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World Premier International Research Center Initiative

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[Special Interview]

from SENDAI *to* the WORLD

Shigemi Mizukami

Professor, Advanced Institute for Materials Research (AIMR), Tohoku University

[Feature article]

How to Make Zigzag Graphene Nanoribbons

Aiming for the Practical Application of the Electronics Material Graphene in the Future

[AIMR in the world]

Tomasz Dietl

Background of the paper with 5,000 citations

Research and creativity

"When I was a child, I already counted everything, and my parents had apparently believed that I would become a mathematician." However, when he was 12, he began to study physics at school. His consuming interest in the subject led him to finish reading his first physics textbook over two nights. "It was at this time that I decided to become a physicist in future." Although he decided early on to become a physicist, he did not really embark on a systematic study of physics, but rather, read many popular books on science. Professor Dietl said, laughing, "I did nothing but read, and did not really study hard. As a result, I didn't have very systematic knowledge which was beyond high school level. However, reading many books about different subjects helped to nurture my sense of creativity. That creativity will always be of great use to me in my research work." To illustrate this point, he then related the following story:
"Many of the students in my high school class aspired to be researchers or scientists. In fact, there are as many as 12 classmates who became researchers at universities just like myself. I think I was in a privileged class. One of the students in that class participated in the International Physics Olympiad while we were at school, and won. He truly became the best student in physics. The interesting thing was that despite his excellent results, he did not do a PhD degree. Although many of our classmates became professors, he quickly began to work in the software industry. He was good at solving clearly defined problems, such as software-related issues. He was extremely efficient at the work of solving well-defined problems, such as in the physics Olympics, but was probably not creative enough that would have enabled him to carry out his own research." With another laugh, Professor Dietl then said that this classmate achieved success in running a software company, and now earned a very high salary.

Expressing complicated phenomenon beautifully using theory

Professor Dietl had been interested in physics and astronomy when he first entered university, but gradually began to develop an interest in materials science. "The properties of materials are very complex, and it looks as if it is impossible to describe them theoretically, but now we can actually explain these complex behaviors of face transitions, or different phases, or different properties like electromagnetic, very nicely." In theoretical physics, it is possible to give simple and beautiful expression to complicated phenomena. Professor Dietl felt the appeal of being able to do that. Nevertheless, the term "theoretical physics" covers a very wide scope, and pursuing studies even in the area of high energy physics, for example, can be an option. "The research of high energy physics is often carried out on a large scale, in groups of a few thousand people, and each individual would be a small element of big machinery. Of course, that is also meaningful in its own way. On the other hand, in materials science, we have our own research laboratories and tackle a single problem individually. We become the master of that problem. Rather than being a part of a large story that can build a theory for solving that problem, we are able to control the whole story ourselves. I was facilitated by this aspect of materials science."
This was how Professor Dietl became a researcher in the field of materials science. He has produced numerous achievements in the field of spintronics, particularly in the area of magnetic semiconductors, including the aforementioned paper. He offered the following explanation for his own motivation to conduct research: "Spintronics is not only about the properties of the charge of an electron, but aims to apply spin properties to electronics. If we can put spintronics technology to practical use, it may be possible to build high-speed devices that consume an extremely low amount of electricity. Hence, the desire to create something that would be useful to society has become a major source of motivation for research." However, Professor Dietl stressed that this was not the only motivation driving his research work. "The physics that forms the foundation for this research is very interesting, and can lead to the discovery of many interesting phenomena. The theories that provide the explanations for these phenomena are actually based on simple assumptions. The ability to understand complex phenomena using a small number of parameters, a small number of theories, and simple yet natural assumptions, is a fantastic thing for a physicist."

