about unsolvable problems and why they cannot be solved.

Nishiura: It was for the same reason that I found “pathological examples,” which can’t be understood intuitively, interesting when I first began studying mathematics at university. At first I had difficulty understanding concepts of continuous functions with numerous non-differentiable functions, or Peano curves covering planes. But for some reason I found it interesting. Perhaps it’s because it is related to the wonders of things like recurrence and infinity.

Mori: Continuity is a difficult concept to understand so they avoid it at high school, and they don’t even teach it actively at university.

Nishiura: But pursuing a knotty concept without giving up makes you realize the fun of building your ideas through logic. Problems in mathematics are often based on the question, “What is…?” Alan Turing pursued the question, “What is thinking?” and arrived at his concept of the Turing machine.

Mori: When I come across a problem I can’t solve, I ask myself why, and I invariably end up investigating “What is … ?” That’s what I find so interesting about mathematics, and it’s the reason behind the deepening of your thoughts. In algebra, too, a second-degree equation is easy to solve, but it becomes difficult to solve as you raise the degree. That’s what gave birth to Galois theory.

Interfaces for Carrying Out Collaborative Research

Nishiura: When we come across something we don’t understand, we ask ourselves, “What is … ?” and logically delve deeper into the problem. That, I believe, is one of the roles of mathematicians. We may meander in our thoughts, but we will ultimately come up with proof based on a clearly defined framework. We hope to stimulate discussions from new perspectives by examining the results of materials science research within a mathematical framework.

Mori: Creating a mathematical model from experimental results, then putting it into practical use through numerical simulation is a relatively easy-to-understand process. But there are instances of the results of pure mathematics such as Riemannian geometry and Fourier transform being implemented in cutting-edge science in unimaginable ways. During the course of such research, mathematicians don’t give a moment of thought to how their research can be put to practical use. But they are applicable to the real world because everything has been thought out thoroughly. What you’re trying to do is to bridge the gap between these two extremes.

Nishiura: That’s right. I want to make use of the power of mathematics in the process of ascertaining the appropriate framework for physical or chemical phenomena.

Mori: You want to make use of mathematics to bring together the different fields of materials science. I can understand this idea, but to put it into practice is by no means an easy task.

Nishiura: That’s the problem. Mathematicians have difficulty even communicating with physicists or chemists. The doctrines are built on backbones of fundamentally different cultures.

Mori: Despite mathematics being a scientific subject, it’s a little different from pure science.

Nishiura: As far as experimental scientists are concerned, when mathematicians start talking about some obscure concept, it’s like, “Woah, wait a minute!” (laughs).

Mori: I believe the key to AIMR’s success lies in closing this gap.

Nishiura: For that reason, we appointed people who can bring mathematics and physics or chemistry together. As mediators, they will act as interfaces between the different disciplines. They are researchers who have worked mainly in the field of research, with experience in materials and a backbone in physics and chemistry.

Mori: Should such mediators ideally have mathematical backgrounds, or experimental backgrounds?

Nishiura: I don’t think there is that much of a difference, but if anything, it may be more interesting to assign a person who has devoted himself to abstract ideas in pure mathematics to a materials-type laboratory. I would tell them that they don’t have to do anything to begin with, except be at the laboratory just to listen to everyone. Needless to say, we would have to set up a work environment to ensure that their imaginations don’t simply wander off on a complete tangent.

Mori: Will this eventually prompt some kind of fusion reaction?

Nishiura: It will prompt some really interesting reactions. A person who had sat in the corner of the room observing will suddenly utter something after about six months to a year. And it will offer unimaginable insights to the people who had been concentrating on their experiments.

Mori: You have also been involved in a similar initiative with CREST’s “Alliance for Breakthrough between Mathematics and Sciences.”

Nishiura: If I were to make use of that experience, I think the best thing would be to let them run free to begin with. Even when you tell them that all they have to do is “listen to others talking,” they want to join in the conversation and grasp an understanding.

Mori: So it’s the desire to participate which motivates the mathematicians into thinking? Watching experiments and thinking about them from a mathematician’s perspective results in crazy ideas leading to a fusion reaction. But having said that, letting a young mathematician run free for a whole year requires the understanding of superiors.

Nishiura: That’s why a mathematician (Motoko Kotani) was appointed as Director. It’s been around a year and a half since the new system was launched, but a new trend has been emerging in which both experimenters and theoreticians are joining forces to think together.

Mori: I can vaguely understand the mechanism of how mathematicians will be inspired into thinking while working alongside experimenters and watching their experiments. Experiments are not based on abstract ideas, but the results can be confirmed visually, which I think is inspiring to mathematicians.

Reaping the Benefits after 10 to 15 Years of Fermentation

Nishiura: What I need to watch out for right now is not to demand immediate results. If I were to aim for the achievement of results only, it is pointless recruiting mathematicians. The work could also be carried out outside AIMR. Mathematics has become so specialized and thoroughly subdivided, and I want to investigate how it can be put to practical use.

Mori: At a level where results are not so easily achieved?

Nishiura: I don't seek to achieve results on the level of simply writing joint papers. I want people to change their way of thinking by spending a few years at AIMR. I want young people who gain experience here to look back in 10 or 15 years' time and feel glad that they spent time at AIMR, then to spread what they gained through that experience to others. That's the kind of thing I dream about.

Mori: It's a great dream. By the way, I think mutual trust is key to the successful collaboration between researchers of different fields. What then concerns me is the fact that a lot of mathematicians tend to be like lone wolves, who think only inside their own heads. They pass each other in the corridor, and simply greeting each other in a normal way is considered strange (laughs).

Nishiura: It's a fact that it's easier to hold discussions with people with good communication skills, but breakthroughs are sometimes achieved when quiet, inactive people suddenly start talking one day. The question is whether we can wait until then.

Mori: Placing importance on having plenty of time is a basic attitude in mathematical research too. Time is what we place greatest importance on at the Research Institute for Mathematical Sciences too. I believe the reason why more than 400 researchers come to the institute from overseas every year is so that they can find time for their research, and meet other outstanding researchers.

