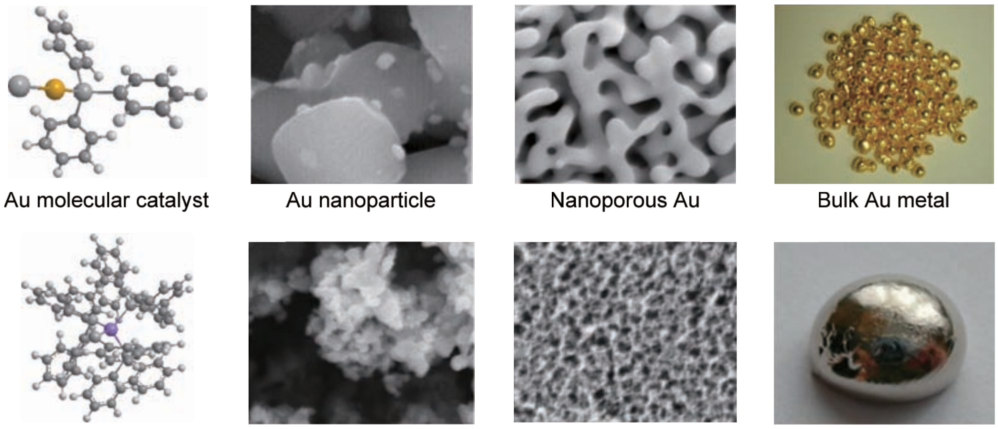
Volume 14

# WPI-AIMR NEWS

December 24, 2011



Au molecular catalyst | Au nanoparticle | Nanoporous Au | Bulk Au metal

Pd molecular catalyst | Pd nanoparticle | Nanoporous Pd | Bulk Pd metal

World Premier International Research Center
Advanced Institute for Materials Research

Tohoku University


**Cover:**

Nanoporous metals can be generally prepared by leaching less noble metals out of the corresponding alloys. They are promising green catalysts due to their high surface-to-volume ratios, high reusabilities, and simple work-up processes.

(Naoki Asao, WPI-AIMR)

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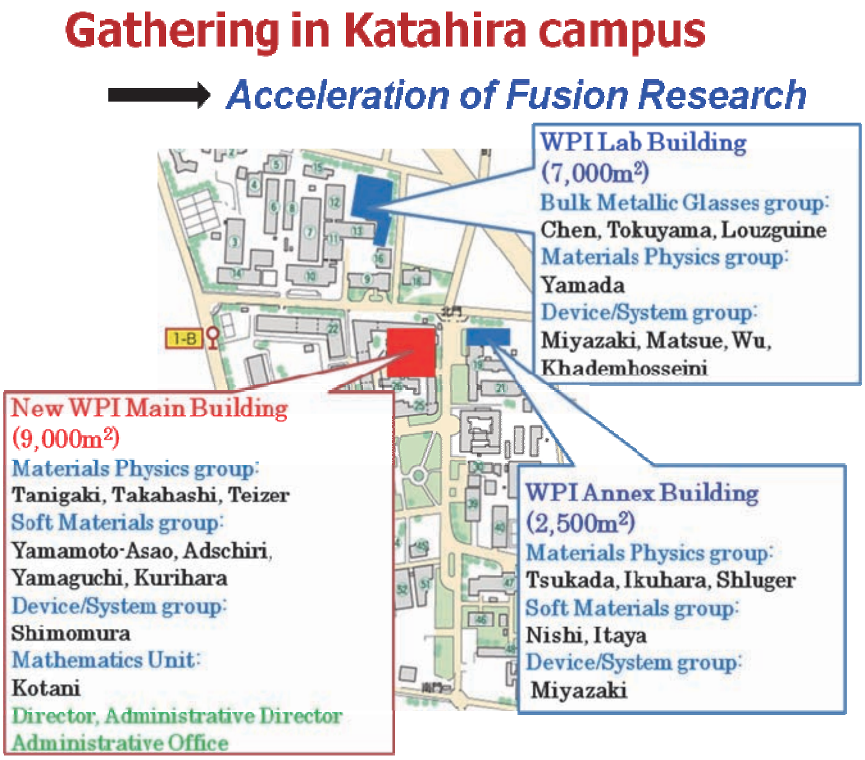
# Contents

# New Main Building of WPI-AIMR and Interim Evaluation

Yoshinori Yamamoto
Director, WPI-AIMR, Tohoku University

When you enter the Katahira campus from the north gate, you can see the new main building of WPI-AIMR at the right hand side. The outer wall of the old-fashioned brickwork building of three stories, which housed the Department of Metallurgy since 1925, has been preserved, and the inside of the historical building has been renovated entirely, in which an administrative office, meeting rooms and researchers' offices have been laid out. A very modernized laboratory building, which has five stories, has been constructed contiguous to the historical building, and the two buildings are covered by a single roof made of glass through which we can see a blue sky. Before the completion of this new building, researchers of AIMR were geographically separated between two campuses, Katahira and Aobayama, but now almost all researchers are able to work together at Katahira campus. I believe that the "one-roof" and "one-campus" environment must further promote the fusion research among different research disciplines through more frequent face-to-face contact. I take this opportunity to thank MEXT for providing the construction budget of 2 billion yen in the scheme of the 2009 supplementary budget.

In Katahira campus, now we have the main building, annex building, and lab building, and these three buildings are within a few minutes by foot. Four research groups (BMG, materials physics, soft materials, and device/system) are carrying out active research in one of the three buildings, and the newly started Mathematics Unit has offices in the main building. I expect that the Mathematics Unit will soon start to catalyze the fusion research among different materials disciplines.




Around the middle of October, there was the interim evaluation of WPI institutes at Tokyo. Presently, six WPI institutes are being supervised by MEXT, among which five institutes received the interim evaluation because nearly five years passed since their inauguration. I have not yet heard any conclusive responses on the result of the evaluation. Perhaps, the result will be announced before this WPI-AIMR NEWS is delivered to you at the end of December. I strongly hope that the outcome of the evaluation for AIMR is not so serious, but encourages us to accomplish entirely new materials science in the next five years.

(Written on December 1, 2011)

# Interviews

**Interview with Professor Yuichi Ikuhara,**

Principal Investigator, WPI-AIMR

## "Materials Design and Manufacturing"

***Humboldt Research Award and Research on Grain Boundary***

**Administrative Director Iwamoto:** Congratulations on receiving the Humboldt Research Award. I heard that you attended the award ceremony held in Bamberg, Germany, in March. You are the third Japanese person to receive the award in the field of materials science, aren't you?

**Professor Yuichi Ikuhara:** Yes, I've heard so. The Humboldt Research Award covers not only the field of natural science but also 23 other fields including literature, law and religious studies. A total of 50 to 60 Japanese people have previously won the award. I think about 30 of them were awarded in the field of natural science. The Center Director, Professor Yamamoto, has also been awarded it in the field of chemistry.

**Iwamoto:** Yes. He won the award in 2002.

**Ikuhara:** Professor Koshiba is one of the earliest award winners.

**Iwamoto:** Yes, Professor Koshiba who received the Nobel Prize in the field of neutrino astrophysics.

**Ikuhara:** In addition to Professor Koshiba, there is also Professor Negishi who was awarded the Nobel Prize last year. Professor Arima, the former President of the University of Tokyo, received it too.

**Iwamoto:** An impressive lineup, isn't it? By the way, you won the Humboldt Research Award for your research on the nanostructure of the interfaces of materials and physical properties. I heard this research was a major breakthrough in the field of materials science. Could you describe it more specifically?

**Ikuhara:** Most materials we use are polycrystals, which contain grain boundaries without exception. Materials are generally composed of a large number of crystal grains that form polycrystalline bodies. This applies to ceramics as well as metallic materials. Most bulks we handle are generally polycrystalline. And grain boundary means a nano space between these crystals.

**Iwamoto:** I see.

**Ikuhara:** There are many cases where physical properties and characteristics are determined by the structure of grain boundaries. The simplest example is that certain things are easier to break. Another example is the electrical properties of electronic ceramics. For instance, whether properties of a varistor are apparent or not depends on the structure of grain boundaries; in other words, how atoms are linked together is important.

**Iwamoto:** I see. So, all these characteristics, such as that certain things are easy to break or have the mechanical or electrical properties you've just mentioned, are related to grain boundaries.

**Ikuhara:** That's why we study the structure of atoms that reside at grain boundaries using electron microscopes to see how these atoms exist, or how the crystal grains are linked each other. I think if these points can be explained, it will be possible to understand the basic mechanism of development of physical properties. This is the reason why I conduct quantitative analysis on the links of atoms using electron microscopes. In my research, I also estimate the method of strengthening materials or conducting electricity.

**Iwamoto:** I see.

**Ikuhara:** And I have been conducting this analysis mainly on ceramics.

**Iwamoto:** Why did you decide to focus on ceramics? What specific properties do they have in comparison to other materials?

**Ikuhara:** There is a great variety of ceramics. There are a lot more different kinds compared to metal, such as carbide, nitride and oxide. Various types of ceramics are available these days, including functional ceramics and functional materials, and all of them can be basically categorized as so-called ceramics, such as carbide, nitride and oxide. This diversity makes me interested in ceramics, but I do research on metallic materials from different angles.

**Iwamoto:** I see.

**Ikuhara:** As you know the research of WPI-AIMR is characterized by atom and molecule control.

**Iwamoto:** Yes.

**Ikuhara:** In that sense, we do not separate metal from ceramics, or organic materials from inorganic. We take the same approach: from the viewpoint of the atomic and molecular level.

**Iwamoto:** Yes, indeed. I see. And you use electron microscopes as your research tool, don't you?

**Ikuhara:** Yes, mainly transmission electron microscopes.

**Iwamoto:** Do you really have to study grain boundaries in all kinds of things like that, one by one? That sounds like a lot of work.

**Ikuhara:** Yes, it is really hard work. That's why we make models of the materials. When you are working on practical polycrystalline materials, it is not very easy to understand them in a uniform way and find existing laws, as crystals are facing various different directions.

**Iwamoto:** I see.

**Ikuhara:** So, we categorize grain boundaries into several types and produce model grain boundaries by ourselves. If you carefully observe materials using a transmission electron microscope and understand in which directions they are linked to and how the atoms are structured, it will be possible to explain the role of crystal grain boundaries in mechanical properties or electrical properties.

**Iwamoto:** It means that you modelize materials to a certain level, rather than simply observing them as they are.

**Ikuhara:** Yes, we modelize them. Thorough analysis by modelization will reveal the nature of the real structure of practical materials that looked complicated at first glance and enable us to make predictions on all kinds of things.

**Iwamoto:** I understand.

**Ikuhara:** You only need to understand the basic points. Then set up principles based on those basic points, establish the so-called materials design guidelines, and finally apply them to practical materials and polycrystalline bodies.

**Iwamoto:** So, materials design is the starting point.

**Ikuhara:** Yes, we don't just look at atoms and do nothing else. I am basically specialized in materials. The ultimate goal is to design better materials or to find out how to make them. In order to achieve this, I make model materials and analyze the structure of grain boundaries in a quantitative manner.

***Manufacturing and Materials Design***

**Iwamoto:** So, it can be said that materials design starts from the awareness to think about why various physical properties are what they are.

**Ikuhara:** Yes. "Why" is the starting point for everything.

**Iwamoto:** Starting from questions, such as why this composition has such strong resistance, and then start thinking about possible shapes…

**Ikuhara:** Yes.

**Iwamoto:** It takes a lot of work.

**Ikuhara:** It means that first we have to establish rational materials design guidelines, and then make actual materials.

**Iwamoto:** That's right. So, I suppose there is various feedback exchanged during this process. When the materials design is finished, it will be analyzed again and changes will be made to the design. Through this process, the ideal material will be produced as intended.

**Ikuhara:** The most important thing is to apply the materials to the actual manufacturing. In the case of ceramics, it means the contribution to the industry and ceramics manufacturers. As you know, one of the most well-known ceramics is alumina.

**Iwamoto:** Yes.

**Ikuhara:** Actually it contains various sintering additives. Alumina contains not only aluminum and oxygen but also various dopants that are added by manufacturers. Ceramics manufacturers add a lot of different elements such as rare-earth and magnesium in order to produce better and stronger ceramics. As for alumina, five or six types of dopants may be added. They have been producing good products, but their method is very thorough like "carpet bombing." For example, they would add a lot of different kinds of dopants, which they call "flavoring," on an empirical basis to create various prototypes and to measure the strength of each prototype. Then, when they identify the best material, they will produce it on a commercial basis.

