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Ken Nakajima
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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

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from SENDAI *to* the WORLD

More than half of the researchers of AIMR are of foreign nationalities, coming from a wide variety of backgrounds in terms of homeland as well as the universities they have graduated from. The Japanese researchers, making up the other half of the researcher population, are similarly outstanding researchers who come from all parts of Japan. Amongst these researchers, some are graduates of local high schools in Sendai who have continued to engage in research in the city even today. What were their lives in high school like, and why did they choose to become researchers? What does research mean to them? For this feature, we welcomed three students from Sendai Municipal Tomizawa Junior High School into our editorial team, and had them interview their seniors from Sendai. Read on to find out how these students perceived the researchers. We hope you enjoy.

Text and photos: Yasufumi Nakamichi

from SENDAI to the WORLD

interview 01

Unable to Imagine a Life Without Research

Professor Shigemi Mizukami was one of the pioneer researchers who discovered the spin pumping effect, who now continues to greatly contribute to the development of spintronics. Till now, he has been consistently engaged in research work related to the development of new spintronics materials and devices from the perspective of high-speed spin dynamics. In the interview, he spoke about the impact that research has had on him.

Shigemi Mizukami

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

profile

Born in Miyagi Prefecture in 1973. Graduated from Sendai Daisan High School. After earning his doctoral degree from the Graduate School of Engineering, Tohoku University, he became a research associate at the College of Engineering, Nihon University. In 2008, he took on the position as Assistant Professor at the Advanced Institute for Materials Research (AIMR). In 2011, he became Associate Professor, and became Professor in 2014. He has received the Outstanding Research Prize from the Magnetics Society of Japan in 2005, among other awards.

-Professor Mizukami, could you tell us specifically what kind of research you are engaged in?

My specialization is in the area of spintronics, which is a part of applied physics. Applied physics involves the study of how we can apply physics in work that is useful to the world. I mainly use magnets in my research, and I study methods of reducing the size of magnets so that they can be used in computer and mobile phone memory.

-Could you tell us about times when you were glad that you became a researcher, or when you wanted to give up on research work?

There are many occasions when I feel glad that I became a researcher. Of these, I think one of the aspects shared by all researchers is the thrill of being the first in the world to know something that nobody else does. However, since I am only human, there are also times when experiments do not turn out as I expected, and I feel like giving up. Furthermore, researchers work from dusk till dawn and we enjoy our work, but our families are left feeling lonely. That is why I have also thought of giving up this work. Even so, I have managed to continue research with the support of my family.

-What does research mean to you? Could you also tell us about the impact that research has had on you?

I'm not sure how to say this since I have never given it deep thought, but I cannot imagine a life without research now.
As the contents of my research are close to natural science and application, I think that my own values have not changed. However, just as the magnets that we stick to our refrigerators have the hidden potential to change the world, I constantly gain new perspectives, ideas, and ways of thinking that are different from before.

-Is there anyone that you aspire to?

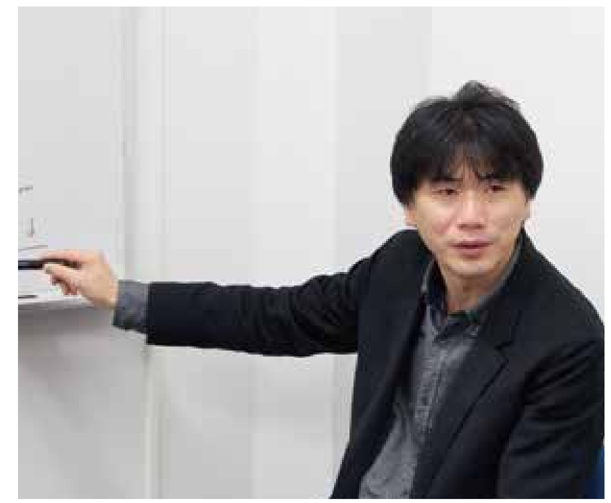
I loved to read when I was a student. Back then, I read the autobiography of a person called Heisenberg, one of the physicist who created the field of quantum mechanics, and I aspired to be like him. Through his autobiography, you can learn about the work of scientists and other information about his daily life, so do give it a read if you are interested.
I am now older, and I don't really have much in the way of such aspirations. However, I have great respect for the teachers who have helped me through the milestones in my life.