Nishiura: AIMR has established an environment that encourages communication between researchers. We have a free lounge on the fifth floor of the research institute, and a "tea time" is held every Friday, allowing people to engage in casual, friendly talks.

Mori: I'm envious because our research institute has no spare room. I can understand the need for a space in which researchers can socialize in a casual atmosphere. Unfortunately it would be next to impossible for us to achieve (laughs).

Nishiura: I think the important thing is to be able to use extra money in the right way. People these days are too bent on cutting extra spending. I think ideally, mathematical research is something that shouldn't have a time limit placed on it.

Mori: Not setting a deadline is a problem, but being limited by time also forces people to overstrain themselves.

Nishiura: That's why we are working hard to achieve "correct extra spending" at AIMR. We will create a success model, which we want to spread throughout the country. To build mutual trust among researchers it is necessary for the total amount of communication to pass the threshold level.

Mori: Seemingly idle talk is important in achieving this. I can understand that really well.

Expectations for Ways of Applying New Mathematics

Nishiura: We are taking up your precious time, asking you for your involvement in an international advisory board.

Mori: I still don't know exactly how I can provide support (laughs). But I'm interested to see how you will further evolve what you have so far achieved in CREST in finding practical applications for mathematics. I can relate to your philosophy of taking on the challenges of making use of new mathematics.

Nishiura: To us, we find it encouraging above all else to have the initiatives of AIMR recognized as a form of mathematics. Even if it's only silent approval, if we are given recognition by mathematicians throughout the country, it will have a major effect on boosting the motivation of younger researchers. In that respect, it's of great value to win the support of the Research Institute for Mathematical Sciences, which plays a central role in mathematical research in Japan.

Mori: I want to provide support to your endeavors because I consider it to be an indicator of the future potential of pure mathematics. At the research institute we also have researchers in applied mathematics who may eventually take part in specific research.

Nishiura: There is a lot of wisdom in mathematics that can almost be called the treasure of humankind. The fact is that even the classical treasures are not being made full use of. What AIMR hopes to achieve is for mathematics to become firmly established in other fields, and for its latent potential to sprout forth in materials science.

Yasumasa Nishiura (Ph.D.)

Born in Osaka in 1950, he finished the Graduate School of Science, Kyoto University. He was a lecturer at Kyoto Sangyo University, professor at Hiroshima University. He became a professor at the Research Institute for Electronic Science (RIES), Hokkaido University, who served as the Director of RIES (2003-2005). Since 2012, he has been a professor and Principal Investigator at the WPI Advanced Institute for Materials Research (AIMR), Tohoku University.

He is currently the Research Supervisor of the CREST & PRESTO Project "Alliance for Breakthrough between Mathematics and Sciences" (ABMS), JST (Japan Science and Technology Agency). He has been awarded "Mathematical Society of Japan Autumn Prize" in 2002 and "Commendation for Science and Technology of the Ministry of Education, Culture, Sports, Science and Technology(MEXT)" in 2012.

Shigefumi Mori (Ph.D.)

Born in Aichi Prefecture in 1951, he finished the Graduate School of Science, Kyoto University. After he served as a research associate at the university, he became an assistant professor at Harvard University and a lecturer at Nagoya University among others. Since 1990 he has been a professor at Research Institute for Mathematical Sciences(RIMS), Kyoto University, where he has been the Director since 2011. In 1990, he became the third Japanese national to win the Fields Medal for a proof of the existence of minimal models for 3-dimensional algebraic varieties. He has also won a number of other prizes, including "Japan Academy Prize" and "Person of Cultural Merit award".

NEWS & INFORMATION

Akari Takayama awarded the JSPS Ikushi Prize

Akari Takayama (AIMR Takahashi Lab, 3rd year of Doctoral Program in the Graduate School of Science) was awarded the Third (FY2012) JSPS Ikushi Prize, presented by the Japan Society for the Promotion of Science (JSPS).

The JSPS Ikushi Prize was founded upon a grant presented by Emperor Akihito to JSPS, in order to support and encourage young scientists who are working diligently to advance their studies and research amidst a severe economic environment in Japanese society. It is awarded to outstanding doctoral students who can be expected to contribute to the development of academic research in Japan in the future. The awards ceremony was held on 4 March 2013 at The Japan Academy (Ueno, Tokyo).

The AIMR International Symposium 2013 (AMIS2013) convened

AIMR organizes an annual international symposium on materials science every February. This year, the symposium was held at the Sendai International Center from 19 to 21 February 2013, with the theme "Challenge for green materials innovation through the fusion of materials science and mathematics." Renowned researchers from around the world, including Nobel Laureate Professor Ei-ichi Negishi, were invited to the symposium.

In particular, this symposium was made up of many sessions that focused on topology and spin, in relation to functional materials. Please refer to the following website for more details, including details on the contents of lectures.

http://sympo.wpi-aimr.tohoku.ac.jp/symposium2013/

Professor Ohno Elected Fellow of the American Physical Society (APS)

Professor Hideo Ohno, AIMR Principle Investigator (Professor at the Research Institute of Electrical Communication and Director of the Center for Spintronics Integrated Systems) has been elected as a Fellow of the American Physical Society (APS). This honor was conferred on Professor Ohno in recognition of his remarkable leadership and his academic contribution to physics and its application, particularly through his research on the observation of ferromagnetism in magnetically doped III-V semiconductors and their application to spintronics.