**Iwamoto:** Yes.

**Ikuhara:** It costs a lot of time, labor and money to commercialize it.

**Iwamoto:** It is indeed "carpet bombing" as you said.

**Ikuhara:** They tend to carry out the work from their experience. Companies have their own know-how and experiences. So, they have accumulation of knowledge and their own best method. This also applies to structural materials and electronic ceramics such as varistors and capacitors.

**Iwamoto:** Yes.

**Ikuhara:** It is normal to add about 10 types of dopants to varistors or capacitors. And as a result, it is not very clear what makes good products.

**Iwamoto:** I see.

**Ikuhara:** But the companies do not worry about it because they sell very well.

**Iwamoto:** In a way, it is like a skill of a craftsman.

**Ikuhara:** Or rather, I would say it is the fruits of their experience, intuition, and tremendous effort over many years.

**Iwamoto:** It sounds very cost-consuming.

**Ikuhara:** It costs a lot, but craftsmanship is what Japan is proud of.

**Iwamoto:** Yes, indeed.

**Ikuhara:** It is the strength of Japan, and Japanese people have been working very seriously and patiently to produce something exceptional and to make it into products. So, if you ask the person in charge of design and development why they added a particular dopant, they often cannot say the reason. They did so, because it produced a good result. When this dopant was added, the strength was increased; or when that dopant was added, the flow of electricity was improved, and so on. These empirical elements were, however, very important in the high economic growth period of Japan.

**Iwamoto:** I can see that.

**Ikuhara:** And as a matter of fact, the products sell very well. This is something hard to catch up with for Europe and the United States, and this is the reason why it is said that Japan is the best manufacturing country in the world.

**Iwamoto:** Yes.

**Ikuhara:** However, the situation has reached a saturation point now, and it is difficult to find the next direction to move into. There are not many things left to do with empirical methods, and there is little future for Japan if it continues this way.

**Iwamoto:** Yes.

**Ikuhara:** Then, I think the next step should be to develop more rational methods of manufacturing. And therefore, we are trying to find out what can improve strength, and why. The simplest example is that aluminum can be strengthened by adding rare-earth elements.

**Iwamoto:** Could you give me examples of the rare-earth elements in this context?

**Ikuhara:** Such as yttrium and lutetium. Adding a tiny amount of these elements as dopants can strengthen materials. In fact, such rare-earth elements are added to high-strength alumina materials.

**Iwamoto:** I see.

**Ikuhara:** It is possible to analyze how these rare-earth elements such as yttrium are located in grain boundaries and how they are linked by using the state-of-art transmission electron microscope. As a result, we found that yttrium atoms periodically move into much localized regions along the grain boundary and significantly change ionic bonding of alumina to covalent bonding. And the link between grains was strengthened. It is as simple as that. Although our finding was very simple, it was published in *Science* magazine (Science 311 (2006) 212-215, “Grain Boundary Strengthening in Alumina by Rare Earth Impurities”).

**Iwamoto:** It’s wonderful.

**Ikuhara:** I think nature is actually very simple. But we did not even know such things. So, systematic research on the relation of dopants and their effects will lead to rational materials design, which specifies what and how much elements should be combined when creating a material with certain properties.

**Iwamoto:** I see. Is it something like, if you mix whisky and soda, it tastes very good, for example?

**Ikuhara:** Yes, you will do it from experience, rather than finding it out. But you don’t know why it tastes good.

**Iwamoto:** No, but you know it tastes good.

**Ikuhara:** So, for example, because you don’t know why it tastes good, you would have to drink it and learn how the element is transformed into taste on your tongue and transmitted to the neurons and to the certain brain area that produces feelings of pleasure. It is necessary to analyze the mechanism.

**Iwamoto:** I see. Analysis is the key.

**Ikuhara:** The best method that produces feelings of pleasure should be identified. It may be the mixing ratio, or the method, like, it is better to put a pickled plum into shochu rather than putting some other certain thing.

**Iwamoto:** I see.

**Ikuhara:** It means to clarify and understand the roots of thing. We do it at the atom and molecule level. That is exactly the mission of WPI-AIMR.

**Iwamoto:** Yes. The methods based on atom and molecule control are certainly the base of WPI-AIMR, and your research is the typical example.

**Ikuhara:** Yes, exactly. Our aim is to control and clarify the role of the atom/molecule. Although we adopt electron microscopes and theoretical calculations, we would like to combine them, clarify the roots and develop rational materials design. I think the trend of materials design will be definitely shifted to that direction in the 21st century.

***From Basics to Application***

**Iwamoto:** Talking about the fundamental issues, companies used to employ methods that use empirical rules; however, do you think they are seeking more rational methods due to the economic downturn?

**Ikuhara:** I think it is because the traditional methods are coming to a dead end, rather than the economic downturn issues.

**Iwamoto:** So, the "carpet-bombing" method does not work anymore.

**Ikuhara:** No. That's why companies are struggling to find the next step, but the sense of stagnation has been growing among various companies in the materials field.

**Iwamoto:** Yes. Then, it is understandable that the industry itself is seeking such rational methods. And on the other hand, what exactly is happening in grain boundaries has been gradually becoming clear in the world of scientific principles.

**Ikuhara:** Until recently, companies, especially ceramics manufacturers and materials manufacturers were not actively taking such an approach, or they seemed to be avoiding it because the study was too basic; however, the trend seems to have changed since the introduction of scanning transmission electron microscopy (STEM) that can identify atoms and show the atomic order. It is now possible to see all kinds of elements including hydrogen. Times have changed, and computing technology has also been greatly developed.

**Iwamoto:** Yes.

**Ikuhara:** Some companies have started realizing that if they use these methods and technologies, it will be possible to develop rational materials design.

**Iwamoto:** Interesting.

**Ikuhara:** I am often contacted by companies.

**Iwamoto:** I thought your lab was specialized in the most basic part of basic research.

**Ikuhara:** Not exactly. I would like to contribute the next step to industrialization, I mean manufacturing. I am sure that substantial manufacturing can only be achieved with the help of basic research.

**Iwamoto:** I see. You would like to contribute to manufacturing. Then, as you mentioned just now, is it closely related to theoretical calculation? In that sense, the approach from the theoretical calculation point of view, which Professor Tsukada and Professor Shluger are taking, is becoming more important. Is that right?

**Ikuhara:** Yes, it is important, but of course, theoretical calculation is not enough for everything. There are a countless number of combinations. Therefore, we first need to confirm the location of the added elements by using an electron microscope and do calculations based on that location. If there is no information about atomic order, the calculation is just a fantasy world.

**Iwamoto:** That's why it is necessary to clarify the actual status in the real world to some degree before starting calculation. It is not possible to produce results if there is no detailed information about atoms.

**Ikuhara:** Yes, it is best if we have properly measured data, which then can be calculated by Professor Tsukada and Professor Shluger. We also conduct calculations to some degree in my lab.

**Iwamoto:** Yes.

**Ikuhara:** Obtained structural data only show how it looks. The electronic state around the added dopant can be explained by calculation, which will enable us to estimate functions. For example, if ionic bonding was changed to covalent bonding, it means that the material was strengthened. These things can be found by calculation. Therefore, calculation is an essential item for us to analyze the measured data. It can be said that calculation is necessary to interpret the obtained data. A function is developed as a result of multiple elements, such as that a single atom moved or a cluster was formed inside.

**Iwamoto:** Yes. Functions are produced by these multiple elements and bonding methods.

**Ikuhara:** This is where grain boundaries and interfaces become important.

**Iwamoto:** I see, that's what it means.

**Ikuhara:** Dopants and impurities tend to gather in such lattice-mismatched sites.

**Iwamoto:** Going back to the tool you mentioned earlier, what level of unit do you use in your observation by STEM?

**Ikuhara:** Currently the maximum resolution can be less than 1Å. As you know 1Å is equal to 0.1 nm. This is how we can see hydrogen atoms.
**Iwamoto:** As you described earlier.
**Ikuhara:** AIMR has such facilities for communal use.
**Iwamoto:** In the context of the relationship with manufacturing, would it be right to say that your research aims to show directions to change physical properties of materials?
**Ikuhara:** I am trying to develop guidelines for such use. I also partly produce actual materials after developing guidelines.
**Iwamoto:** How do you make them?
**Ikuhara:** I use design guidelines that were obtained from nano characterization and theoretical calculation. For example, if I find out which elements should be added in order to strengthen alumina, I would actually apply the method to sintering to make sintered bodies.
**Iwamoto:** So, you are tackling it from two directions: guidelines on the upstream side and manufacturing.
**Ikuhara:** Yes. However, thankfully the final production of bulk is carried out by companies or other co-researchers following our guidelines. We mainly provide models and samples.
**Iwamoto:** Yes. Models and samples for establishing guidelines are created here. I see.

***Before Coming to AIMR***

**Iwamoto:** You graduated from Kyushu University, but where are you from originally?
**Ikuhara:** I was born in Tsu City in Mie Prefecture. My mother's parents' home was in North Kyushu, and I was familiar with the place. That is why I chose Kyushu University. I grew up in Tsu City (former Hisai City) due to my parents' work.
**Iwamoto:** How long did you live in Tsu City?
**Ikuhara:** Until I finished high school.
**Iwamoto:** Before you came to AIMR, were you familiar with Tohoku University and Sendai?
**Ikuhara:** Yes. My professor at Kyushu University had previously worked for the Institute for Materials Research (IMR), Tohoku University.
**Iwamoto:** Who was that?
**Ikuhara:** Professor Hideo Yoshinaga. He worked as an associate professor at IMR and then moved to Kyushu University as a professor.
**Iwamoto:** And he was your professor at Kyushu University?
**Ikuhara:** Yes, Professor Yoshinaga was in Professor Shigeyasu Koda's lab at Tohoku University. He is a relative of the novelist Rohan Koda and a very famous professor in metal physics. I was very lucky to study under Professor Yoshinaga after he came to Kyushu

University. He regarded the basics as very important, and I learned various ways of thinking from him. In that sense, I have connections to Tohoku University.

**Iwamoto:** I see, since your university days.

**Ikuhara:** In addition, when I started working as an associate professor at the University of Tokyo 15 years ago, I worked with Professor Takeo Sakuma who was also from Department of Metallurgy, Tohoku University. I learned a lot about ceramics research from him. Before I came to the University of Tokyo, I served as a division head of the Japan Fine Ceramics Center (JFCC) in Nagoya. JFCC is also a very important laboratory for me, and I currently work for them too. Mr. Masaaki Ohashi was the Chairman at that time. Mr. Ohashi is the current chief director of Meijo University, and I still learn a lot from him. He has also graduated from Metallurgy Department of Tohoku University. It is interesting that all three professors have some connection to Tohoku University, and they all have served as the president of the Japan Institute of Metals.

**Iwamoto:** So, there were people associated with Tohoku University very close to you.

**Ikuhara:** After all, all of my bosses had connections to Tohoku University.

**Iwamoto:** That's right.

**Ikuhara:** In that sense, Tohoku University has produced so many different human resources in the field of materials science and engineering all over Japan.

**Iwamoto:** That's right. In fact, they do not stay at Tohoku University forever. They play active roles in many different places. This is quite influential. On the other hand, Tohoku University itself also invites professors from various organizations, which I think great. I see. By the way, after you graduated from Kyushu University, you joined JFCC, and then studied at Case Western Reserve University from 1991 onward.

**Ikuhara:** Yes, the university is located in Cleveland in the United States. I studied there for a year and half.

**Iwamoto:** Was your research mainly on materials analysis of ceramics there too?

**Ikuhara:** Yes. I was researching interfaces, specifically hetero interfaces which are, for example, interfaces between ceramics and metals.

**Iwamoto:** Do you still keep in touch with the professors from your days in the United States?

**Ikuhara:** Yes, very much so. I learnt under Professor Pirouz who specializes in dislocation theory, especially lattice defects, and Professor Heuer who specializes in ceramics. I maintain contact with them.

**Iwamoto:** After that you returned to JFCC and then have been working for the University of Tokyo as an associate professor since 1996. Have you been working in the Hongo campus all the time?

**Ikuhara:** Yes, I have.

**Iwamoto:** You have also been working for AIMR as a PI since its start. Do you feel a difference in the academic culture between the University of Tokyo and Tohoku University?

**Ikuhara:** Yes. From a materials research point of view, I think Tohoku University covers a wider and deeper range. I accepted the offer to be a PI as it would give me an opportunity to work with the top-class professors in materials science in Tohoku University.

**Iwamoto:** Do you think the tradition of Tohoku University or the culture to put emphasis on practical science has an influence?

**Ikuhara:** I think it has significant strength in materials science or study of materials, rather than practical science.

**Iwamoto:** Yes, of course, Tohoku University has a long continuous history since the days of Dr. Kotaro Honda. This compares favorably with the University of Tokyo.