-When junior high school students engage in research projects, are there any tips to ensuring their success?

I think that themes are of great importance. Most of research is determined by the theme; that's how important they are. Hence, where the question lies in the theme becomes greatly important. You might be surprised to find that a simple question could be one that many people have not thought of. For example, it might be good to focus on something that others take for granted. After that, it is important to consider how you can come up with something that is different from what others think.

-Could you tell us about something you did in high school that you apply to your life now, or something that you wish you had done more of?

In junior and senior high school, I was in the sports club, and I'm glad I was. That's because I acquired tenacity, physical strength, and willpower through sports; and perseverance is important when it comes to critical moments. Physical strength is also necessary in research.
As for what I wish I had done more of, that would be liberal arts activities. In particular, I sometimes wish that I had taken up an artistic skill, such as a musical instrument. I think I would have acquired a sense of creativity that would have been useful in research. After all, I believe that it is important to be well-rounded.



-Do you have any thoughts or messages for today's high school students?

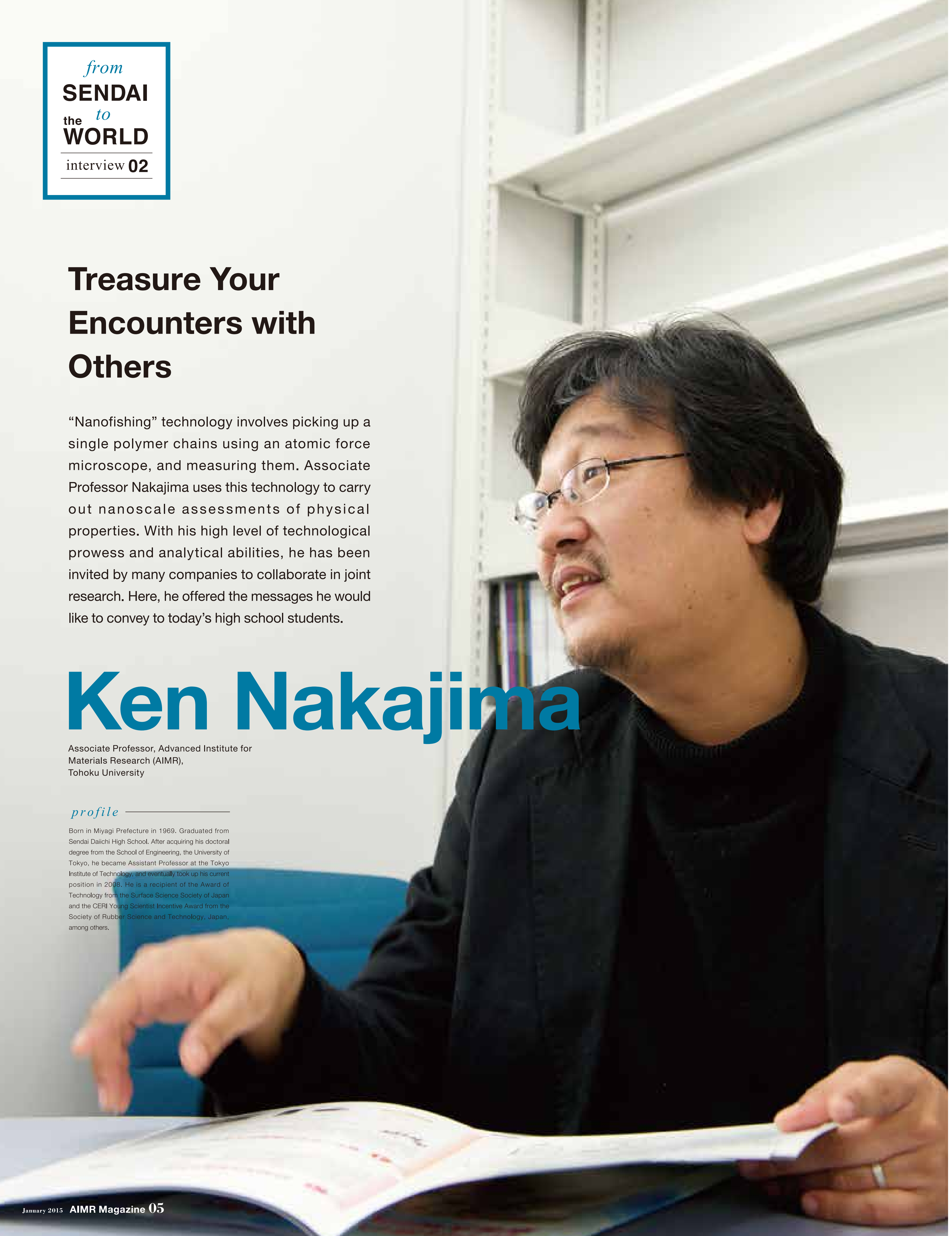
Have fun with studying, sports, and cultural activities just as a high school student should, and focus above all on enjoying your youth. You all have enormous hidden potential within yourselves, so I think that it is important to experience a wide variety of things. I would also be as bold to add that it would be useful to learn English. I also think that it would be a good idea to direct your attention to social situations, such as politics or economics, beginning from high school. If you do all of these things, I am certain that a path will open up naturally for you as, and when the time comes, when you hope to take up research work as a researcher.