Preparation for receiving discoveries

Even after returning to Poland in 2000 after the end of his stay at Tohoku University, Professor Dietl participated in many projects led by Professor Ohno, maintaining their cooperative relationship and even visiting Japan several times. In 2012, he took on the position of Principal Investigator at AIMR alongside with Professor Ohno. Even today, he stays at AIMR for at least one month every year to conduct research.
"I am very proud and honored to be a part of AIMR," said Professor Dietl. In the collaborative research that he has been involved in so far, he has been particularly inspired by the motivated attitude of young Japanese researchers. "They are hardworking and efficient, and fast at their work. For something that they have been told to do today, they complete it by the next day, or even within the same day. After a discussion, they are sure to take measurements and perform calculations; you will receive figures that you expect to receive next week on the same night or the next day. They are highly motivated, and work in a speedy and efficient manner. This was certainly extremely advantageous. I produced many excellent papers together with these researchers. Compared to young researchers in other countries, the efficiency of young researchers in Japan is without question a significant advantage to Japan."
He also spoke about the appeal of AIMR. "The world-class research facility of AIMR has two important aspects. The first is that it offers cutting-edge science, and even realizes the creation of a new form of science. Not only does it excel in certain sciences, it also stays on the forefront of science and takes up the challenge of an entirely new form of scientific research. I am confident that this new academic field, which involves collaboration between mathematics and materials science, will in time become renowned around the world as a research field that began at a World Premier International Research Center (WPI)." The second point, he pointed out, is that AIMR is revolutionizing Japan's research system. "At AIMR, foreign researchers, including myself, make up a large proportion of the research system. They engage in a horizontal form of exchange while involving Japanese researchers, and are thereby producing something that is not present in the conventional Japanese system, which has a vertical hierarchical structure." He emphasized that this was not the result of chance or coincidence, but had been realized in a planned manner. "The system was conceived with the aim of generating research results through exchange, by promoting integration through activities such as parties for researchers, as well as promoting horizontal cooperation between teams. AIMR's research system breaks down Japan's traditional vertical relationships, and creates a horizontal spread in its place. In this way, it will produce fruitful outcomes."
AIMR brings together world-class researchers in various fields related to materials science, and creates horizontal relationships that go beyond the boundaries of academic fields. In this way, it aims to produce a breakthrough in the field of materials science. The final question for Professor Dietl was if he thought that AIMR's initiatives fulfilled the criteria for producing a breakthrough. He answered, "It is difficult to define the necessary criteria. This is because it often comes to us unexpectedly. However, major discoveries, which can bring about changes to society, only visit the places that are prepared to receive them."

Tomasz DIETL

Born in Poland in 1950. Professor Dietl received his doctoral degree from the Polish Academy of Sciences. After serving as Research Associate at the same Academy, he went on to become a researcher at Technische Universität München, followed by other research positions. He was appointed Professor at the Polish Academy of Sciences in 1990. Since 2012, he has served concurrently as Principal Investigator at AIMR.

EVENT REPORT

The 6th AIMR-SSH International Exchange Program Held

The 6th International Exchange Program between AIMR and SSH (Super Science High Schools) was held at Sendai Daisan High School on 15 November (Saturday). 16 foreign students and 45 high school students participated in the event.
The event was moderated in English by a high school representative, commencing with a welcome greeting to the foreign students and an overview of the program. After that, the participants were divided into 16 groups with one foreign student in each group, and the exchange program began with enthusiastic discussions on various topics, such as the foreign students' home countries, why they had come to Japan, and the research work they were involved in at Tohoku University. At the end of the exchange, the foreign students gave their impressions: "The conversations were more enjoyable than when they were held at the university, perhaps because the event was held at a venue that the high school students were accustomed to;" "I was impressed with the high school facilities, which are wonderful in comparison to what we have in my home country."

AIMR Booth at the 4th WPI Joint Symposium

The 4th World Premier International Research Center Initiative (WPI) Joint Symposium was held on 13 December (Saturday) at Yurakucho Asahi Hall in Tokyo. This symposium, organized and held jointly by the nine WPI centers every year since 2011, is mainly targeted at high school students, and aims to communicate information about cutting-edge science and its appeal to these students. This year, the event was hosted by the University of Tokyo's Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU). Lectures were delivered by Director Hitoshi Murayama, as well as researchers from Kyoto University and Kyushu University. In addition, young researchers representing the nine WPI centers were also present at the event to convey the interesting aspects of research directly to the participants. The AIMR booth provided an introduction to the center, and featured a poster presentation by Assistant Professor Daniel Packwood on research involving the use of probability theory.

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.

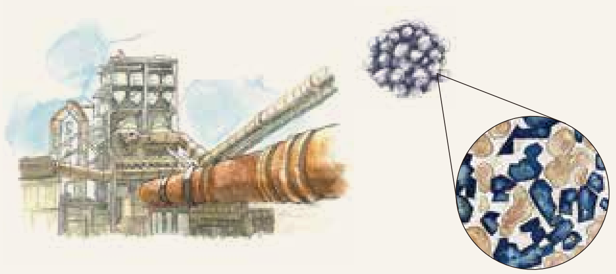
Part 6 Talking About Cement

Although it isn't necessarily a research subject at AIMR, I would like to write about cement, which I used to research. There's various types of cement out there, but the type that probably comes to your mind is the gray powder variety which is used to make mortar and concrete. The gray cement that we know of was invented by Joseph Aspdin about 200 years ago, and is categorized as Portland cement. It was named for its color and texture, which resembles those of Portland stone (a kind of limestone) originating from the Isle of Portland in England. What other types of cement are out there besides Portland cement? There's dental cement, as well as alumina cement; the latter is used in refractory applications. There's also white cement (colored cement can be made by adding coloring) though it is of Portland cement.