**Ikuhara:** I would rather say that Tohoku University is definitely better in materials research.

**Iwamoto:** Great.

**Ikuhara:** Materials research in Tohoku University covers wider and deeper subjects such as metals, ceramics, organic materials. That is why it is internationally regarded as the highest in the field of materials. I think this is why WPI was established in Tohoku University.

***Tasks for AIMR***

**Iwamoto:** What do you think of WPI-AIMR? It has been three and a half years since it was established. Do you think the research environment is good?

**Ikuhara:** Yes, I think so.

**Iwamoto:** What do you think is good about it?

**Ikuhara:** As I also work for the University of Tokyo, I only come to Tohoku University four days a month, but it provides an environment where we can focus on our research. I think it is a great thing that young researches can focus on their research and compete. It is also great that President Inoue encourages “putting a lot of focus on research.”

**Iwamoto:** As AIMR is specialized in research, we are trying to keep odd jobs away from professors.

**Ikuhara:** Yes, indeed.

**Iwamoto:** It is typical that bigger universities tend to have many different kinds of meetings, but we are trying to minimize these meetings. From this point of view, I think we are very different from others.

**Ikuhara:** Thanks to this system, the young staff in their 30s can concentrate on their research and compete with others. And their effort is recognized. This is very encouraging.

**Iwamoto:** Yes. Especially, as next April is the start of the second term of five years, the current mid-career members, who are not PI but associate professors or lecturers, are working really hard.

**Ikuhara:** Yes they are. I think the fact that they are on a fixed-term contract makes them more vigilant in their research.

**Iwamoto:** I would like to add one more thing. WPI adopts internationality as its slogan and there are a few foreign researchers in your lab. Do you think they are blending in well?

**Ikuhara:** Yes. Currently we have Assistant Professor Wang and other young researchers in my lab, and Dr. Wang is working very hard.

**Iwamoto:** Yes, he is. I can see it from various points. Do you have something you especially care about in terms of training the young researchers in your lab?

**Ikuhara:** Yes, we always discuss things thoroughly. Discussions are necessary. In addition, I try to respect young researchers' opinions as much as possible when determining the direction of research.

**Iwamoto:** I see.

**Ikuhara:** I don't want to say, "Do this" or "Do that," although I decide the outlines.

**Iwamoto:** I understand. So, you respect various different ways of thinking. I see. Then, we really have to work hard in the next five years too. As we are heading toward the mid-term evaluation, do you have any requests or expectations toward AIMR in terms of improvement?

**Ikuhara:** I think we need more integration.

**Iwamoto:** I see.

**Ikuhara:** I mean we are in a sense outsiders here. For example, say we want to have a tea time discussion from five o'clock. The attendance will be different depending on whether AIMR staff have students or not, like us. I feel we need more mutual communication with the internal staff.

**Iwamoto:** The construction of new building will be completed soon and a lot of researchers are coming from the Aobayama campus. I am looking forward to it, but I think we have to do more than just wait. Actually I am thinking of a way to combine staff meetings and tea time. It needs some consideration.

**Ikuhara:** If this system works well, we can be more powerful.

**Iwamoto:** Yes. As it is often said, the professors in AIMR, including you, are all top players.

**Ikuhara:** I think it may be quite true.

**Iwamoto:** As WPI puts emphasis on fusion research, a collaborative research with theory is in a way indispensable, as you mentioned. Does your lab also work with researchers of soft materials?

**Ikuhara:** Yes it is. But it is rather related to inorganic materials. We do some research on such subjects with Professor Kawasaki and Professor Adschiri, as well as with Professor

Asao and Professor Hitosugi.

**Iwamoto:** It is our mission to establish new academic principles through fusion research.

**Ikuhara:** We have published our achievement of fusion research, the work with Professor Kawasaki and Professor Tsukada, in *Nature Communications* (Vol. 1, Article number 106, "Dimensionality-driven insulator-metal transition in A-site excess non-stoichiometric perovskites"). The research with Professor Kawasaki's group was also published in *Science* (Vol. 332 (2011) 1065-1067, "Electrically Induced Ferromagnetism at Room Temperature in Cobalt-Doped Titanium Dioxide").

**Iwamoto:** Wonderful.

**Ikuhara:** The fruits of our research have already been published in those top journals.

**Iwamoto:** Yes, indeed. As the result of fusion research has been already recognized like this, I think it is important to improve it in future too. I have one more thing to ask, which I always ask as a general question. You told me earlier that young researchers in their 30s and 40s are doing great job. On the other hand, younger researchers such as post-doctoral fellows or researchers in their 20s, especially Japanese ones, are said to be reclusive or not very energetic. What do you think about this?

**Ikuhara:** I think it depends on the field. Young researchers in my lab are generally energetic. It is true that some of young researchers are not very energetic in Japan. I think it is also a reflection of the fact that they did not learn science with enthusiasm in their education from when they were in primary school. It caused them to lose interest in science.

***Science Education Activities***

**Iwamoto:** I agree with you. As a child, were you interested in science and manufacturing?

**Ikuhara:** Yes. I have been interested in scientific ways of thinking and physics since I was a junior high school student.

**Iwamoto:** As you were born in 1958, it was about 1970?

**Ikuhara:** Yes.

**Iwamoto:** It was 1965 when Dr. Tomonaga was awarded the Novel Prize. Although pollution problems were emerging, there were dreams for science and technology at that time.

**Ikuhara:** Yes, indeed. Events such as Apollo 11's landing on the moon made everyone aware that science and technology had a great future.

**Iwamoto:** Yes, indeed. School teachers also told us more interesting stories.

**Ikuhara:** About science. Then, students became interested in science and wanted to learn more about it. But I cannot see that in the current primary school education.

**Iwamoto:** I agree. On the other hand, AIMR is conducting various outreach activities such as participating in the science café. We may ask for your support in future for these activities.

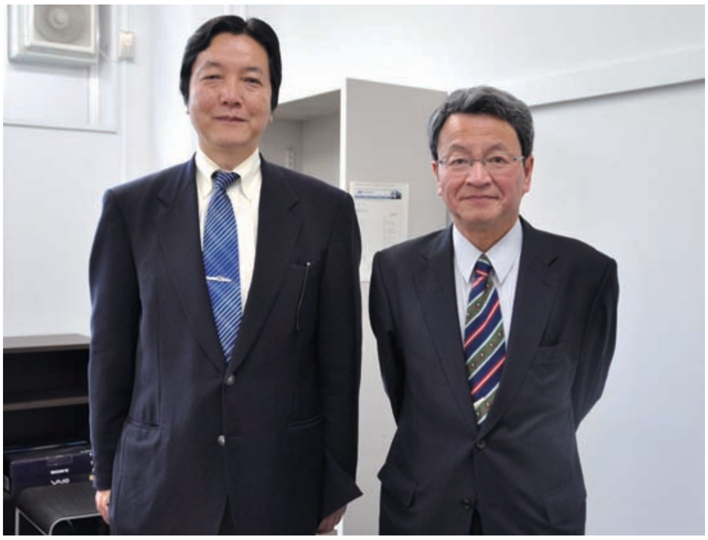
**Ikuhara:** I also think that media is responsible for the loss of interest in science. In the US, there are TV channels dedicated to science programs such as Discovery Channel and Science Room. These programs have started to be broadcasted in Japan recently, though. There is a trend in Japan that encourages young people to think that there is nothing wrong with showing TV programs in which comedians are making a fuss—and nothing else. I don't think this is acceptable.

**Iwamoto:** There are only a few science programs on NHK. I think it is of course important for researchers to publish their real opinions, but I also think it is important to interpret them and tell Japanese people in a form that they can understand. That is the role of the outreach activities.

**Ikuhara:** Dr. Kitazawa, the President of JST, often says the same thing.

**Iwamoto:** Dr. Kitazawa, and JST itself, is very keen on promoting public understanding of science. As Japan's pension burden increases in future, I think how we can gain public support for science and technology will be the key to increase public investment in science and technology.

Thank you very much for taking your time for this interview.



Interviewer: Administrative Director, W. Iwamoto

*At Ikuhara Laboratory, WPI-AIMR Annex Building*

*May 25th, 2011*

WPI-AIMR PI　幾原雄一教授に聞く
(Interview with Professor Yuichi Ikuhara－Japanese version)

# 材料設計とものづくり

## フンボルト賞と粒界の研究

**岩本：**今回はフンボルト賞ご受賞おめでとうございます。３月にドイツ、バンベルクで行われた授賞式に出席されたとのことですが、材料科学分野では日本人では３人目の受賞だそうですね。

**幾原：**はい、そう聞いています。フンボルト賞は、自然科学だけではなくて文学、法学、宗教学と２３分野ぐらいカバーしているようです。日本人では全部合わせると今まで５，６０人。自然科学では３０人くらいが受賞しているようです。山本機構長も化学の分野で授与されています。

**岩本：**そうですね。２００２年に受賞されていますね。

**幾原：**最初の頃にもらわれた方は小柴先生ですね。

**岩本：**ニュートリノ天体物理学でノーベル賞を受賞された小柴先生ですね。

**幾原：**そうですね、そして昨年ノーベル賞を受賞した根岸先生もそうですね。元東大総長の有馬先生も受賞されています。

**岩本：**そうそうたる顔触れですね。ところで、フンボルト賞の受賞の対象となった研究は、「材料界面の超微細構造と物性に関する研究」というものですね。これは、材料科学の分野に大きなブレークスルーを与えたと聞いていますが、具体的に言うとどういう内容ですか。

**幾原：**我々が使っている材料というのは多結晶が多いのですが、多結晶というのは、必ず中に粒界があるんです。材料は、小さな結晶の粒がいっぱい集まって多結晶体になっています。それはセラミックスもそうですし金属材料でもそうですし、我々が取り扱うバルクというのは、大抵の場合多結晶なのです。その結晶と結晶の間を粒界と言うのです。

**岩本：**はい、分かります。

**幾原：**その粒界構造が物性とか特性を決めているというのが非常に多いのです。例えば一番簡単に言うと、物が割れやすいとか。あるいは例えば電子セラミックスの電気的特性もそうです。たとえば、バリスタの特性が出るとかというのも粒界の構造、すなわち粒界で原子がどうつながっているかということが重要なのです。

**岩本：**：なるほど。だからそれを物理的に壊れやすいだとか、弾性があるとかということもそうだし、今おっしゃったような電気的な特性がみんな粒界と関係しているわけですね。

**幾原：**だから、粒界に存在する原子の構造を電子顕微鏡で見て、どういうふうになっているか、どういうふうに結晶の粒と粒がつながっているかとか、そこを明らかにすれば、根本的な物性の発現機構が理解できるだろうということで、その原子のつなぎ目を電子顕微鏡で定量的に解析しています。そして、こうやったら材料が強くなるとか、電気が流れるとかを予測した研究を進めています。

**岩本：**そうですね。

**幾原：**それを、主にセラミックスを対象としてこれまで取り組んできました。

**岩本：**セラミックスに着目されたというのは、ほかの物質に比べてどういう特性があるからなのですか。

**幾原：**セラミックスは多種多様なのです。金属に比べていろいろな種類があります。炭化物とか、窒化物、酸化物とか。だから、今いろいろな機能セラミックス、機能材料が出ていますけど、そういうものも基本的には酸化物とか窒化物とか炭化物とか、いわゆるセラミックスのグループに入るわけです。そういう多種多様な面白さからセラミックスを対象としていますが、金属材料についても違った角度から研究はしております。

**岩本：**なるほど、わかりました。

**幾原：**我々、原子分子材料科学高等研究機構は、原子分子制御が特色ですよね。

**岩本：**ええ。

**幾原：**その意味では、金属もセラミックスも、有機も無機も区別しない。アプローチは同じで、視点は原子・分子レベルです。

**岩本：**そうでしたね。わかりました。

先生の場合には、それを調べるツールは、電子顕微鏡ですね。

**幾原：**はい、主に透過電子顕微鏡です。

**岩本：**でも、万物のいろんな粒界を、一々そうやって調べていくわけですか。
大変な手間ですね。

**幾原：**大変だから、我々はそのモデル材料を作っています。多結晶の実用材料を対象とすると、結晶が色々な向きを向いているので、それを系統的に把握し、そこに存在する法則性を見出すのはなかなか難しいと思います。

**岩本：**そうですね。

**幾原：**だから、ある程度カテゴライズして、粒界を幾つかの種類に分けて自分たちでモデル粒界を作製します。透過電子顕微鏡でじっくりと観察して、こういう方位でつながっているとか、原子構造がどうなっているかを理解すれば、その結晶粒界が機械的特性とか電気的特性にどういう役割を担っているかというのを明らかにすることが可能になります。