Reporters = Masanori Naruse, Momoko Makino
Text = Masanori Naruse
Photo = Himari Saijo (p.4)

from SENDAI to the WORLD
interview 02

Treasure Your Encounters with Others

“Nanofishing” technology involves picking up a single polymer chains using an atomic force microscope, and measuring them. Associate Professor Nakajima uses this technology to carry out nanoscale assessments of physical properties. With his high level of technological prowess and analytical abilities, he has been invited by many companies to collaborate in joint research. Here, he offered the messages he would like to convey to today’s high school students.



Ken Nakajima

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

profile

Born in Miyagi Prefecture in 1969. Graduated from Sendai Daiichi High School. After acquiring his doctoral degree from the School of Engineering, the University of Tokyo, he became Assistant Professor at the Tokyo Institute of Technology, and eventually took up his current position in 2008. He is a recipient of the Award of Technology from the Surface Science Society of Japan and the CERI Young Scientist Incentive Award from the Society of Rubber Science and Technology, Japan, among others.

-Associate Professor Nakajima, could you tell us specifically what kind of research you are engaged in?

I conduct research on macromolecules such as rubber, plastic, and fiber. For example, with rubber, my research forms the foundation for the study of seismic isolation rubber used in the Great East Japan Earthquake. Recently, I have also been conducting fundamental research on fiber-reinforced plastic that is used as aircraft material.

-Why did you decide to become a researcher in this field?

I originally intended to become a scientist. However, under the influence of a physics teacher whom I got to know when I was in high school, I began to think about pursuing the world of physics. I was inspired by that teacher’s attitude of continuing to learn and study regardless of your age. Although he was about 60 years old then, he had been studying cutting-edge science using books he had bought himself. At the time, he showed me his notebooks and I thought, “I want to be just like him.” That was the catalyst that made me aspire toward becoming a researcher.

-Could you tell us about times when you were glad that you became a researcher, or when you wanted to give up on research work?

There are three things that I feel glad about. The first is that the results of my research are useful to society. I feel truly happy when I actually feel that. The second is when the contents of our own research are reflected in joint research with companies. Another appeal of being a researcher is the dynamic way of life that gives us the opportunity to connect with people from overseas. I have never once thought of giving up this work, because we are truly doing something that we like for a living.

-How important is research to you? Did anything change in you before and after you became a researcher?

To me, research is not the end-all, be-all of life. However, it is the greatest honor in my life to know that my research is contributing to society and being useful to others. That is why it is very important to me.
Since I became a researcher, I think that my perspective of the world has expanded. Furthermore, as I conduct research in consultation with researchers from around the world—and sometimes in competition with them as well—the international exchange and interaction has made the world feel much smaller.

-When junior high school students engage in research projects, are there any tips to ensuring their success?