INDEX

01 **A Friendly Discussion**
Shigefumi Mori × Yasumasa Nishiura
The Goals of an Endeavor to Lead the World
"Collaboration between Mathematics and Materials Science"

04 **News & Information**

05 **Feature articles**
The Potential of Spintronics Unlocked by Ferromagnetic Semiconductors
Fumihiro Matsukura and Hideo Ohno

08 **Event Report**
- Professor Tanigaki talks about the strange relationship between symmetry and materialproperties
- A study-abroad experience at the Katahira Campus?!
- A one-week experience in advanced materials science

09 **AIMR in the world**
AIMR Joint Center (AJC) at University of Cambridge

12 **Research Highlights**

13 **A short detour**
MATERIALS

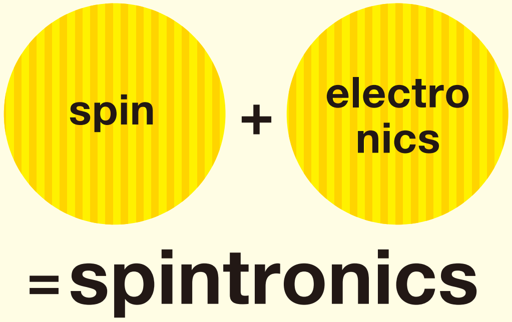
14 **New Staff**
Katherine Orchard

The Potential of Spintronics Unlocked by Ferromagnetic Semiconductors

Advanced Institute for Materials Research,
Tohoku University
Fumihiro Matsukura and Hideo Ohno

Semiconductors are currently used in most electronic products. Indeed, it is no exaggeration to say that our lives are surrounded by semiconductors. Meanwhile, magnetic materials have also been used by humans throughout history, which can be extrapolated from proof that knowledge of magnets existed in ancient Greece. Magnetic materials also play an integral role in modern society as a material used in hard disks and other electronics.

Semiconductors and magnetic materials were the focus of a very different type of research until very recently. In recent years, magnetic semiconductors—materials that possess the properties of both semiconductor and magnetic materials—have gathered more attention, creating expectation as a candidate for leading component and a test bench for concept both in spintronics. This article first offers an overview of spintronics and the positioning of magnetic semiconductors within this field of research. It will then introduce research that uses two key magnetic semiconductors—gallium manganese arsenide (Ga,Mn)As and indium manganese arsenide (In,Mn)As—and explores the potential of spintronics unlocked by magnetic semiconductors.



Electrical conductivity can be used to separate materials into three categories: conductors, semiconductors, and insulators. The archetypal conductor is metal, while materials that do not conduct electricity, such as rubber, are referred to as insulators. The term semiconductor indicates a material with an electrical resistivity value that lies between those of conductors and insulators, possessing both conductive and insulator properties. In other words, semiconductors are able to regulate electrical conductivity, functioning as a switch that blocks and releases electricity as necessary. The use of semiconductors as a material in electronics depends greatly on its natural ability to control electric currents and signals like an on/off switch (or between the extremities of "on" and "off"). Electronic engineering that mainly utilizes this type of semiconductor is collectively referred to as "electronics". Electronics makes use of electrical electron "charges" (electrons have negative charges), which are the basic component of electric currents. Meanwhile, another type of electronics that makes use of "spin", another property of electrons, is referred to as "spin electronics", or "spintronics".

Spin relates to the rotation of electrons. When the spin of a large number of electrons in a material converge in the same direction, magnetic properties (magnetism) appear. Spintronics uses the spin of electrons to produce high-speed, low-power consumption, and high-performance electronic devices, computers and other products that were not possible with conventional electronics.

A look into the history of spintronics research reveals that it started with a discovery in 1967 by Leo Esaki and others. Esaki and his colleagues showed that the properties of the electric current and voltage of elements made from europium chalcogenide*1—a semiconductor with magnetic properties—are controlled by the direction of the electrons' spin. This was the first case anywhere in the world where the charge properties of an electron (electron conduction) were controlled using spin (magnetic properties). This was the starting point of electronics that make use of spin—spintronics.

Magnetic semiconductors

In 1988, Albert Fert and Peter Grünberg discovered that when taking ferromagnetic metal (metal with spontaneous magnetic properties) and metal with no magnetic properties, reducing their thickness into nanometers and then stacking them alternately on one another, the resistance dramatically changes by the application of small external magnetic field. This was the discovery of so-called giant magnetoresistance*2 (GMR). GMR heads, which take advantage of this phenomenon, have allowed for inventions such as high-density hard disks, spreading the significance and potential of spintronics to non-scientific fields. This discovery led Fert and Grünberg to receive the Nobel Prize in Physics in 2007.

In parallel to these developments, research into another type of spintronics, magnetic semiconductors, rapidly advanced. Semiconductors do not generally have magnetic properties. Research at the time, however, aimed to create a material that was a semiconductor while also having magnetic properties. Of the magnetic semiconductors created as a result of this research, a material called the "ferromagnetic semiconductor" shows semiconducting and ferromagnetic properties simultaneously.

Currently, most research in the field of magnetic semiconductors focuses on "dilute magnetic semiconductors" (see Figure 1), which add a small amount of magnetic elements to an existing semiconductor without magnetic properties. The reason lies in the fact that, with respect to dilute magnetic semiconductors, only a substantially small portion of the semiconductor's constituent atoms (several percent)—which are already being used widely—are replaced with magnetic elements, making it easy to incorporate them into transistors and light-emitting device structures, just like existing semiconductors. Moreover, another benefit is that the thickness of many dilute magnetic semiconductors can be controlled on the atom level. The phenomenon observed in multilayer consisting of different thin semiconductors (semiconductor heterostructures) has been applied to a diversity of technologies, such as semiconductor lasers.

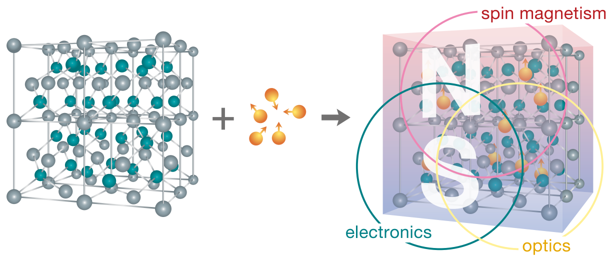


Figure 1: Replacing a portion of the elements that make up a semiconductor with impure ions introduces magnetic spins and carriers to the semiconductor, creating a magnet.

Electron holes: The mechanism behind ferromagnetism

Research on dilute magnetic semiconductors began around 1980. In the 1990s, attention began to gather around ferromagnetic semiconductors such as (In,Mn)As and (Ga,Mn)As that had added manganese to indium arsenide (InAs) or gallium arsenide (GaAs); InAs and GaAs, the so-called, III-V semiconductors, originally played an important role in industry. This was because of their ferromagnetic properties, or, in other words, because they were proven to also function as magnets. If it were possible to maintain the electrical properties of a semiconductor while also utilizing magnetic properties, there was strong potential for creating a new kind of device.