**岩本：**単に自然にあるものを見るというのではなくて、ある程度モデル化してということですね。

**幾原：**モデル化しています。モデル化できっちりそれを解析すると、一見複雑な実用材料の構造もその本質が見えてきて、万物の予測もできるわけですよ。

**岩本：**そういうことですね。

**幾原：**基本的なところを押さえておけば良いのです。それを起点に原理原則を打ち立てて、いわゆる材料設計の指針を得て、実用材料、多結晶体に持っていくのです。

**岩本：**まず材料設計から始まるわけですね。

**幾原：**はい、我々は単に原子を見ているだけではないですよ。私は基本的には材料屋ですから。

最終的なゴールは、より良い材料を設計する。または作るためにはどうしたらいいかということを明らかにするために、モデル材料を作って粒界の構造を定量的に解析しているということです。

### ものづくりと材料設計

**岩本：**その材料設計というのは、いろいろな物性についてなぜこうなのだろうという問題意識から始まっているのですね。

**幾原：**そうです。“なぜ”がすべての出発点です。

**岩本：**こういう組成なのに、何でこれだけ抵抗が強くてとか、そういう疑問から始まって、ではこんな形なのかなというのから始まったということですね。

**幾原：**そうです。

**岩本：**それは大変な作業です。

**幾原：**合理的な材料設計指針を得て、それで実際の物まで作るということですね。

**岩本：**そういうことですね。だから、そこの場の中では、もう多様なフィードバックが行われているわけですね。材料設計を行い、それをまた調べることによって、では今度はこういった設計にしたらどうなるかと。それで理想的な、こちらのねらっているような材料を作っていこうというプロセスですか。

**幾原：**特に重要なのは、実際の物づくりへ展開するということです。たとえば、セラミックスですとセラミックスメーカーなど産業界への貢献です。最も広く知られているセラミックスにアルミナがありますよね。

**岩本：**ええ。

**幾原：**それにも実際にはいろいろなものが入っているのですよ。アルミナだからアルミと酸素だけではなくて、いろんな鼻薬を、メーカーは入れているのです。セラミックスメーカーは、希土類や、マグネシウムなど色々な元素を入れて、いいもの、強いものを作っているわけです。例えばアルミナにしても、例えば５種類、６種類入れたり入っていたりしているわけです。それでいいものを作っているけれども、彼らの今までのやり方というのは、絨毯（じゅうたん）爆撃ですよ。例えば、何種類ものドーパント、現場では鼻薬と言いますが、それを色々と経験的に入れて多数の試作品を作って、そのたびに強度を測ったり。それで一番いいものがこれだということで商品化しているわけですね。

**岩本：**そうですね。

**幾原：**それを商品化するためには、莫大な時間と労力、お金もかかるわけです。

**岩本：**絨毯爆撃とおっしゃいましたけど確かにそうですね。

**幾原：**それも経験でやっていることが多いのです。各企業はノウハウ、経験を持っているのですよ。だからその蓄積があって、これがいいというものを、各企業は持っているわけです。それは構造材料でもバリスタとかコンデンサなどの電子セラミックスも一緒です。

**岩本：**はい。

**幾原：**バリスタ、コンデンサの場合は中に１０種ぐらいの鼻薬が入っています。だから結局、

何が理由でいいものができているかというのがわからなくなっているのです。

**岩本：**ええ。

**幾原：**でも商品として売れるから、企業としてはそれでいいわけです。

**岩本：**ある意味では職人芸的にやってきているわけですよね。

**幾原：**職人芸というか、経験と勘と莫大な努力でずっとやってきたわけです。

**岩本：**でもそれも随分コストのかかる話ですよね。

**幾原：**コストはかかるけれども、そこは日本の得意技、職人技だったのですね。

**岩本：**そうですよね。

**幾原：**日本が得意で、非常にまじめな日本人だからそういうことをこつこつやっていって、それで非常にいいものを作って製品になっているわけです。それで本当に開発設計の責任者に、「何でそのドーパントを入れたのですか」と聞いても、理由は良くわからないわけです。入れたらよかったからと。この鼻薬を入れたら、強度が強くなりましたとか、この鼻薬を入れたら電気がよく流れましたとかね。そういう経験的要素というのがしかし、これまでの日本の高度経済成長期には非常に大事だったのですよね。

**岩本：**わかります。

**幾原：**実際それが売れているわけですから。そういうことはなかなか、欧米などは余り追従できないから、日本はものづくりで世界一とか言われますよね。

**岩本：**はい。

**幾原：**ただ、もうここまで飽和状態になってくると、次の打つ手がなかなか打てないわけです。かなりやり尽くしてしまっていますし、経験的な手法だけではもう日本の将来はないと思います。

**岩本：**そうですね。

**幾原：**そうすると次のステップは、やはり合理的にものを作らなくてはいけない

だから我々は、これを入れたら強くなるが、なぜ強くなるのかと考えるわけです。一番簡単な、例えばアルミでは希土類元素を入れたら強くなるのですよ。

**岩本：**希土類元素というのは、ここでは例えば。

**幾原：**イットリウムとか、ルテシウムとか、そういうものをちょっと、ほんの微量、鼻薬で入れると強くなるのです。実際の高強度アルミナ材料にはそういう希土類元素が入っているわけです。

**岩本：**はい。

**幾原：**最先端の透過電子顕微鏡を用いると、イットリウムのような希土類元素が粒界のどこに入って、どういう結合をしているかとかいうところまで解析ができるようになっています。そうすると、例えば我々が見つけたのは、イットリウム原子が粒界の特異なサイトに周期的に入っていて、アルミナのイオン結合を共有結合にぐっと変えているわけです。そして、粒と粒を強く結びつけた。たったそれだけなのです。そういうことがわかったということで、非常にシンプルな話にも関わらず５年前ですが、サイエンス誌（Science 311 (2006) 212-215、“Grain Boundary Strengthening in Alumina by Rare Earth Impurities”）に掲載されました。

**岩本：**素晴らしい。
**幾原：**自然は非常にシンプルなのだと思います。でも、そんなことでさえわかっていなかったのです。だから、その鼻薬を入れたらどういう作用をしてということを系統的に研究していくと、こういう特性のものを作りたいというときに、どの元素とどの元素をどれくらい配合して入れて作れば良いという合理的な材料設計ができます。
**岩本：**そうか。だから、アルコールで言えば、ウイスキーにソーダを入れたらおいしいというようなものですか。
**幾原：**だれかが見つけたというよりは、それは経験でやっていたことですね。でも何故おいしいかわからないでしょう。
**岩本：**しかし飲むとうまいです。
**幾原：**だから、何でおいしいかわからないから、それをやるためには、例えばそれを飲んで、舌からその要素が味覚に発展していって脳のニューロンを伝わって脳の快感をつかさどる部位を刺激するという過程を分かる必要がある。そのメカニズムを解明していかないといけない。
**岩本：**その分析をしないといけないですね。
**幾原：**それがちゃんと、どういうふうにしたら一番快感を覚えるとかというのを明らかにすると、配合比とかね、あるいは焼酎に氷だけを入れるのではなくて、梅干をぽんと入れたほうがいいよとかですね。
**岩本：**そういうことですか。
**幾原：**物事の根源をクリアーする。それを原子、電子レベルで、まさに原子分子材料科学高等研究機構のミッションですよね。
**岩本：**そうですね。確かに私どもの機構は、原子分子制御法というものを土台にしていますが、まさにその代表的な研究なわけですね。
**幾原：**はい、まさにそこを制御して、その役割を明らかにすること。電子顕微鏡と理論計算もやりますけど、それをコンバインして、根源を明らかにして、合理的な材料設計をしていく。私は、今世紀の材料設計は、必ずそういう方向になると思います。

### 基礎から応用まで

**岩本：**ちょっと根源的な話になりますけれど、昔は経験則に基づいて各企業がやっていたわけですが、やはり経済情勢の悪化などでそういうのが求められるようになったと言えますか。
**幾原：**経済情勢というか、もうこれまでの手法では立ち行かなくなっていると思います。
**岩本：**絨毯爆撃的な手法ではだめということですね。
**幾原：**ええ。だから、次の一手が打てないから、今は材料系のいろいろな会社も閉塞感が漂っていますよね。
**岩本：**そうですね。そうすると産業界としても、当然そういう手法を求めているし、また一方では、学理の世界では、当然今までの蓄積で粒界で何かが起きているということがだんだんわかってきたということですね。

**幾原：**ちょっと前まではそういうところを企業は、特にセラミックスメーカー、材料メーカーは、あんまりやらなかったというか、むしろ基礎学問過ぎて敬遠していたようなイメージがあったのですけど、原子を識別してその配列が直接見えるSTEM（透過電子顕微鏡）法が登場して少し流れが変化しているように感じます。現在ではもう水素に至るまですべての元素が見えてきています。ということは、そういう時代になってきて、あと計算技術も非常に発達しているではないですか。

**岩本：**はい。

**幾原：**そういう手法を上手く利用したら、合理的な材料設計ができるだろうということを一部の企業の方々は既に気づき始めているのです。

**岩本：**ほう。

**幾原：**結構企業の人が私のところへもコンタクトしてきますよ。

**岩本：**私は幾原先生のところは、基礎研究の中でも特に基礎かと思っていました。

**幾原：**いや、そうではないです。次のステップは産業化に役立てたいと思います。物づくりです。基礎研究があってこそはじめてしっかりした物づくりにつながると確信しています。

**岩本：**物ですね。ものづくりに役立てようということ、わかりました。

そうすると、それと同時に今ちょっとおっしゃいましたけど、理論計算と大きなつながりがありますね。だから、塚田先生やシュルガー先生のそういった理論計算的なアプローチというものが、重要になってくるわけですね。

**幾原：**重要になってきます。なってくるけれども、理論計算だけでは勿論不十分ですよ。もう無数の組み合わせがありますから。だから、電子顕微鏡で、加えた元素がどの位置にあるかということをまず押さえてから、それをベースに計算する必要があります。原子配列の情報も何もなくて計算したって、それは単なる空想の世界になりますから。

**岩本：**だから現実に、どこまでこうだからというのをある程度クリアーにして、計算するというならわかるけど、何かこういう原子と原子がありますから計算してくださいでは何も出てこないですね。

**幾原：**だから、ちゃんと計測したものがあって、それを塚田先生とかシュルガー先生が計算してくれるのがよいと思います。我々も研究室の中でもある程度の計算はやっていますよ。

**岩本：**そうですね。

**幾原：**得られた構造データだけだったら、それは見ただけになりますから。計算によって、入れたドーパン等の周りの電子状態がどうなっているとか、そういうことがわかると機能の予測につながるわけですよ。結合が、例えばイオン結合から共有結合に変わっていたら、それは強くなっていることを示唆しますから。そういうことまで計算でわかります。だから、我々にとって計算は計測データを解釈する必需品です。得られたデータを解釈するところで計算が必要だと考えていただいたらよいと思います。原子１個が入ったり、クラスターが中にできたりして、その複合的要素として機能が発現するのです。

**岩本：**そうですね。その複合的要素として、その結びつき方だとか、そういうことで機能が生

まれてくるわけですね。

**幾原：**そこで重要になってくるのは、粒界とか界面です。

**岩本：**そういうことなのですね。

**幾原：**そういった格子不整合領域にはドーパントや不純物などが集まりやすいですから。

**岩本：**先ほどのツールのお話で、STEMで実際に観察するといった場合には、どのくらいの単位のものを見ているわけですか。

**幾原：**もう今は最高分解能でいくと、１オングストロームを切っています。１オングストロームというのは０．１ナノメートルですよね。だから水素原子が見えるのです。

**岩本：**先ほどのお話でそうですね。

**幾原：**そういう設備が、AIMRの共通設備としても既にあります。

**岩本：**先程のものづくりとの関連に戻りますが、先生の場合は物の性質を変えていく上での方向性をお示しになるということでしょうか。

**幾原：**そういう指針を得ることをしています。指針を得て実際に作ることも一部行っています。

**岩本：**どうやって作るのですか。

**幾原：**ナノ計測プラス理論計算で得た設計指針を用いて、例えばアルミナを強化するためにはどの種類の元素を入れたらよいのか、ということがわかりますと、今度は実際の焼結でそれを応用して焼結体を作製する。

**岩本：**そうすると、指針という川上の面とものづくりと両方から攻めるのですね。

**幾原：**そうですね。ただ、最終的なバルクの作製はもう例えば企業の人がやってくださったり、ほかの共同研究者が我々の指針を用いてやってくれています。我々は、モデル、サンプルのところを主に行っております。

**岩本：**そうですね。指針を得るためのモデル、サンプルはここで作られるわけですね。わかりました。

**AIMRと出会うまで**

**岩本：**先生は九州大学ご出身ですけど、お生まれはどちらなのですか。

**幾原：**生まれは三重県の津です。母方の実家が北九州でしたので、九州にはなじみがあったから九大に行ったのですけれど。親の仕事の関係で三重県の津市（旧久居市）で育ちました。

**岩本：**津にはどのくらいまでいらっしゃったんですか。

**幾原：**津は高校までです。

**岩本：**AIMRに来られるまで、東北大学とか仙台には馴染みがあったのですか。

**幾原：**はい。九州大学の私の恩師が、やはり東北大の金研におられましたから。

**岩本：**どなたですか。

**幾原：**吉永日出男先生です。東北大の金研で助教授までやられて、九大に教授で来られました。

**岩本：**その方が九大の恩師でいらっしゃる。

**幾原：**吉永先生は、東北大の幸田成康先生の研究室におられました。幸田先生というのは小説

家の幸田露伴のご親族で、非常に有名な金属物理の先生です。吉永先生が金研から九大に教授で来られてそこで勉強させて頂いたのが私にとっては非常によかったです。基礎を非常に大切にする先生で、ものの考え方をいろいろと学びました。そういう意味でも東北大に接点があるのです。