I think it is important to have an attitude to investigate something, regardless of how obvious it may seem. I think that it is a very good thing to gather information new to you, and to expand your base of knowledge. In our world today, there are many methods for carrying out investigations, which is why it is important to absorb knowledge from various angles instead of merely taking in a single piece of information.

-Could you tell us about something you did in high school that you apply to your life now, or something that you wish you had done more of?

I think it’s advisable for students to study everything regardless of discipline, all the way through high school. For example, if you have a good grasp of world history, you will be able to talk to people from other countries using that knowledge as a basis for conversation. That is why I don’t think it’s a good idea to decide early on, “This is the discipline for me.”
It is necessary to understand various things in an even, well-rounded way. It is also very important to learn about foreign cultures.

-Do you have any thoughts or messages for today’s high school students?

I hope that all of you will treasure face-to-face encounters with people, rather than focusing solely on Internet encounters. According to the idea of “six degrees of separation,” if you trace the acquaintances of one of your own acquaintances, you can move six degrees beyond that to connect with people around the world. Simply by understanding that we live in such a world can change the way you look at things. That is why I would like to ask all of you to treasure these interpersonal ties.

Reporters = Himari Saijo, Masanori Naruse
Text = Himari Saijo
Photo = Momoko Makino (p.6)

from SENDAI to the WORLD
interview 03

The Support of Those around Me Made Me Who I Am

Graphene, a single thin layer of atoms obtained from the graphite used to make pencil lead, is now drawing great attention from the perspective of its application in highly-functional devices for the next generation. Using ultra-high resolution angle-resolved photoemission spectroscopy, which boasts the highest resolution in the world, Assistant Professor Sugawara is engaged in researching the physical properties of graphene. He talks about why he is glad that he became a researcher.

Katsuaki Sugawara

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

profile

Born in Sendai City, Miyagi Prefecture in 1981. Graduated from Sendai Daisan High School. After acquiring his doctoral degree from the Graduate School of Science, Tohoku University, he became an research associate at the Advanced Institute for Materials Research (AIMR) and took up his current position in 2010. He is a recipient of the Harada Young Research Award, ATI Research Award, and the 9th Young Scientist Award of the Physical Society of Japan.

-Assistant Professor Sugawara, could you tell us what kind of research you are currently engaged in?

I am primarily engaged in research that looks at the state of electrons in substances. Specifically, when we expose materials, such as metals, to ultraviolet light, that material receives energy and emits electrons to the external environment. My research looks at the state of such electrons. I also conduct research on the state of graphene electrons, a material only as thick as an atomic layer; and on superconductivity where substances lose all of their electrical resistance. There is intense competition in the field of superconductivity research and I have many rivals. However, with the support of many people around me, I hope that I will be able to conduct research on par with other work.

-Why did you decide to become a researcher? What do you think is the key to successful research?

At first, I wanted to leave behind something that could serve as proof of my existence. Hence, during my undergraduate years, I felt I would be able to leave my name behind in the world if I could publish a research paper (which isn't exactly a good motivation for pursuing a career in research). In graduate school, I entered the research laboratory headed by Professor Takahashi, where I am currently affiliated. The research being conducted there, such as on superconductivity and the giant magnetoresistance effect, involved elucidating the origin of various substances' properties using photoelectron spectroscopy. I found this to be interesting, and I began to feel that it might be able to serve mankind. Hence, I decided to pursue the path of a researcher.
Failure is a part of research work. The important point is whether or not you are able to find a path to success through the failures.

-Could you tell us about times when you were glad that you became a researcher, or when you wanted to give up on research work?

What I like about research is the sense that you are supported by those around you, such as your teachers and students. If I was alone, I'm sure that I would have crumbled from failure and troubles.
There are many times when I felt like I wanted to give up. When experiments and research don't yield good results, I feel like I'm not cut out to be a researcher. I still feel that sometimes, even today. However, it is thanks to those around me that I have been able to continue on this path, and now I am glad that I did not give up.

-Do you feel worried about whether or not your English is correct when you have to speak to foreigners? How did you learn English?

I often worry if the English I am speaking is correct. However, communication can also be achieved by using gestures, so the message will be conveyed one way or another. That's how I learned not to worry whether my English is correct or not. Even if you use only a single word, the person that you are speaking to may absorb and understand it. I always tell myself that it is fine if I'm not perfect, as long as I communicate my message.