Since the creation of these ferromagnetic dilute magnetic semiconductors, concentrated discussion has taken place on the mechanism behind realizing ferromagnetism. While magnetic elements were added (manganese is not ferromagnetic on its own, but is referred to as "paramagnetic"), the incorporation of a small amount of manganese creates a phenomenon where all materials become ferromagnetic. The following is a description of how we view the mechanism at play.

Manganese is comprised of divalent ions, and when it is replaced with trivalent indium and gallium, the difference in valence causes a positive electric charge. When a quadrivalent ion takes its place it creates a negative electric charge. In other words, one electron is created, but when divalent manganese is replaced, an "electron hole" is created with a positive charge. Furthermore, manganese is an element with magnetic properties, and when indium arsenide or gallium arsenide is mixed with it, it creates spin. It is difficult to generate ferromagnetism with this small amount of spin alone; however, the interaction between the spin and electron holes makes the spin of the materials align and thus become ferromagnetic. The magnetic strength depends on the concentration of the holes, so by increasing the holes it is possible to enhance the magnetic properties. It can be said that the true appeal of dilute magnetic semiconductors is the magnetic property generated by electron holes.

Using the electric field to change magnetic properties

All ferromagnetic materials lose their magnetic properties and become paramagnetic after exceeding a certain temperature (Curie temperature). This is because thermal fluctuation forces the spin out of alignment. In other words, ferromagnetic materials generally shift (phase transition) between ferromagnetic and paramagnetic states as a result of temperature changes. In contrast, it is understood that for ferromagnetic semiconductors, the ferromagnetic properties are produced by electron holes, and if the amount of holes can be regulated—not the temperature—phase transitions are envisaged to occur between ferromagnetic and paramagnetic states. In order to change the amount of holes, one can fabricate devices (field-effect transistors (FET)) using ferromagnetic semiconductors and apply an electric field to the FET. The higher the negative voltage applied to the FET, the more holes it is possible to create. In 2000, we fabricated FET using indium manganese arsenide (In,Mn)As and verified that it was possible to regulate phase transition between ferromagnetic and paramagnetic states by applying electric field (See Figure 2). During the experiment the change in Curie temperature remained only around 2 degrees centigrade. We later confirmed for gallium manganese arsenide (Ga,Mn)As as well that it is possible to regulate magnetic properties by controlling the amount of holes using the electric field effect. It is also demonstrated that (Ga,Mn)As makes it possible to electrically control the direction of magnetization.

Hard disks and other magnetic recording devices record the direction of magnetization as either 0 or 1 when saving data. If it is possible to control the direction of magnetization without using an external magnetic field or electric current, it can be expected that this science will lead to applications for low power consumption memory. The results from a series of experiments where the magnetized direction was electrically controlled are gathering significant attention, and currently research is even underway on experimentally monitoring switches in magnetized direction using voltage.

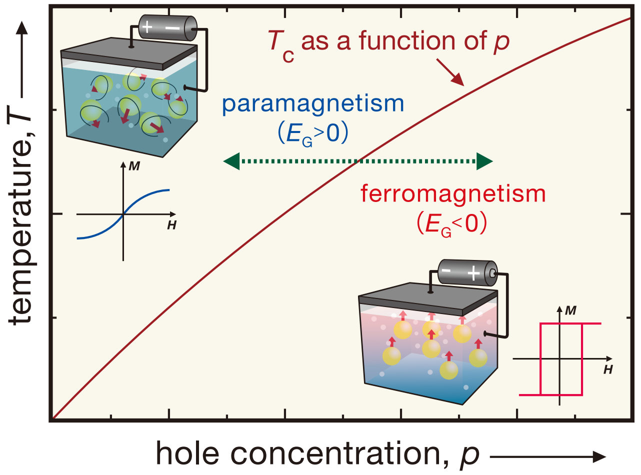


Figure 2: The Curie temperature of ferromagnetic semiconductors rises in correlation with increases in hole concentration. By changing hole concentration using electric fields, it is possible to incite a phase transition without changing the temperature.

Spintronics using ferromagnetic semiconductors

At present, the Curie temperature of ferromagnetic semiconductors is below room temperature and there has yet to be a successful attempt at realizing ferromagnetic semiconductors at room temperature. Achieving this is a vital step in applying ferromagnetic semiconductors to commercial products, which requires further research efforts.

However, ferromagnetic semiconductors have already made a great contribution with respect to new findings about physical phenomena related to spin, the proposal of new spintronic devices, and the operational testing of those devices. In addition to the phenomenon of changing magnetic properties due to the application of electric field (change in the number of electron holes) as introduced in this article, research continues to present numerous other fascinating phenomena. One example is the displacement of the boundary of magnetic domain (magnetic domain wall) that occurs with the application of an electrical current. The achievements of this type of research into ferromagnetic semiconductors have been used in research and development of ferromagnetic metal devices that operate at room temperature, and have surpassed material differences to create a ripple effect in many other fields of study. Of course, the research aimed at realizing ferromagnetic semiconductors at room temperature introduced in this article continues. In the future when a ferromagnetic semiconductor is created that works at above room temperature, the findings accumulated hitherto will instantaneously gain tremendous significance. The vast potential presented by ferromagnetic semiconductors continues to engender great interest from the perspectives of both basic and applied research.

*1: Eu chalcogenide
A chalcogen (oxygen, sulfur, selenium, tellurium) compound of europium.
*2: Giant magnetoresistance (GMR)
The magnetoresistance effect of normal metals is no more than a few percent; however, some multi-layer membranes that stack ferromagnetic film with non-magnetic film produce a magnetoresistance effect of several dozen percent. This type of phenomenon is referred to as giant magnetoresistance.

Fumihiro Matsukura(Ph.D.)