**岩本：**そうですね。そのころから。

**幾原：**また、１５年程前に東大に助教授として赴任したときの教授が、東北大学の金属系から来られた佐久間健人先生でして、セラミックスの研究に関して色々とご指導を頂きました。また、東大に赴任する前は、私は、名古屋にある財団法人ファインセラミックスセンターの部長をしておりました。このセンターは私にとっても非常に大事な研究所でして、現在も兼務させてもらっていますが、当時の理事長が大橋正昭氏でした。大橋先生は現在は名城大学の理事長をされておられ今でも色々とご指導頂いていますが、彼もまた東北大学の金属系のご出身でした。面白いことに３人とも東北大の金属にゆかりのある方々で、３人とも金属学会の会長を歴任しておられます。

**岩本：**では東北大学ゆかりの方とは随分身近に接しておられたのですね。

**幾原：**結果としてゆかりの方々が上司だったのですね。上司には非常に恵まれたと思います。

**岩本：**そういうことになりますね。

**幾原：**はい、そういう意味では東北大の金属からは実にいろいろな人材を日本中に輩出してきたというのもあるわけですね。

**岩本：**そういうことですね。確かに東北大学だけにとどまっていないのですね。いろんなところで活躍されている。そういった影響というのは大きいですね。また逆に東北大学自身も、今現在もいろんなところから逆に先生方を迎えているし、そこはすばらしいところだと思いますね。わかりました。

　ところで、先生は九州大学を卒業されて、ファインセラミックスセンターに入られて、それから９１年からは、ケースウエスタンリザーブ大学にいかれましたね。

**幾原：**アメリカのクリーブランドにある大学です。そこに１年半いました。

**岩本：**ここでも主にセラミックスについての材料分析をされていたのですか。

**幾原：**そうですね。そこで界面でもヘテロ界面というのを研究しました。ヘテロ界面というのは、セラミックスと金属の界面とかです。

**岩本：**そのころの先生とは、今でもおつき合いありますか。

**幾原：**非常にあります。恩師は、転位論特に格子欠陥の専門家のピローズ教授とセラミックスの専門家のホイヤー教授で、今でもおつきあいをさせて頂いています。

**岩本：**それからまたファインセラミックスセンターに戻られて、９６年から東京大学に助教授になられたのですね。ずっと本郷ですか。

**幾原：**本郷です。

**岩本：**先生の場合には、もうAIMR創設当初から私どものPIとして、併任で来ていただいている訳ですが、東大と東北大の学風の違いを感じられますか。

**幾原：**そうですね。やはり材料の研究という意味では、やはり東北大学のほうが幅も広いし、

深みがあるのではないですかね。そういう意味で、はじめPIのお誘いがあったときも、東北大学のトップクラスの材料科学の先生方と組めるということでお引き受けした次第です。

**岩本：**やはり東北大学ならではの伝統というか、実学重視というのが影響していますか。

**幾原：**実学というか、材料科学は非常に強いですね。材料学といいますか。

**岩本：**それはもう、本多光太郎博士から始まってずっと連綿たる歴史がありますものね。これは決して東大に比べて遜色ない。

**幾原：**遜色ないというよりは、材料研究という観点からはもう断然勝っているのではないでしょうか。

**岩本：**そうですか。

**幾原：**東北大の材料研究は、金属、セラミックス、有機材料など非常に幅広くて深みがある。だから、国際的にも材料では一番レベルが高いという評価もされていますね。だからWPIも東北大にできたと思うのですよ。

**AIMRの課題**

**岩本：**WPI-AIMRというのはどうですか。できてからこれで３年半になりますけど、やはり研究環境としてはいいですか。

**幾原：**いいと思いますね。

**岩本：**どういった点がいいですか。

**幾原：**私の場合は東大と兼務のため、定期的に月４日位しか来ていないのですけれども、研究に特化できる環境になっていますよね。若手の研究者が研究に特化して勝負できるということはいいですよ。井上総長も“研究中心”と言われているのは実にすばらしいですね。

**岩本：**一方AIMRは、研究に特化していて、なるべく私どもも先生方に雑用はさせないようにしています。

**幾原：**ないです。

**岩本：**それと、何々会議、何々会議というのがどうしても大きな大学ほどありますよね。それはなるべく少なくしていますが。そういった点は確かに非常に違いますでしょうね。

**幾原：**そういうシステムだから若手の３０代前半から後半にかけての人は研究に集中して、競ってやる。しかもそれが評価されているわけですから、それは非常に大きいと思います。

**岩本：**そうですね。特に私ども、来年の４月から第２期の５年に入るわけで、そのときに今の中堅クラスというか、PIではないけれども、准教授や講師などの人たちが特に頑張っていますよね。

**幾原：**頑張っています。だから、任期もつきながらやっている状況にあるとやはり、非常に緊張感を持って研究できていいのではないですか。

**岩本：**あともう一つ、WPIの特色として国際性を標榜していますが、先生の研究室にも外国人の研究者が何人かいらっしゃいますけれど、そういった方々は、割と溶け込んでやっているという感じですか。

幾原：そうですね。今私のところで助教をしているのは王君と若手研究者なのですが、彼は非常に頑張っていますよ。

岩本：彼は頑張っていますね。いろんなものを見ても。

特に先生の研究室では、そうやって若手研究者の指導にあたって気を使ったりしているところはございますか。

幾原：それは、常に徹底したディスカッションをします。ディスカッションは当然ですけど。あと、若手から出てきた意見は、なるべく尊重しながら研究の方向性を決めていくんですけど。

岩本：なるほど。

幾原：あんまり「これ、せい」という感じではなくて進めます。アウトラインは決めますけどね。

岩本：そうでしょうね。だけど、割といろんな考え方を尊重してやらせていこうと。わかりました。そうすると我々も本当に第２期頑張っていかなくちゃいけないですね。

これから中期に向かっていくわけですけれど、先生の目からごらんになって、当然AIMRってもうちょっとこうなったらいいのにとかというそういうご希望とか期待とか。

幾原：もっと融合を進めたほうがいいでしょうね。

岩本：そうですね。

幾原：というのは、私たちはどちらかというと外から来ているわけです。例えば５時からティータイムを持っていろいろ話しましょうというときも、学生を持ってAIMRをやっている人と、我々みたいに学生なしでやっている人と集まり方の違いが出ますよね。やはり中の人ともう少しミューチュアルにやったほうがいいなと感じます。

岩本：もうすぐ新棟ができて、そこにまた青葉山からわっと研究者が来るので、それは期待していますけれども、でもそれも単にそれを待っているだけでもいけない。実はスタッフミーティングとティータイムをうまく連動させようとか、そんな工夫もしていますけれども。ちょっと考えましょう。

幾原：この仕組みをうまいことやると、もっと強力になるでしょうね。

岩本：そうですね。これはよく言われていることなんですけれども、AIMRの場合には、幾原先生を初め、先生お一人一人は、皆さん４番バッターなんです。

幾原：それはあるかもわからないですね。

岩本：WPIは、融合研究というのを大きく打ち出していますけど、先ほどおっしゃられたそういう理論との共同研究というもの、これはある意味で当然でしょうが、先生の研究室は、またソフトマテリアルとかとも関係してきますか。

幾原：しますね。でもそれはどちらかというと無機材料。川崎先生や阿尻先生と、そういう研究を少しやっていますけど、浅尾先生や一杉先生とも今やっていますね。

岩本：融合研究というものを通じて新しい学理を生み出すということが使命ですからね。

幾原：ネイチャーコミュニケーション誌では、融合研究で、川崎先生と塚田先生と組んだ融合研究の成果を出させていただきました。（Nature Communications Volume 1, Article number 106、 “Dimensionality-driven insulator-metal transition in A-site excess non-stoichiometric perovskites”）今度川崎先生のグループと組んだ研究は、サイエンス誌に出ました。（Science 332 (2011) 1065-1067、“Electrically Induced Ferromagnetism at Room Temperature in Cobalt-Doped Titanium Dioxide”）

**岩本：**そうですね。

**幾原：**そういうトップジャーナルにも我々の融合研究の果実が出てくるわけです。

**岩本：**そうですよね。融合研究も成果がこうやってもう出てきているわけですから、これをどんどん深めていくということがやはり重要なのでしょうね。

あともう一つ、これもいつも一般論みたいにして伺うのですけれど、先ほど３０代、４０代の研究者はよくやっているというお話でしたけど、一方ではもっと若いレベル、２０代とか、ポスドクなども含めて、特に日本人の研究者は、引きこもりだとか、なかなか覇気がないとか、その点はどうお考えですか。

**幾原：**分野にもよると思いすね。私の研究室の若手は一応元気なんですけどね。確かに全体を見ると元気のない人もいますよね。

あと小学校からの教育で、あんまり理科を熱心にやっていないというのは影響していると思います。理科離れを助長しているでしょうね。

科学啓発

**岩本：**やはりそういうのを助長していますよね。先生は、お小さいころからやはりこういった科学とか、ものづくりとか、そういったことに興味を持っていらっしゃいましたか。

**幾原：**科学的なものの考え方や物理については、中学生の頃から興味がありました。

**岩本：**中学というと、先生は１９５８年生まれだから１９７０年ぐらいですか。

**幾原：**そうですね。

**岩本：**朝永博士がノーベル賞をとったのが６５年でしたか。公害問題などが出てきましたけれども、当時は、それでもやはり科学技術に対する夢というのはありましたものね。

**幾原：**そう。アポロ１１号の月面着陸などがあったりして、科学技術は将来すごいことになるなとみんな思うじゃないですか。

**岩本：**そうですよね。それと学校の先生もおもしろい話をしてくれたりとか。

**幾原：**理科のね。これはおもしろいから理科をやろうというふうになりますよね。それが今の小学校はあまりないような気がします。

**岩本：**そうなんですね。一方AIMRでは、アウトリーチアクティビティとして、サイエンスカフェに今度出ようとか、いろいろやっています。そういった面でもまた先生たちにもいろいろとお世話になるかもしれませんけれど。

**幾原：**あとはマスコミのほうにも、やはり責任があると思います。最近少しずつそういう科学番組が放映されるようになってきたけれども、アメリカにいくとディスカバリーチャンネルとか、科学の部屋とか、専用チャンネルがありますよね。日本の場合は、テレビはどこを見ても漫才師が出ていてわっとやって、面白おかしく過ごしていけばよいというような風潮を若者に与えてい

ます。あれはどうかと思いますね。

**岩本：**科学番組というとNHKで少しやっている程度でないでしょうか。勿論研究者が研究者の生の声で話すことも大事だし、それをまたインタープリテイトして国民にわかりやすい形で伝えるということも重要だと思います。アウトリーチはそういう役割を持っています。

**幾原：**それはJSTの北澤理事長もよくおっしゃっていますね。

**岩本：**北澤先生とか、JST自身も科学の理解増進に非常に熱心ですよね。今後年金負担等が増えていく中で、科学技術への公的投資を増やしていくには、科学技術に対する国民のサポートが大きなカギになりますよね。

本日は長時間にあたり貴重なお話しをどうも有り難うございました。

２０１１年5月２５日

WPI-AIMRアネックス棟　幾原研究室にて

事務部門長　岩本　渉

**Interview with Professor Takashi Takahashi**,

Principal Investigator, WPI-AIMR

## "Everyone is a Front-Runner"

***Interests in Science***

**Administrative Director Iwamoto (I):** Thank you very much for taking time for this interview today. First of all, when did you become interested in science?