-When junior high school students engage in research projects, are there any tips to ensuring their success?

Even if the answer is given in a book or in another source, if it is something that you are interested in or have doubts about, think about if that information is truly accurate, and take proper steps to verify it for yourself. It's important to do that. Through that process, you may find a different way of viewing things. I feel that it's important to try out something for yourself, even if it's a fact you take for granted.

-Could you tell us about something you did in high school that you apply to your life now, or something that you wish you had done more of?

I belonged in sports clubs when I was in junior high school and in university, and I feel that it armed me with physical strength and perseverance. Research is a job that involves standing for long periods, as well as constant failure, so strength and perserverence are two surprisingly important characteristics to have. There are many things that I wish I had done more of. With regard to studies, I wish I had put more effort into all subjects. In particular, language studies like English are necessary, and I also feel that subjects like history are important for expanding a conversation when speaking to a foreigner. History does not end simply with the result—"This is what happened"—so I feel that it would have been good if I had also studied about the background of historical events.

-Do you have any thoughts or messages for today's high school students?

I think it's important not to go with the flow, but to think about and make your own decisions on your own path.
Regardless of your future career, please put great importance on the reasons why you want that job.

Reporters = Momoko Makino, Himari Saijo
Text = Momoko Makino
Photo = Masanori Naruse(p.8)

from SENDAI *to* the WORLD

Notes from the Reporters

Momoko Makino

The overall impression I gained through this internship was to think carefully on my own about my future path. All of the three Professors whom we interviewed for this feature said that being a researcher is not the only career choice. In addition to seeing the world through broad perspectives, I think it is also important to be able to give clear reasons when we make decisions.

Being involved in creating AIMR Magazine taught me to reflect on things from a third person perspective. Even if the text you wrote seems perfect to you, other people may notice the flaws when they read it, such as not being able to understand, or the beginning and end being poorly connected, or the article not flowing smoothly. In the future, I would like to gain the ability to view myself from a third person perspective in all matters.

Masanori Naruse

I am really glad I chose AIMR for my internship. There are many reasons why, but I'm particularly happy about two points. The first is that I had the opportunity to meet researchers, which I aspire to be in future, and to hear their thoughts on various topics. I learnt about the joys and difficulties of a career in research. The second is that I had the chance to learn about various points to note in publicity work. I now understand that even in a single word, "publicity", the methods change depending on your target audience. From here on out, I would like to apply the things that I have learnt here and the knowledge I have acquired to my school life. I aim to become a researcher in the future, and to work in a research institution like AIMR.

Himari Saijo

I made it to my first choice, AIMR's the PR and Outreach Office. I chose it purely out of curiosity, and I didn't have a good idea of what "materials science" even meant. After interviewing Professors Sugawara, Mizukami, and Nakajima, I have come to understand that materials science is closely tied to our everyday lives, and that it is a very interesting field of study. The interviews with the professors were a wonderful experience, and I often ended up forgetting to take notes as I was too absorbed in what they were saying.

I didn't know that there was such an amazing place in Sendai, where I live. I would like more people to know about AIMR. I was truly delighted to have the chance to be involved in this publicity work. I aim to bring the lessons I have learnt and the impressions I have formed back to school, and share them with everyone.

INDEX

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How to Make Zigzag Graphene Nanoribbons

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

Advanced Institute for Materials Research, Tohoku University

Taro Hitosugi
Patrick Han

Winning the Nobel Prize with Pencil Lead and Scotch Tape?!

Did you know that both pencil lead and diamonds are crystals made up of carbon atoms? It's true that both objects are made of carbon, but the ways in which the atoms are bonded (crystalline structure) are different, resulting in the differences in their appearance and properties. Diamonds have a regular, three-dimensional structure—also known as a diamond structure, and are characterized by the properties of being transparent and hard. On the other hand, the carbon material used to make pencil lead is called graphite, which has a structure comprised of multiple overlapping layers of carbon atoms arranged in the shape of a honeycomb (Figure 1).