Born in Hokkaido in 1966. Matsukura graduated from Hokkaido University's Faculty of Science before becoming an assistant and then associate professor at the Research Institute of Electrical Communication at Tohoku University. After serving as a visiting researcher on the Institute of Physics, Polish Academy of Sciences, in 2012 Matsukura became a professor at the Advanced Institute for Materials Research, Tohoku University (AIMR). His area of specialty is semiconductor spintronics.

Hideo Ohno(Ph.D.)

Born in Tokyo in 1954. Ohno graduated from Tokyo University's Faculty of Engineering before working as an instructor and associate professor at Hokkaido University. After serving as a visiting researcher at IBM's Thomas J. Watson Research Center, Ohno in 1994 moved to Tohoku University's Faculty of Engineering as a professor. Since 1995, he has served as a processor at the Research Institute of Electrical Communication, Tohoku University. In 2010, Ohno became Director of the Center for Spintonics Integrated Systems and in 2012 became a principal investigator at the Advanced Institute for Materials Research, Tohoku University (AIMR). He is a recipient of the illustrious Japan Academy Prize and is a Thomson Reuters Citation Laureate.

AIMR
EVENT REPORT

Professor Tanigaki talks about the intriguing relationship between symmetry and material properties

"The properties of materials are greatly affected by the structure of the materials. In particular, significant changes are observed when the symmetry collapses," explained Professor Tanigaki enthusiastically to approximately 600 participants as he raised various examples to illustrate his point. This talk was one of the sessions at the WPI 6 Institutes Joint Symposium, which is held annually at a WPI research center for the public (hosted by the International Center for Materials Nanoarchitectronics (MANA), 24 November 2012, Tsukuba City, Ibaraki Prefecture) titled "Inspiring Insights into Pioneering Scientific Research". At the symposium, six researchers from each of the WPI research centers introduced research based on various themes, such as materials, energy, life, and space. Professor Tanigaki, representing AIMR, spoke about designing materials with mathematics and geometry.

Participants listened with keen interest to his explanations about how the phenomena of superconductivity and thermoelectric conversion is related to symmetry. An exhibition of materials was also held in conjunction with the talk, at an exhibition booth set up at the side of the main hall. Here, visitors were able to see a superconductor called C60 fullerene, which has the same structure as that of a soccer ball, as well as a superhydrophobic material that resembles the structure of rose petals. At the end of his talk, Professor Tanigaki turned up at the booth and received many questions from the senior high school students. This event successfully gave participants a taste of the interesting world of materials. The next WPI Joint Symposium is scheduled for 14 December 2013, at Sendai City.

A study-abroad experience at the Katahira Campus?!

On 17 October last year, an international exchange program, involving seven international researchers from AIMR and 27 senior high school students, was held at the AIMR Main Building on Tohoku University's Katahira Campus. This program comprised a lecture on probability and molecules, given by AIMR Assistant Professor Packwood, and an interview of the researchers held in small groups. The entire event was held only in English, with no interpretation, so that students could experience the academic life at AIMR, where English is the official language.

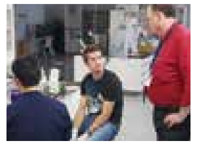
This program may appear to be somewhat difficult for senior high school students. Although the participating students also had expressed their worries about the English lecture, with the numerous technical terms that would be thrown at them at high speed, Assistant Professor Packwood gave his explanations in careful and easy-to-understand English. Thanks to his efforts, students commented that they were "surprised that probability plays an important role in the molecular world," and that they had "gained a good understanding of the processes that researchers go through in conducting their research." After the lecture, students were also active in raising questions about the contents of the lecture.

The group interview with the international researchers proved to be difficult indeed. There were times when students fell completely silent because they did not know how to express themselves in English. They admitted that they felt the need to learn more English, and the need to improve their vocabulary skills since there were many words that they did not understand. Upon hearing these comments, the teacher leading the group of students (Nishizawa-sensei) said, "Now that they have attempted to speak in English, they have probably felt, for the first time, that their English skills are not applicable to practical use. By overcoming this hurdle, they can also turn it into your motivation to study English in the future."

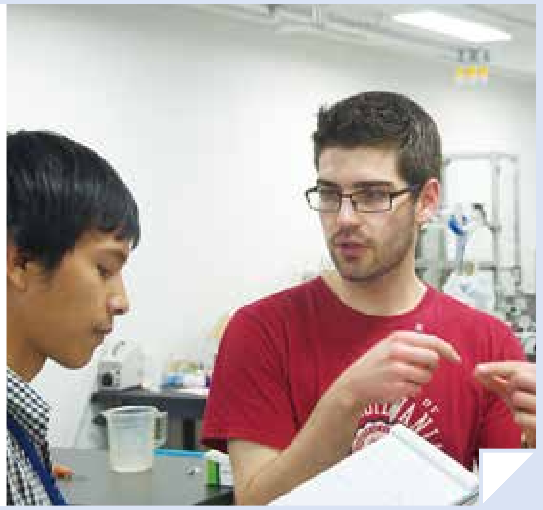
A one-week experience in advanced materials science