**Professor Takashi Takahashi (T):** I think when I was in primary school. My uncle, who is a doctor, bought me some comic books about science and biology that he thought would be useful for my homework during summer vacation. I read them and thought they were very interesting.

**I:** I guess these books still exist, but there were a lot of them available in the past.

**T:** Yes, there were. None of my family was into science, so I think such books were the first things to trigger my interest in science.

**I:** Thanks to your uncle's present.

**T:** Yes, indeed.

**I:** I heard you were born in Niigata Prefecture. Where about in Niigata?

**T:** It was in the middle of the Echigo Plain, which is now called Niigata City, but was called Shirone City then. It is famous for rice production. It is also famous for the Kite-Fighting Festival. People fly kites as large as $16m^2$ on both sides of a river and get the kites tangled in the air and drop them into the river then pull the strings to each direction until they will be cut off. It is a very dynamic festival.

**I:** Is it a big event in the area?

**T:** Yes. When I was in primary school and junior high school, the schools were closed around the time of this festival, and I used to spend a week flying kites.

**I:** That sounds wonderful. How long did you live in Shirone?

**T:** I went to a high school in Niigata and I commuted from home, so I lived there until I was 18.

**I:** So you spent your high school days in Niigata, and then went to the University of Tokyo.

**T:** Yes. I enrolled in Science I course for the first two years, and then the Department of Physics in the Faculty of Science.

**I:** You kept an interest in science since your primary school days.

**T:** I liked making things such as model railways since I was a child. I used to make them from wood as plastic models did not exist those days. I remember making various things from shop-bought long, thin split bamboo strips and so on. This experience may help the production of experiment devices in my work.

**I:** I see. The roots go back to your childhood.

By the way, what did you study at the graduate school at the University of Tokyo?

**T:** Actually, I was working for a company before I went to the graduate school.

**I:** Was it a manufacturing company?

**T:** Yes. I was assigned to a factory that produces cathode-ray tubes, where I worked with factory workers to handle defective products. In addition, as I belonged to the development department, I also worked with production line workers and developed various products such as image pick up tubes.

**I:** I see. After the experience in the field, why did you go back to the university?

***Encounter with Photoemission Spectroscopy***

**T:** I worked for the development department for about three years, but I felt I was lacking knowledge, and I also became interested in photoemission spectroscopy while I was working for the company. This is actually related to Tohoku University.

**I:** How come?

**T:** My direct manager studied in the Department of Applied Physics in Tohoku University. I learned a lot about research and development from him. One day he showed me an article about photoemission spectroscopy, saying, “This is very interesting, and I wonder if you want to try it”. I read the article and thought it was a very interesting experiment. I wondered how I could do something like this by myself, and then came to the conclusion that I had to go back to a university for further study. That was my first contact with Tohoku University. Unfortunately, the manager passed away in an accident while I was still working there. He was three or four years older than me. I saw him dedicating himself to research and study in a pleasant manner and felt the spirit of Tohoku University.

**I:** So you became acquainted with Tohoku University through that person.

**T:** I had no relation to Tohoku University before then.

**I:** Then you went to the graduate school at the University of Tokyo.

**T:** I looked for a laboratory where I could study photoemission spectroscopy as a graduate student. Then I found that Harada Laboratory in the Department of Chemistry. I went to see the professor and took the exam. Later I found out that I was the first graduate student in Harada Lab. This is how I came to study photoemission spectroscopy and chemistry at the graduate school.

**I:** Chemistry too?

**T:** I studied a lot of things in the Harada Lab, including organic materials, photochemical reaction, metal, glass, and amorphous semiconductors.

**I:** I see. So you are perfect fit for AIMR.

**T:** I am kind of a living example of the fusion of different fields.

When I completed the two-year doctoral course, I was invited to come to Sendai and I decided to accept the offer.

**I:** I see. That's how you came to Tohoku University. Which department of the Faculty of Science did you belong to at that time?

**T:** The Department of Physics in the Faculty of Science.

**I:** You studied at the Department of Chemistry at the University of Tokyo until you completed the doctoral course, didn't you?

**T:** Yes. So I am very comfortable to handle various kinds of subjects.

**I:** I see.

**T:** I can handle organic materials, semiconductors and metal with no problem.

**I:** An all-round player.

**T:** I have no hesitation regarding the subjects of the research.

**I:** Researchers tend to concentrate on a very specific field, but in your case, with the experience of working for a company, you know about topics from the real manufacturing environment to chemistry and physics.

By the way, your research has achieved fruitful results in iron-based high-temperature superconductor, graphene and topological insulators. How would you summarize and describe your research?

**T:** Since photoemission spectroscopy is my only research method, my research policy is to use photoemission spectroscopy to study materials which attract considerable attention in the field of condensed matter physics and material science. I had been studying graphite and related materials since I came to Sendai, however, when the high-temperature superconductor was discovered I switched to that field, and have been studying it ever since. High-temperature superconductors were discovered in 1986, so it's been about 25 years.

**I:** It was discovered by Dr. Bednorz and Dr Muller, wasn't it?

**T:** Yes, I knew Dr. Bednorz before he received the Nobel Prize.

**I:** Oh, really.


By the way, could you explain about photoemission spectroscopy so that even a layman can understand?

**T:** Yes, of course. When a material is exposed to light, the electrons within the material absorb the energy of the light. Then the electrons are placed in an "excited state" and they are emitted from the material. This is called the external photoelectric effect in physics. It is based on the photon hypothesis proposed by Einstein in 1905, which argues that light consists of particles. When particles of light hit electrons, the electrons absorb the energy and are emitted outside. Although Einstein is famous for the theory of relativity, he actually won the Nobel Prize for the photoelectric effect.

**I:** Oh, really. Then when the electrons within the material are exposed to light, they become excited and come out. What happens after that?

**T:** These electrons originally existed in the material. A material is basically a conjugate of electrons and an atomic nucleus. However, the basic property of a material is determined by electrons, not by the atomic nucleus. For example, an atomic nucleus is like the pillars that structure a house, and electrons are like the people who live in the house. The atmosphere of the house heavily depends on the characteristics of the people who live there. Similarly, the property of a material depends on the property of its electrons. For this reason, researchers want to observe electrons to study their property. However, it is very difficult to see electrons when they are inside a material. Having said that, since the electrons are emitted from a material in the external photoelectric effect, it is possible to study the property of electrons in precise detail. Therefore, we can say that photoemission spectroscopy is a very direct and highly accurate experiment method.

**I:** I see. You can see the electrons as they are.

**T:** Yes. Since electrons originally existed in a material, if you study the property of the emitted electrons you will be able to understand the state of them when they were inside the material. Their state is exactly same as the electronic state of the material, and can be used as basic information for investigating the cause of various material properties, such as superconductivity.

**I:** So different types of electrons will come out depending on which material you shine a light on.

**T:** Yes, although they are all electrons, just like every human has a different face, each electron has a different property, such as energy, momentum or spin. When a material becomes superconductive, the electrons come out in the superconductive state. In short, the electrons are taken outside the material while maintaining the same state as they are inside the material. Since electrons can be taken out in the superconductive state, you can study them in a very direct way.

**I:** So it really leads to solving the mechanism of physical property.

**T:** Yes, exactly. Photoemission spectroscopy is a relatively new experiment method and was not explored until 30-40 years ago, but it has been rapidly developing in accordance with the research on high-temperature superconductors.

**I:** Who started using photoemission spectroscopy?

**T:** The physical phenomena is based on Einstein's photoelectric effect, as I mentioned earlier, but it is said that photoemission spectroscopy was first used as an experiment method by Kai Siegbahn, a Swedish physicist who won the Nobel Prize in 1984.

**I:** By the way, are there many Japanese researchers who study photoemission spectroscopy?

**T:** When I was a graduate student, there were basically only two places for that: Tohoku University and the University of Tokyo. Nowadays, a lot of research institutes study photoemission spectroscopy, such as universities and national research institutes. The number of researchers has probably not only doubled but nearly increased to ten times more than before.

**I:** Then you went to a laboratory at Tohoku University.

**T:** Yes. Professor Takashi Sagawa who invited me as an assistant professor was studying photoemission spectroscopy.

**I:** In a way, he is the pioneer of the field of photoemission spectroscopy.

***ARPES***

**I:** I hear that you make a full use of Angle-resolved photoemission spectroscopy (ARPES) as a tool for photoemission spectroscopy.

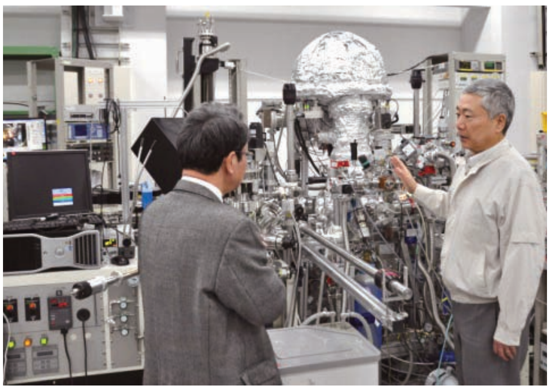
**T:** Yes, I use ARPES. It is a rather large experiment device. We make all our devices, from one that produces the light to make the electrons excited to one that captures the emitted electrons. Recently, we successfully developed a device that observes the spins of the emitted electrons.

**I:** By the way, what is the difference between Spin-resolved ARPES and ordinary ARPES?

**T:** Spin-resolved ARPES means "ARPES + Spin", and it is an ARPES equipped with a detector that can observe the spins.

**I:** In addition, your Spin-resolved ARPES has high resolution.

**T:** Yes. It means that we have started seeing what we were unable to see before. Especially in experiments, whether there is one band or two bands can be a big issue. Now the resolution has been improved to a level that is sufficient to analyze the spins.



Spin-resolved ARPES

**I:** What level of unit do you use?

**T:** At the moment, the resolution is measured in a few milli-electron volts. Previously it was about 100 milli-electron volts, so we managed to increase it more than one digit.

**I:** I see. I heard that such Spin-resolved ARPES with high resolution is internationally recognized as an excellent machine.

**T:** In terms of the resolution, it is the best in the world.

**I:** I don't mean to talk about the budget screening process which took place two years ago, but who has the second best machine?

**T:** Various countries in the world have started following us and developing such machines recently. I heard there is a very good machine in Switzerland. I also heard that the United States has also started development.

**I:** So you are competing with such countries, in a sense.

**T:** Yes. It is machine development competition.

**I:** So, you have three ARPES machines.

**T:** Yes. Two of them are operating, and one is currently not used as it will be modified for student experiment purposes. We are going to start building the fourth machine under the Grants-in-Aid for Scientific Research (S).

**I:** When are you actually going to start building it?

**T:** Starting from this year, I think it will take three to four years to complete.

**I:** There is of course no ready-made machine, so you and the members of your lab are going to develop it here.

**T:** Yes. We will be in charge of design and architecture. Based on that, we will place an order to a manufacture to produce the machine. We will provide a design draft that incorporates new ideas and a rough draft.

**I:** I guess your experience in manufacturing helps a lot for background.

**T:** Yes, exactly.

***From Superconductors and Spintronics to Green Materials***

**I:** By the way, recently your lab has been publishing new research results one after another in newspapers. The most recent ones include iron-based high-temperature superconductor, copper-oxide high-temperature superconductors, and graphene. In particular, the results of the iron-based high-temperature superconductor were published in "Physics Today" this year, wasn't it? (http://blogs.physicstoday.org/thedayside/2011/04/fashionable-physics.html)
In addition, there is topological insulator. Are these four results all the fruit of ARPES?

**T:** Yes, they are. Basically, ARPES is the only experiment method, so we use ARPES to analyze the materials that are attracting attention.

**I:** I see. For example, the iron-based high-temperature superconductor was discovered by Professor Hosono from the Tokyo Institute of Technology. What kind of approach did you take for that subject?

**T:** Obviously, the most basic problem is how superconductivity is caused. This can be clarified by directly observing superconductive electrons. Photoemission spectroscopy enables us to extract superconductive electrons from a material as they are and observe their properties. This cannot be easily done in other experiment methods.

**I:** Why is superconductivity important here?

**T:** Before the discovery of superconductivity in 1986, it was considered that superconductivity occurs at an ultralow temperature, such as liquid helium at the temperature of 4 Kelvin, minus 270 degrees Celsius, which is a very different world from ours. However, the temperature of high-temperature superconductors can be as high as 160 Kelvin. Therefore, liquid nitrogen with a boiling point of 77 Kelvin can be used. Liquid nitrogen is liquefied atmospheric nitrogen and is almost inexhaustible. It is very cheap too. So we can produce superconductivity by using a very low-cost refrigerant, which will save a lot of energy. For example, oil is pumped up in the Arabian Peninsula and transported by oil tankers. This consumes a lot of energy and time. However, if superconductive cables are used, it will be possible to burn oil at the site to produce electricity, and then transmit the electricity to Japan without any transmission loss. It will save a lot of energy.