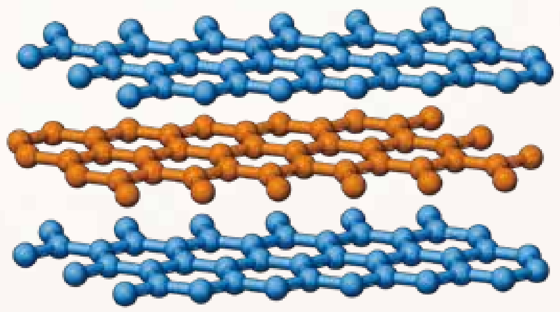


Figure 1: Graphite structure

At the same weight, would you rather have pencil lead or diamond? Most of us would probably choose diamond. In modern monetary terms, diamond is much more valuable than pencil lead—and some say more beautiful. However, the black mass known as graphite, so commonplace at first glance, has the hidden potential that can bring about major changes to our world.

The research hinting at this potential was carried out using graphite and scotch tape. Graphite, as described earlier, is comprised of carbon atoms arranged in the shape of a honeycomb in numerous overlapping graphene layers. A single sheet of graphene is expected to have many exotic properties, such as a fast electron transfer rate. However, as there were no technology that could neatly peel off just a single layer of graphite, it was not possible to verify these properties for a long time. In 2004, Dr. Andre Geim, a physicist, succeeded in isolating a clean, single atomic layer of graphene by pasting scotch tape onto graphite and peeling it off. This triggered dramatic progress in graphene research. In addition to verifying its extremely high levels of electron transfer rate and thermal conductivity rate, other surprising properties were discovered in quick succession. In 2010, a mere six years after the production of the first graphene sample, Dr. Andre Geim and his collaborator Dr. Konstantin Novoselov were awarded the Nobel Prize in Physics for "ground-breaking experiments regarding the two-dimensional material graphene."

The Significance of Different Edges

Why did graphene research progress so dramatically over such a short period of time? The answer lies in the unique structure and properties of graphene. Although graphene is extremely thin and lightweight, as it is made up of a single layer of atoms, it is very strong. Further, due to its extremely high electron transfer rate, it is regarded as an important material for building next-generation computers that consume little power while still operating at a high speed. Much active research is being carried out from the perspectives of physics, chemistry, and practical applications. Of these, the spotlight has recently fallen on a substance known as graphene nanoribbon.

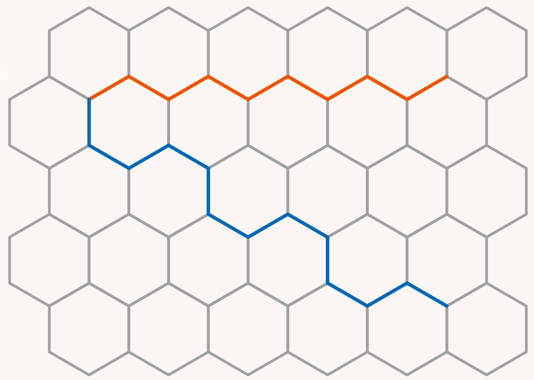


Figure 2: Zigzag and armchair edge structures

Graphene nanoribbon refers to graphene in a ribbon form. They are two main types of graphene edges—zigzag and armchair (Figure 2). Why have graphene nanoribbons garnered such attention? That is because the edge configurations of these ribbons are expected to bring about significant changes in their electronic and magnetic properties. For example, with edges in the zigzag form, graphene nanoribbons are expected to exhibit metallic properties; with edges in the armchair form, graphene nanoribbons are expected to have a band gap that changes with ribbon width. This structure/property relationship opens the possibility for using graphene to tailor the properties of future electronics materials while retaining graphene's advantages (i.e., small dimensions, light weight, chemical strength, etc.).

However, a major problem stands in the way of putting graphene nanoribbons to practical use. In actuality, the differences in the physical properties of graphene nanoribbons brought about by the differences in their edges have not yet been verified. That is because synthesizing graphene nanoribbons with zigzag edges is fraught with difficulties. If we succeed in synthesizing graphene nanoribbons with zigzag edges, it would signify a huge step toward understanding the applications and properties of graphene. Hence, we harnessed the strengths of AIMR, which is home to researchers of various fields, and worked together with specialists in the fields of organic synthesis and theory to synthesize graphene nanoribbons with zigzag edges.