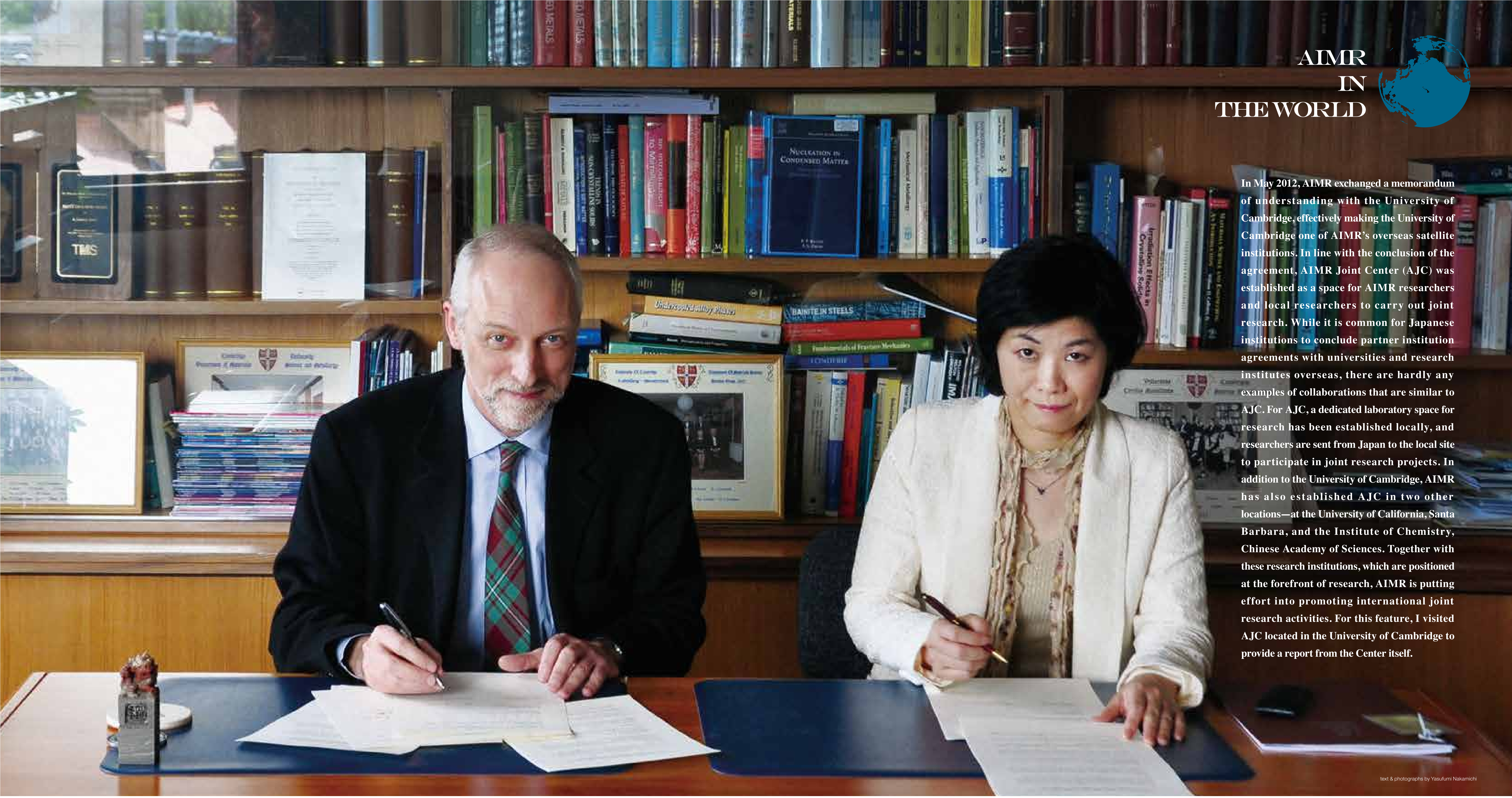
A summer school targeted at students in graduate schools was held for the first time at AIMR from 23 to 29 July 2012. There were about 200 applications from around the world, and 30 graduate students from 13 countries were selected from among all the applicants. These students attended lectures given by AIMR Principal Investigators, and participated in practical work in the laboratories of their choice. Their research work covered advanced research fields such as physics, materials science, and device engineering.

At the conclusion of the summer school, participants gave the following feedback: "I was impressed by the wonderful research equipment and environment in research laboratories in Japan;" "Through the practical work, I was able to gain a deeper insight into my field of specialization;" "It was very stimulating and exciting to be able to interact with students from around the world who are striving to become researchers in the same field of research." Not only did students gain a deeper insight into materials science, they also appeared to have enjoyed the interaction with renowned materials science researchers from AIMR, and with students from around the world who aspire to become researchers in similar fields of research. The AIMR researchers who had given lectures at the summer school were also stimulated by the discussions with the motivated students. This summer school had thus been a meaningful experience for all participants.



A detailed report is available on our website,
at the following link.
http://research.wpi-aimr.tohoku.ac.jp/jpn/spotlight/701



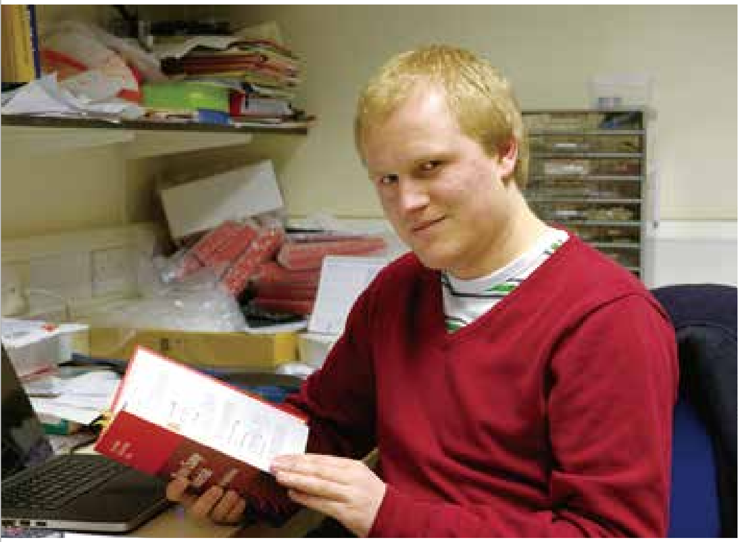


In May 2012, AIMR exchanged a memorandum of understanding with the University of Cambridge, effectively making the University of Cambridge one of AIMR's overseas satellite institutions. In line with the conclusion of the agreement, AIMR Joint Center (AJC) was established as a space for AIMR researchers and local researchers to carry out joint research. While it is common for Japanese institutions to conclude partner institution agreements with universities and research institutes overseas, there are hardly any examples of collaborations that are similar to AJC. For AJC, a dedicated laboratory space for research has been established locally, and researchers are sent from Japan to the local site to participate in joint research projects. In addition to the University of Cambridge, AIMR has also established AJC in two other locations—at the University of California, Santa Barbara, and the Institute of Chemistry, Chinese Academy of Sciences. Together with these research institutions, which are positioned at the forefront of research, AIMR is putting effort into promoting international joint research activities. For this feature, I visited AJC located in the University of Cambridge to provide a report from the Center itself.

text & photographs by Yasufumi Nakamichi

AIMR Joint Center at University of Cambridge

AIMR Joint Center at University of Cambridge



It was a cloudy day in December 2012. I had come to the University of Cambridge to meet AIMR Principal Investigator and head of the Department of Materials Science and Metallurgy, Professor Alan Lindsay Greer, and AIMR Research Associate, Dr. Jiri Orava. The University of Cambridge is constantly ranked among the top universities in the world, and has produced numerous renowned graduates. As we sat in fellows room in Sidney Sussex College, which Professor Greer is affiliated to, he turned to me and said, “The chair that you are seating on is a replica of the chair used by a graduate of the University of Cambridge. Do you know him? His name is Isaac Newton.”