**I:** I see. Professor Hitosugi also told me so.

**T:** Actually, I heard this plan had already been developed and JST had started working on it.

**I:** That will bring a significant economic effect, won't it?

**T:** Yes, it will be an immeasurable economic effect. That is why superconductivity is considered to be very important as an energy measure.

**I:** And it is related to green materials which AIMR is currently working on.

**T:** Yes, exactly. Since there is no electric resistance, there will be no transmission loss. So, a lot of energy will be saved.

**I:** I see.

**T:** For example, it is said that in hydraulic power generation, by the time the electricity is transmitted from a dam to a town, 10% of it will be already lost. This loss can be reduced to zero, which is groundbreaking.

**I:** I see. Then is this what your research was about on the iron-based high-temperature superconductors we discussed earlier?

**T:** Yes. However, the superconducting transition temperature is lower in terms of iron-based high-temperature superconductors.

**I:** In other words, you discovered the cause of suppression.

**T:** Yes. I proposed that if the cause is eliminated, the superconducting transition temperature can be increased.

**I:** What prevents the emergence of high-temperature superconductivity?

**T:** I discovered that there was something magnetic.

**I:** This was published in “Nature Communications”, wasn’t it? (http://www.nature.com/ncomms/journal/v2/n7/full/ncomms1394.html)

**T:** Yes.

**I:** It’s great.

**T:** In terms of superconductivity, it is said that while the 20th century was “the century of semiconductors”, the 21st century will be “the century of superconductors”. It is expected that various things will be produced using superconductivity.

**I:** Yes, indeed. On the other hand, some people say that there has been not much progress in the field of superconductivity.

**T:** I’d rather say that there has been significant progress in superconductivity and it is already entering into our lives. Superconductive cables that use high-temperature superconductors are already produced and sold on a commercial basis, and the trial cables have been installed and used in daily life in New York. I think it will become an essential technology for our lives in the future as a core technology for the smart grids that minimize electricity consumption. In addition, as you know, the Linear Central Shinkansen (bullet train), which has been decided to be built between Tokyo and Osaka, uses magnetic levitation based on superconductivity. As such, superconductivity has been started to be used for various purposes.

**I:** I see.

Your success in the direct observation of electron spins of a new material topological insulator also attracted a lot of attention.

**T:** Yes, it did. The topological insulator is one of the most widely discussed materials at present. Traditional electronic devices, such as this computer, are operated by an electric charge that exists in electrons. However, electrons have another property which is totally different from an electric charge. That is spin, and it is a magnet so to speak. Electrons rotate themselves and generate an upward or downward magnetic field, depending on whether the direction of the rotation is clock-wise or counter-clockwise. In other words, electrons can be seen as a small magnet with a N-pole on top or bottom. In this manner, spins can transmit information similar to an electric charge. Like there is plus or minus electric charge, there is an upward or downward electron and it can transmit information. Spintronics is an electronic device that uses the spins of electrons. Spintronics, as opposed to electronics.

**I:** While electronics has a focus on electric charge, spintronics has a focus on spins which are upward or downward.

**T:** One of the characteristics of spintronics is that energy consumption is considerably lower than electronics. It uses two or three digits less energy than an electric charge. Modern computers become hot after being used for a long time. It is because they use electronics, and if spintronics is used, such loss will be eliminated.

**I:** This is also green.

**T:** Since modern large-scale computers tend to become very hot during operation, they have to be cooled down by large-scale air cooling devices in order to prevent overheating, which consumes enormous energy. However, it will not be necessary for spintronics computers. The topological insulator is attracting attention as a spintronics material. The reason is that the use of topological insulators enables us to line up electron spins.

**I:** What is the topological insulator exactly?

**T:** In general materials, electron spins are facing various different directions and it is difficult to control them. On the other hand, electron spins are lined up in a certain direction on the surface of a topological insulator. However, it is not very easy to find out which material is a topological insulator. It can be estimated by theoretical calculation, but in reality, it can be only found out when an electronic state is analyzed and observed at the spin level. For this reason Spin-resolved ARPES is very effective.

**I:** I see. Whether or not something is a topological insulator can be determined by whether or not the spins are lined up to the same direction. Is it right?

**T:** Yes. You only need to check whether electron spins are lined up or not. So this is where Spin-resolved ARPES comes in handy.

***Ambition for Fusion Research***

**I:** AIMR has been promoting fusion research all together. As you described, your research is related to various fields, such as BMG, organic materials, and devices.

**T:** Yes. Although I am currently studying superconductors, I studied organic materials and even biomaterials when I was a student. Actually, biomaterial is a subject of photoemission spectroscopy. My research subject was rhodopsin in the optic nerves, and I studied electric charge distributions around the retinal molecules that play a central role in optic response by using photoemission spectroscopy. I achieved interesting results and wrote several papers. I think they were one of the first papers on biomaterial research using photoemission spectroscopy.

**I:** I see. Researches can spread across various fields.

**T:** As for AIMR, there are various people making various materials. Whether it is metal or soft material, all of them can be research subjects for ARPES. If there are some interesting materials, I would like to hear about them so that we can promote fusion research more actively.

**I:** I see. The more participation from staff in other fields is expected, isn’t it?

**T:** Yes, they are welcome.

**I:** You were in Graduate School of Science for a long time then came to AIMR. It's been about four years now. What do you think of the atmosphere of AIMR?

**T:** Let me see. I think it will be better if PIs communicate with each other more actively.

**I:** I see. We finally started holding PI meetings last year, and I am hoping the completion of the new building will make a change.

**T:** I hope so too.

**I:** We know each other's name through papers, but as we all belong to the same organization, I think there should be more mutual exchanges.

**T:** I agree. Since WPI has been established, for example, we started joint research on graphene related to spintronics with Professor Miyazaki's lab, as well as measuring metallic glass samples received from the BMG Group. In this sense, some new fusion research has already started.

**I:** Yes, indeed. Professor Miyazaki is specialized in tunnel magnetoresistance in the field of spintronics.

**T:** Yes.

**I:** You are connected by "spins".

**T:** Yes, we provide or receive samples from each other.

**I:** So, you come to the Katahira Campus more frequently now, which will make you even more involved in fusion research.

**T:** I think so. We moved the Spin-resolved ARPES machine to the Katahira Campus so that we can work with all other researchers.

**I:** By the way, did the earthquakes last March cause any damage to the ARPES devices?

**T:** Some joints of the vacuum devices were damaged, but luckily, there seems to be no serious damage to the core part of the energy analyzers and spin detectors.

**I:** I see. Joints and such parts are likely to be affected.

**T:** At the moment, we are repairing the Spin-resolved ARPES machine in Katahira, with problems such as electric discharge and vacuum leakage, and we are working on the final adjustment in order to restart measurement in the initial high resolution as soon as possible.

***Expectations for Young Researchers***

**I:** Professor Souma is currently working as an Assistant Professor in your lab. Who else from WPI is in your lab?

**T:** Assistant Professor Sugawara, Research Associate Arakane, and a doctoral course student Takayama.

**I:** I see. They all seem to be working very hard.

**T:** We are a very small group, so they have to do two or three people's jobs.

**I:** Is there anyone from abroad?

**T:** We had Assistant Professor Pierre Richard, but he was head-hunted by a Chinese institute.

**I:** I guess we can say that he really grew up here.

**T:** Yes. He worked very hard with us.

**I:** He is currently working as a professor of physics in the Chinese Academy of Sciences, isn't he?

**T:** Yes. He has become really successful. He is originally from Canada, but moved to Boston before he came to Japan.

**I:** Perhaps he heard of ARPES and came to join your lab?

**T:** Maybe.

**I:** He is a good example of brain circulation.

**T:** Yes, indeed. We now have an American master's course student in our lab. He is from Illinois. He wanted to study in Japan and came to study here at his own expense.

**I:** Impressive. So, he was also attracted to your research.

**T:** I would like to support him financially, but we haven't found a way to provide him with financial aid so far, which is a problem.

**I:** I see. It must be difficult. Although I often hear professors saying that young researchers, especially in AIMR, are working very hard, it is generally said that recent young people are not very energetic or are too reclusive. What do you think about this?

**T:** Well, I admit that they seem to be less aggressive these days.

**I:** But they are hard-working.

**T:** Yes, they are. Some students are really motivated, too. The number ratio may have been decreased from the past, but there are still some. So, I think it is important to nurture such students properly. We need to nurture them with care so that they can develop their ability and self-awareness, then they will do the rest by themselves.

**I:** With care.

**T:** Yes, but it doesn't mean that we should spoon-feed them. The students have their own strong motivation for research and development. They will grow very fast and significantly with just a little push.

**I:** It is certainly important to adjust support for such motivated students.

**T:** That is actually the difficult part, and I can only talk from my experience. I think the important thing is to raise their motivation higher and higher.

**I:** Could you summarize your message to young people?

**T:** Let me see. I always tell the students who come to my lab to "gather experimental data by themselves". "It is your own experimental data. Nobody else in the world knows about it, except you.” Then I say, “Because you are the only person who knows about it, you must complete the research by yourself”. This is actually based on my experience. In the world of research, there are very few people who are looking at the same thing in the world. This means that you are the first person to see what you are looking at in the world. What a remarkable thing it is!

**I:** Yes, it is.

**T:** So, “You have to deal with your data properly.” This was what my professors told me when I was a student.

**I:** I totally agree with you. Certainly, it is very rare to see the same phenomena twice, one after another, in natural scientific experiments.

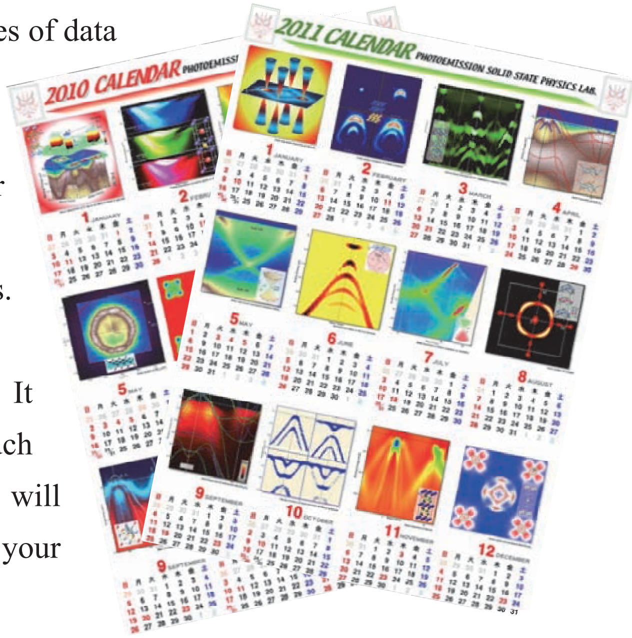
**T:** It is important to tell them that they are already leading the world, they are the front-runners.

**I:** Yes, indeed.

**T:** So, they are running at the very front line of the world.

**I:** I see. Each of them is a front-runner.

By the way, I heard you publish a calendar every year (see photograph).




**T:** Yes, we make a calendar that contains images of data which we obtained in a year, and then send them to researchers abroad. They are very popular and we have been making them for about six or seven years now.

**I:** Perhaps AIMR should do something like this.

**T:** I think we should.

**I:** Thank you very much for your time today. It was very educational to learn about such complicated topics in a simple way. We will continue our efforts, and we appreciate your cooperation very much.