Success in Synthesizing Zigzag Edges Through a Bottom-Up Approach!

There are two ways of controlling the edges of graphene. The first is a top-down approach utilizing semiconductor lithography technology. The second is a bottom-up approach starting out from the molecules, which binds the molecules through chemical reaction. Although attempts have previously been made using the method that harnesses semiconductor lithography technology, flaws and defects always emerge during production. As such, we conducted an experiment that aimed to control the edges of graphene nanoribbons through the bottom-up approach.

First, we evaporated the molecules of a dibromobianthracene compound, which forms the base for graphene nanoribbons, on a copper substrate. The compound was kept for about 10 minutes on the copper substrate at a temperature of 500 °C. After that, we observed the molecules that were generated using a scanning tunneling microscope, which is able to identify and differentiate each individual molecule. We found that graphene nanoribbons with periodic regions of zigzag edges had been produced (Figure 3). How was it possible to produce zigzag edges through such a simple method? When we investigated the phenomenon in detail, we found that the dibromobianthracene molecules are arranged in a fixed direction on the surface of the copper, resulting in a unique chemical reaction. This then brought about the generation of graphene nanoribbons with a zigzag-edge structure. In short, it became clear to us that the substrate plays an important role in the bottom-up production of zigzag edges in graphene nanoribbons.

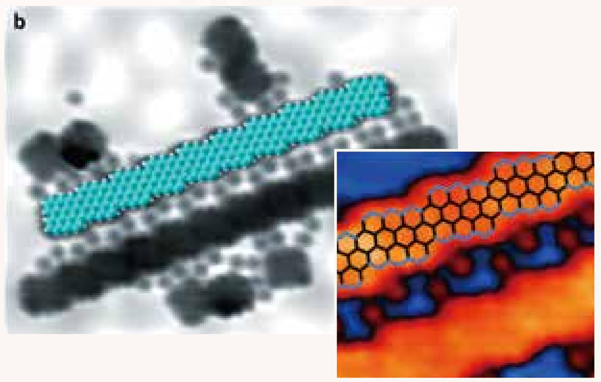


Figure 3: Image of the graphene nanoribbon under the scanning tunneling microscope (left) and enlarged view of the zigzag edges (right)

Through our proposed method, it has become possible to produce graphene nanoribbons while controlling the length of the ribbon and shape of the edges. As described earlier, graphene nanoribbons are characterized by a high level of electrical conductivity and thermal conductivity, and may be applied for use as wiring material for integrated circuits. The development of graphene nanoribbons for use in new devices, by harnessing the strong magnetism present only in the edges, can also be taken into consideration. Hence, the results of this research are expected to contribute to the creation of new electronics and spintronics devices. Going forward, we plan to synthesize graphene nanoribbons of various lengths, widths, and edges, uncover new physical properties, and engage in research related to the practical application of the results.

NEWS & INFORMATION

Joint Workshop Held in Collaboration with National Chiao Tung University

AIMR held a joint workshop with Taiwan's National Chiao Tung University (NCTU) from 22 to 23 September 2014.

This workshop, held in Hsinchu City in Taiwan, where NCTU is located, was based on the joint research conducted over ten years by AIMR Principal Investigator, Professor Seiji Samukawa; and Professor Yiming Li from NCTU. The aim of the workshop was to widely promote fusion research in nanomaterials, nanodevices, and mathematics between the two universities. AIMR and NCTU researchers working on the frontlines of their respective fields were invited to conduct lectures at the workshop. A total of 12 researchers from AIMR, including Director Kotani and Professor Samukawa, delivered presentations, and active discussions were carried out on topics such as the latest research results of their respective research activities, and fusion research that encompasses the field of mathematics.