The University of Cambridge, which boasts a long history, is situated all around the Cambridge city, approximately one hour north of London by train. When I visited AJC, I found that the city was not so big that I could walk around. The University’s buildings could be spotted in literally every nook and cranny of the city, creating the impression that the entire city was made up of the University itself. The research building of the Department of Materials Science and Metallurgy, where AJC is housed, is positioned close to the center of Cambridge. Here, researcher Dr. Orava is currently engaged in a joint research project that AIMR and the University of Cambridge had been working on. To conduct experiments for the project, which is based on studying glasses, he travels between Sendai and Cambridge.

He greeted me with a warm smile when I arrived at AJC. Since our last encounter at Sendai in November 2012, I had not met him for about a month. After exchanging greetings, I turned promptly to questions about the research project that he is currently working on.

Standing in front of the experimental facility, he explained, “We are currently studying structure and properties of new phase-change materials.”

Phase-change materials are materials that are used, for example, in recording media such as CD-RW or Blu-ray™. They are alloys based on chalcogenides, which can reversibly switch between a state with a regularly lined up structure (crystalline phase), and one with an irregularly arranged structure (amorphous phase). If a strong laser is applied to the materials, it enables data recording by changing from a crystalline to an amorphous phase. Conversely, to erase the data, weak laser is applied to change its phase from amorphous to crystalline.

Dr. Orava explained enthusiastically, “Much research is being conducted on phase-change materials with the aim of applying it to computer memory such as random-access memory or for portable devices. If this were achieved, it would be possible to create high-speed computer memory with a large capacity without expending high levels of energy. Moreover the material under study allows multi-level data recording and has promising potential for cognitive switching applications. However, we still do not have a clear idea about the conditions and the mechanisms under which this material changes between the crystalline and amorphous phases. It is our goal to discover these facts and develop the memory of the future.” I had seen him singing karaoke in Sendai and witnessed his playful side, but when it came to research, he spoke continuously and interestingly, and with great passion.

Prior to the establishment of AJC, a research group led by Professor Louzguine (AIMR) and Professor Greer (Cambridge) had already been active in the study of metallic glasses at AIMR. Now, Dr. Orava plays the important role of bridging AIMR and Cambridge through AJC, which was established with the aim of accelerating the research process. At the end of the visit, he sent me off with the following words, “It is my great honor to be able to participate in this project as a researcher of AJC. It is my hope to continue developing new materials that can support our future, through joint research between AIMR and Cambridge.”

Research Highlights *from* AIMResearch

AIMResearch is an online and print publication highlighting the scientific achievements and activities of top researchers of the Advanced Institute for Materials Research (AIMR), Tohoku University. Here we introduce abbreviated articles from the latest AIMResearch. The full articles are available on the AIMResearch website:

http://research.wpi-aimr.tohoku.ac.jp

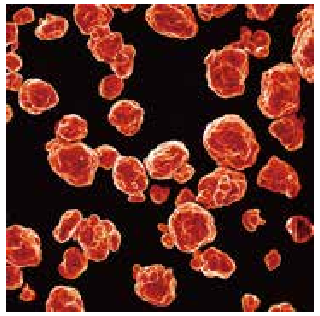
Bulk metallic glasses

1

Taking the color out of polluting dyes

Scientific Reports **2**, 418 (2012)

Dye molecules that contaminate effluent streams can be efficiently degraded by metallic glass powders



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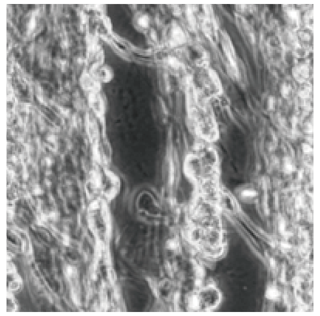
Tissue engineering

2

A scaffold for longer-lasting cells

Lab on a Chip **12**, 2959 (2012)

A semi-natural hydrogel scaffold serves to create highly complex artificial tissues with long-term cell viability



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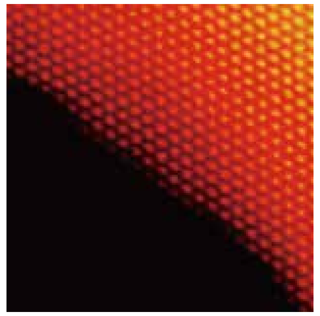
Catalysis

3

A kink in the golden rules

Nature Materials **11**, 775 (2012)

High-resolution imaging of nanoporous gold reveals that ‘kinked’ surface defects are responsible for its high catalytic activity in carbon monoxide oxidation



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Lab-on-a-chip

4

Electrochemical imaging

Angewandte Chemie International Edition **51**, 6648 (2012)

A high-density electrochemical device has been developed to monitor and image stem cells in three-dimensional embryoid bodies

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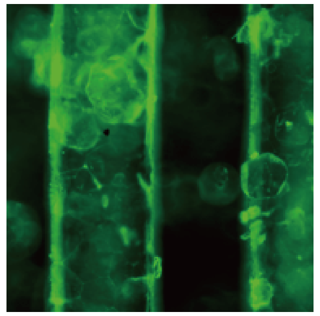
Biomaterials

5

Stimulating patterns

Advanced Functional Materials **22**, 3799 (2012)

Microscopic patterns made of tiny drug-filled polymer spheres stimulate stem cell growth and differentiation for bone tissue repair



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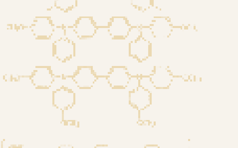
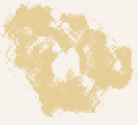
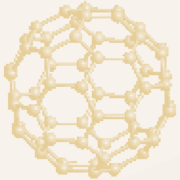
Column



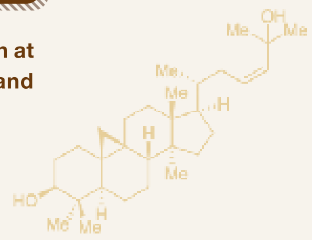


A short detour

MATERIALS



This corner contains essays that cover topics relating to materials science research at AIMR, including fundamental facts, history, research trends around the world, and advanced research at AIMR.