Let's look more closely at Portland cement. Its main ingredients are limestone ($CaCO_3$) and clay (made up principally of SiO_2 and Al_2O_3), but materials such as silica stone and iron oxide materials are also used to make up for a lack in SiO_2 and Fe_2O_3 respectively. These are crushed into powder form and mixed well, and heated gradually. Those who have ever gone to a cement factory will recall a tall tower (suspension preheater) used for preliminary heating of raw materials, and a rotary kiln connected to the preheater used for the actual firing (these are cylindrical rotary furnaces, and large kilns can reach up to 6m in diameter and 100m in length). The heat is mainly supplied from the downstream part of the kiln through the burner, towards the preheater. The limestone raw material in the preheater, which reaches about 900°C, undergoes calcination ($CaCO_3 \rightarrow CaO + CO_2\uparrow$) to become CaO. It reacts with the SiO_2, Al_2O_3, Fe_2O_3, and other ingredients in the kiln, beginning to melt partially at about 1,200°C. At a maximum temperature of about 1,450°C, it successively generates new compound crystals that grow. Rock-like masses (clinker) measuring several centimeters in diameter will then flow from the vent at the downstream part of the kiln. After these have cooled, they are mixed with gypsum and made into powder to produce Portland cement.

If we polished a cross-section of cement clinker and examined it under a microscope, we'd find that it's made up of four principal compound types. These four cement compounds are alite ("Alit" in German), belite ("Belit" in German), aluminate phase, and ferrite phase. According to the unique notation conventions used in cement chemistry, CaO can also be represented as C, SiO_2 as S, Al_2O_3 as A, and Fe_2O_3 as F; so the four compounds are represented by C_3S, C_2S, C_3A, and C_4AF. The properties of cement are determined by the quantitative ratio of these compounds, and it is possible to control this quantitative ratio by changing the mixture ratio of the abovementioned raw materials. Typically, Portland cement contains the greatest proportion of alite, and only a small amount of belite. As much as alite has fast hydration and cementing reactions, it also generates a great deal of heat (heat of hydration). Hence, it accumulates heat quickly, causing cracks when it's used to build large structures like dams. When casting large structures, moderate-heat cement or low-heat cement is used, because these contain a higher proportion of belite that generates heat gently. Although it is an everyday material, the scientific background behind cement is deeper than it seems.

Finally, I'd like to share one of the fundamentals I first learnt when I began working at a cement manufacturing company. Do you know the difference between cement, mortar, and concrete? Mortar is produced by mixing cement, sand, and water into a paste. Concrete is formed when gravel is added to that paste. The difference between concrete and mortar is whether or not it contains gravel. Incidentally, the paste formed simply by mixing cement and water is known as cement paste. While these are simple definitions, I didn't know them until I began working at the cement manufacturing company.



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).

NEW STAFF

Kazutoshi INOUE

Kazutoshi Inoue has been a member of the Ikuhara Laboratory, a global leader in the field of materials research using the transmission electron microscope, since June 2014. His field of specialization was not originally materials science, but he eventually made his way into the field after a series of twists and turns.

During his teenage years, Inoue happened to see "A Galactic Odyssey" and "Einstein Roman" on television. These programs stirred a sense of excitement in him, leading him to major in physics as an undergraduate. However, he began to feel the restrictions of using only theories to explain the results of experiments, and decided to major in mathematics when he entered graduate school. He explained, "When I began to study mathematics, I was bewildered by its stylistic differences in comparison to physics. Yet, at the same time, I was delighted by the freedom it provided."

While delighting in the freedom of mathematics, he gradually began to worry about how he could play a useful role in the real world. "I dropped out from graduate school once, and took up studies in translation and other areas." During this time, Professor Kotani encouraged him to earn his degree, and pushed him to complete his doctoral thesis while working as a Industrial-Academic Partnership Project researcher in the Kotani Laboratory. There, he began to participate in discussions with Professor Ikuhara's team. "I was amazed that such clear images of atoms could be taken. I began to be drawn toward materials science."

Currently, he has taken up the challenge of geometrically elucidating defect structures, such as grain boundaries present in substances, by applying his mathematical knowledge. "The good thing about having studied mathematics is that I am able to approach things with an open mind, with an attitude of sparing no effort to reconstruct things from scratch. I believe that it is my role to harness my strength in reading and absorbing literature in both the areas of materials science and mathematics, in order to develop new theories."

Kazutoshi INOUE

AIMR research associate

Born in Tsuruoka City in Yamagata Prefecture. Graduated from the Department of Physics, Faculty of Science, Tohoku University. After working as an Industrial-Academic Partnership Project researcher, he obtained his doctoral degree from Tohoku University's Graduate School of Science. He took up his current role in 2014.

Text and photo: Yasufumi Nakamichi