plenary talk by Prof. Simon M. Sze

ERATO Isobe Project Experimental Facility Receives Good Design Award

The experimental facility used for the JST ERATO Isobe Degenerate π-Integration Project, helmed by AIMR Principal Investigator Hiroyuki Isobe, has received the 2014 Good Design Award. The Award was presented for the room on the third floor and the laboratory on the fifth floor of the AIMR Main Building on the Katahira Campus. Designed by an architect who holds a Masters degree in Chemistry, the experimental facility is equipped with an ideal environment based on his own research experience. The design meets the needs of the project, bearing in mind the concept of fusion research involving researchers from different fields of specialization, and pursues aesthetic beauty without compromising functionality.

photo: Takumi Ota

Background of the paper with 5,000 citations

Professor

Tomasz Dietl

AIMR Principal Investigator, Professor Tomasz Dietl, is the primary author of the most cited paper amongst those published by Tohoku University in the past. We spoke to him about the background leading to his specialization in the research of magnetic semiconductors, as well as his impressions of the AIMR research environment.

Researchers summarize the results of their research activities in the form of academic papers, which they then publish. Each paper is a report of valuable findings, and it is difficult to make comparisons to identify the paper of greater significance. However, one indicator used is the citation count, which shows how often a paper is cited in other papers. If the paper has a significant impact on future research, it will naturally be cited by many other papers.

To date, Tohoku University has published more than 100,000 papers. Do you know which of these is the paper with the largest citation count? That paper, which discusses magnetic semiconductors, has been cited more than 5,000 times over the 13 years since its publication in the American science journal, *Science*, in 2000. According to data released by Thomson Reuters in 2013, the average citation count for each paper published by Tohoku University over the 11-year period from 2002 to 2012 was 11.70. Based on this figure, it is easy to see how large a citation count of 5,000 is.

The author of that paper is Professor Tomasz Dietl, a theoretical physicist who is current Principal Investigator at AIMR. Research collaborators whose names were also included in the paper were Professor Hideo Ohno, Professor Fumihiro Matsukura, who had been a postdoctoral researcher in the Ohno research laboratory at the time; and other researchers. At the time of publication, Professor Dietl had transferred to Tohoku University for a one-year period from the Polish Academy of Sciences, at the invitation of Professor Ohno. With the transfer, he joined the Research Institute of Electrical Communication at Tohoku University. Professor Dietl reflected on his encounter with Professor Ohno.

"I first met Professor Ohno at one conference in Austria in 1994, and then Professor Ohno visited Warsaw for a Polish-Japanese conference on magnetic materials. And we had many discussions about the discoveries he had made at Tohoku University. Eventually, he invited me to come to Tohoku University for a one-year period."

At the point in time when Professor Dietl received the invitation from Professor Ohno, he was holding many responsibilities at the Polish Academy of Sciences, which was his main affiliation. In addition to his own research activities, he was also coordinating other projects and taking charge of administrative duties. Hence, it was not easy for him to go to Japan, even just for a year. However, he somehow managed to make this possible by taking a leave of absence, and arrived in Japan in 1999. According to Professor Dietl, that decision was certainly not a mistake, and the year was an extremely productive one. "We fused different specialized knowledge and expertise, and conducted research in this way. Professor Ohno is an outstanding physicist, and at the same time, an outstanding electrical engineer. He possesses in-depth knowledge of device physics as well as an understanding of the needs of the electronics industry. I gained knowledge in these aspects from Professor Ohno, and I hope that he also learnt something about the physics of magnetic materials from me through our long years of research in this field. In this sense, his complementary expertise was very successfully implemented in papers which we did together."

The paper completed at this time became the most cited paper from Tohoku University. Professor Dietl, who has continued to produce significant achievements as a theoretical physicist, was only 12 years old when he decided to become a physicist.

Text and photos: Yasufumi Nakamichi

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.

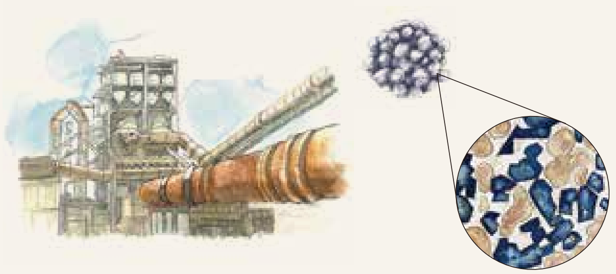
Part 6 Talking About Cement

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