＊Part 1＊

Is Materials Science a Treasure Hunt?

Materials science is not a subject that we study at elementary, junior, or senior high school. It is only in university or technical college that faculties and majors with the title “materials” first appear. However, if we were to look at our society, we would find that a large number of materials manufacturers are providing support for our daily lives. It would then seem somewhat unnatural that we never come across the term “materials science” until we leave senior high school. In a sense, this is inevitable because materials science is an integrated research field that connects a diverse range of subjects from its fundamentals, to its application. These subjects include science, engineering, pharmaceutical science, environmental science, information science, and so on. It is therefore difficult to represent it as a single academic discipline. I have often been asked this question by senior high school students who come to visit the university on open campus day, “Which faculty should I enroll in if I wish to work in the materials field in future?” In response to this question, I recommend that they enter the materials science faculty (e.g. the Department of Metallurgy, Materials Science, and Materials Processing at Tohoku University) when it is clear that they wish to pursue the field of materials. For senior high school students who are interested in biology or earth science, for instance, I sometimes advise them to first study biology or earth science at the undergraduate level, and then take up materials research in the future. I am, myself, a graduate of the faculty of earth sciences for my undergraduate degree.

Human beings have created civilization by developing stoneware, earthenware, copperware, bronze ware, ironware, and other tools that are necessary for the sustenance of life. The history of these tools is also the history of the development of materials such as stone, china, copper, bronze, and iron. While human beings had already possessed a metallic material—bronze, they turned toward iron even though it had a higher melting point and was more difficult to refine and cast. It is believed that they did so because iron was much stronger than bronze, and would therefore improve agricultural efficiency, and be useful as a weapon. This “strength” that is required for agricultural tools and weapons is one of the “functions” of materials. We constantly seek useful functions in materials.

Bronze, described above, is an alloy of copper and tin. Although there are materials that we use in their natural state, in many cases, we process these materials to achieve our desired materials. These processes include mixing and melting two or more substances in various proportions, crystallizing substances, or allowing them to cool rapidly to become glassy state. A particularly interesting aspect of materials science is the fact that we can mix the approximately 90 elements that stably exist on Earth in an infinite number of combinations. It is also interesting that the properties of the resulting materials differ based on the pressure or the temperature. This means that there are still many materials that we do not yet know about. The study of materials science is just like a treasure hunt, and it is this sense of hunting for treasure that gives this field of research its real thrill.

However, in our modern society where materials science is required to provide materials that can respond to pressing energy and environmental problems, it is a fact that we do not have the time to enjoy that treasure hunt in a leisurely manner. By building up and expanding on the information and research results that we have achieved thus far, we have to design and create new materials that possess functions which are useful for resolving energy and environmental problems instead of just searching them haphazardly. AIMR is putting this into practice by incorporating mathematics into the field of materials science, since mathematics is able to extract the universal principles that all phenomena is founded upon. In this way, AIMR aims to create a new type of materials science. For more details about the tie-up between mathematics and materials science, please refer to the interview at the beginning of the magazine.

Starting from the next issue, we will turn the spotlight on specific materials science topics. We hope you will enjoy these articles.

Susumu Ikeda

Born in Saitama in 1967. Ikeda graduated from Tohoku University’s Faculty of Science in 1990. After working at a cement company, he received his Ph.D. degree from the Graduate School of Science, the University of Tokyo. He became an Assistant Professor at the Graduate School of Frontier Sciences at the same university, and then moved on to become an Assistant Professor at AIMR. In 2010, he was appointed Associate Professor, and in 2011, took on a second position as the Deputy Administrative Director (for Research).

Katherine Orchard

Believing in the potential of “thinking out of the box”

“Developing a technology to be market-ready is a huge undertaking, and the pace and focus required of the research is very different to that of fundamental materials study and design. While I learned a great deal and I am very proud of the achievements of the company during my time in industry, I wished to have greater creative freedom over the research questions that I could choose to address, and return to a more academic approach to materials discovery.”

So says Dr. Katherine Orchard in response to a question on her return to the academic world. Originally engaged in a research position at a major chemical company, made the transition to academia when she joined AIMR as a researcher last December.

Currently involved in a collaboration project between AIMR and the University of Cambridge, she has begun a busy life of constant travels between Sendai and the U.K. Her schedule puts her in Sendai from January to February 2013, but this is in fact her first stay in Japan. Has she experienced any anxiety?

“My main impression of AIMR is that it is an institute that highly values open discussion and collaboration between research groups and across research disciplines. I have already met many interesting people and learned a great deal about the research being carried out here. All members of the staff are working very hard to establish a global reputation for AIMR and, as a member of a new satellite center, they have done a great deal to make sure my needs are met. I have been made to feel very welcome here.”

Katherine Orchard leads an active life even away from her research work. For the past five years, she has been a player in her local women’s rugby team. She tells us, “If I have the time, I would like to go hiking. I also love to travel, and I hope that I will be able to see a great deal of Japan during my time with AIMR (and beyond!).”

Katherine Orchard
AIMR Research Associate

Katherine Orchard holds a master’s degree from the University of Cambridge and a doctoral degree from Imperial College London. After the completion of her studies, she worked as a researcher at Nanoco Technologies Ltd. before taking up her current position at AIMR.

text & photograph by Yasufumi Nakamichi