Interviewer: Administrative Director, W. Iwamoto

*At Takahashi Laboratory, Physics A Building*

*September 29, 2011*

WPI-AIMR PI　高橋隆教授に聞く
(Interview with Professor Takashi Takahashi－Japanese version)

# 一人ひとりがフロントランナー

**科学への関心**

**岩本：**今日はお忙しいところ、インタビューに応じていただき有難うございます。そもそも科学に興味をもたれたのは、いつ頃からですか。

**高橋：**小学生の頃だと思います。医者の叔父が、夏休みの宿題の役に立つようにと漫画の科学や生物といった本を買ってきてくれて、それを読んで、たいへん面白そうだと思いました。

**岩本：**今でもあるのでしょうが、昔は結構そういう本がありましたね。

**高橋：**いろいろありましたね。我が家にはそういった理科系の者がほとんどいなかったものですから、そういうのを見たのが科学に関心を持った最初だったと思います。

**岩本：**叔父様のプレゼントのおかげでということですね。

**高橋：**そうですね。

**岩本：**先生、お生まれは、たしか新潟県ですね。どちらですか。

**高橋：**越後平野の真ん中で、今は新潟市になっているのですが、昔は白根市と言って、米どころです。凧合戦というお祭りで有名で、１０畳くらいの大きな凧を川を挟んで向こうとこちら側で上げて、空で絡めて川に落として、綱が切れるまで引っ張り合うのです。勇壮な祭りです。

**岩本：**それはその地域では大きなお祭りなのですね。

**高橋：**ええ。小・中学校ぐらいまでは、この祭りがあると学校が休みになって、１週間ぐらい毎日凧上げをしていました。

**岩本：**素晴らしいです。その白根にはいつ頃までいらっしゃったんですか。

**高橋：**高校は新潟でしたが、家から通っていましたので、１８歳まででですね。

**岩本：**高校まで新潟でお過ごしになって、それから東京大学に進まれたのですね。

**高橋：**はい。理科Ｉ類に入り、その後、理学部物理学科に進みました。

**岩本：**小学生の頃に持たれた科学への関心がずっと続いたわけですね。

**高橋：**小さい頃から鉄道模型とか、物を作るのが好きでした。昔はプラモデルなどなかったので木で作りました。ひごとかいろんなものを買ってきて作っていたのを覚えています。今の実験装置作りに繋がっているのかもしれません。

**岩本：**なるほど。それは小さい頃から芽生えがあったわけですね。

　　ところで、東大の大学院では主にどういう研究をされたのですか。

**高橋：**実は、大学院に入る前に一回会社で働きました。

**岩本：**製造業関係の企業ですか。

**高橋：**そうです。配属になったのがブラウン管をつくる工場で、工員さんと一緒に不良品対策とかをやる一方、開発部にいたので生産ラインと一緒になって、撮像管などいろんなものを開発

していました。

**岩本：**そうですね。その現場のご経験を経て、またなぜ大学に戻られたのですか。

## 光電子分光との出会い

**高橋：**３年ほど開発部にいましたが、一番は勉強不足を痛感し、また、会社にいるときに今やっている光電子分光をやりたいなと思ったのです。これは実は、東北大学とも関係しているのですけれども。

**岩本：**と申しますと。

**高橋：**直接の上司が東北大学の応用物理の出身の方でした。彼には、研究開発についてたくさんの指導を受けましたが、あるとき彼が「こういう面白いのがあるからやってみませんか」と光電子分光の論文を持って来たのです。それを読み始めて、これは面白い実験だなと思いました。何とかこういうものが自分でもできればと思って考えた結果、大学に戻ってもう一回勉強しなくてはと考えました。それが東北大との最初の接点です。しかし残念なことに、その上司の方は、私がまだ会社にいるときに事故で亡くなられました。私より３－４才上だったと思います。飄々（ひょうひょう）と研究開発に打ち込んでいる姿を見て、東北大学の気風のようなものを感じました。

**岩本：**その方を通じて、東北大学との出会いがあったんですね。

**高橋：**それまでは東北大学とは全く関係なかったですね。

**岩本：**それで、大学院は東大ですね。

**高橋：**大学院に戻るに当たって、光電子分光をやっている研究室を探しました。そうしたら、化学の原田研究室というところでやっていることが分かったので、先生に会いに行って、受験させて頂きました。後で分かったことですが、私は原田研究室の最初の大学院生だったそうです。そんなことで、大学院では光電子分光と化学を学びました。

**岩本：**化学ですか。

**高橋：**原田研では、有機物、光化学反応、金属、ガラス、アモルファス半導体とか、いろんなことをやりました。

**岩本：**そうですか。では、AIMRにはうってつけですね。

**高橋：**体をもって異分野融合を体現しているようなものですね。

たまたまドクター２年が終わった時に、仙台の方から来てくれないかという声があって、それでこちらに来ました。

**岩本：**それで東北大学に来られたわけですね。そのときには理学部のどちらにいらしたのですか。

**高橋：**理学部の物理学教室です。

**岩本：**ドクター２年までは東大の化学でしたよね。

**高橋：**そうです。ですから、いろいろな物を扱うのには全然アレルギーがありません。

**岩本：**そういうことですね。

**高橋：**有機物も扱えるし、半導体も金属も扱えるし、その辺は全然問題ないです。

**岩本：**オールラウンドプレイヤーですね。

**高橋：**研究する物に対するアレルギーはありませんね。

**岩本：**それは、とかく研究者というと、一つの狭い分野であれということになりますよね。先生の場合は企業の経験もおありだし、まさに物づくりの現場から化学、物理までということですね。

ところで、先生は現在鉄系高温超伝導体やグラフェンやトポロジカル絶縁体などに関し優れた研究成果を上げられているのですが、先生の研究を一言で言うとどういうことになりますか。

**高橋：**研究手段は光電子分光しか有りませんから、光電子分光を使って物性物理学とか材料科学の分野で注目されている物質を研究するというのが私の研究方針です。私は仙台に来てから、グラファイトとその周辺の物質を研究していたのですけれども、高温超伝導体が出現したものですから、そちらに乗り換えて、それ以来ずっと高温超伝導体をやっています。高温超伝導体は１９８６年に発見されているので、もう２５年ぐらいですか。

**岩本：**ベドノルツ先生とミュラー先生によるものですね。

**高橋：**ええ、ベドノルツ先生は、彼がノーベル賞をもらう前から存じ上げています。

**岩本：**そうですか。

そもそも光電子分光について素人わかりする説明をお願いします。

**高橋：**分かりました。光を物質に当てますと、その光のエネルギーを物質中の電子が吸収します。そうすると、電子は励起状態というか、言ってみれば興奮状態になって物質の外に出てきます。物理の言葉では外部光電効果と言います。もともとはアインシュタインが、１９０５年に提案した光は粒であるという光量子仮説に基づいています。光の粒が電子に当たって、そのエネルギーを電子がもらって外に出て来るわけです。ちなみに、アインシュタインは相対性理論で有名ですが、ノーベル賞は光電効果でもらっています。

**岩本：**そうなのですか。そうすると、光が物質の中の電子に当たると、電子が励起して外に出てきて、それからどうなるのですか。

**高橋：** もともと電子はその物質の中にあったものです。物質というのは一体何かと言うと、電子と原子核の結合体です。けれども、物質の基本的性質を決めているのは原子核でなく電子です。言ってみれば、原子核というのは屋台骨を組んでいる家の柱みたいなもので、そこに住んでいる人間は電子なのです。家の雰囲気というのは、そこに住んでいる人の性質で大きく決まります。同じように、電子の性質が物質の性質を決めているのです。ですから我々研究者は、その電子を観測して、その性質を調べたいと考えています。しかし、物質の中にいる電子は、なかなか見ることができません。ところが、外部光電効果はその電子自身を外に引き出してきますから、その電子の性質を非常に精密に調べることができます。ですから、光電子分光というのは、非常に直接的でかつ精度の高い実験手段と言うことができます。

**岩本：**そうか、直接その電子を見られるわけですね。

**高橋：**そうです。電子はもともとは物質の中にいたものですから、出てきた電子の性質を調べてやれば、もとの物質中にいたときの電子の状態がわかります。これは、物質の電子状態そのも

ので、物質の様々な性質、例えば超伝導などの原因を探る基本情報になります。

**岩本：**そうすると、違う物質に光を当てて出てくる電子は、全然違う電子なんですね。

**高橋：**電子であることは同じですけれども、同じ人間でも顔つきが違うのと同じように、電子の持っているエネルギーとか、いろいろな性質が違います。運動量も違いますし、スピンも違います。超伝導になったら、超伝導になった時の状態がそのまま出てきます。要するに、物質の中の電子の状態をそのままフッと外に持ってきたような感じですね。超伝導状態の電子をそのまま持ってきますから本当に直接的に見えます。

**岩本：**そうすると、まさに物性発現機構の解明につながるわけですね。

**高橋：**その通りです。光電子分光というのは比較的新しい実験手段で、３，４０年前まではほとんど未開拓の実験手段だったのですけれども、高温超伝導体の研究と相まって最近急速に発展しました。

**岩本：**これはそもそも光電子分光というのは、どこで始まったのですか。

**高橋：**物理現象としては、先ほど言ったアインシュタインの光電効果に由来していますが、実験手段としての光電子分光は、１９８４ 年にノーベル賞を受賞したスウェーデン人のカイ・シーグバーンが始めたとされています。

**岩本：**ところで、こういった光電子分光をやっていらっしゃる日本の研究者人口としては結構いるのですか。

**高橋：**私が大学院生の頃は、この東北大と東大の、基本的に２カ所でした。今は、大学や国立研究所など多くの研究機関でやっています。研究者人口としては、当時と比べて２倍どころか、１０倍近くになっていると思います。

**岩本：**東北大は先生の入られた研究室だったのですね。

**高橋：**そうです。私を助手として呼んで下さった佐川敬教授が光電子分光をやっておられました。

**岩本：**ある意味、光電子分光についての草分けのような方ですね。

**ARPES**

**岩本：** 高橋先生の場合、光電子分光のためのツールとしては、高分解能電子分光装置(ARPES: Angle-resolved photoemission spectroscopy)を駆使されているのですね。

**高橋：**ええ、ARPES（アルペス）です。実験装置としては、かなり大きなものですが、私のところでは、電子を励起する光を作るところから、出てきた電子を捕まえるところまですべての装置作りをやっています。最近は、出てきた電子のスピンを観測する装置の開発に成功しました。

**岩本：**ところで、スピンアルペスというのは通常のアルペスとどう違うのですか。

**高橋：**スピンアルペスというのはアルペス＋スピンで、アルペスにスピンのディテクターを装着したもので、スピンまで観測できるということです。

**岩本：**それでしかも、スピンアルペスで高解像度のものができたわけですね。

**高橋：**そうです。今まで見えなかったものが見えてきたということです。特に実験の分野では、

バンドが１本なのか２本なのかというのが大きな問題になることがあります。それをちゃんと分解能を上げ、さらにスピンにまで分解して見ることができるようになったということです。

**岩本：**どのくらいの単位になるのでしょうか。

**高橋：**現在は、分解能として数ミリ電子ボルトというところです。従来の分解能は１００ミリ電子ボルト程度でしたから、一桁以上上げることができました。

**岩本：**なるほど。そういった超高解像度のスピンアルペスという装置自体は世界的にも優れたものと聞いていますが。

**高橋：**分解能で言えば世界ナンバーワンです。

**岩本：**事業仕分けではないですが、ほかに第２位というとどこになりますか。

**高橋：**最近、世界のあちこちで我々の後を追って装置開発を始めています。スイスには、かなり良い装置があるようです。アメリカでも始めたと聞いています。

**岩本：**そういうところと、ある意味競争しているのですね。

**高橋：**そうです。装置の開発競争です。

**岩本：**それで、こちらでは３台のアルペスがあるわけですか。

**高橋：**そうです。動いているのは２台で、１号機は学生実験用に改造するため休止しています。現在、科学研究費の基盤研究(S)で、４台目の建設を始めたところです。

**岩本：**いつから建設の予定ですか。

**高橋：**今年から３，４年かけて建設しようと考えています。

**岩本：**もちろん、既製品を売っているわけではないので、みんな先生及び研究室の方々がここで考えるのですね。

**高橋：**そうです。我々は、デザインと設計を行ないます。それに基づいて、こういったのを作ってくれと業者に発注して作ってもらいます。こちらとしては、新しいアイデアと大まかなドラフトを入れ込んだ設計図を提案するのです。

**岩本：**その裏には先生の先ほどの物づくりの経験というのが生かされているのですね。

**高橋：**その通りです。

### 超伝導、スピントロニクスからグリーンマテリアルへ

**岩本：**ところで、最近先生の研究室からは次々と研究成果が新聞発表されています。最近だけでも鉄系高温超伝導体、銅酸化物高温超伝導、グラフェンのお話がありました。特に、鉄系高温超電導体については、今年、“Physics Today”にも取り上げられましたね。
(http://blogs.physicstoday.org/thedayside/2011/04/fashionable-physics.html)
それから、トポロジカル絶縁体ですね。この４本は、みなアルペスによるものですね。

**高橋：**全部アルペスです。基本的に、実験手段はアルペスしかないので、アルペスを使って、現在注目されている物質を解明していくという方針ですね。

**岩本：**なるほど。例えば鉄系高温超伝導体とういうのは、東工大の細野先生が発見されたものですが、それについて先生はどういうアプローチをされたのですか。

**高橋：**最も基本的な問題は、当然ですが、なぜ超伝導が起きるかです。それを明らかにするには、超伝導になった電子そのものを直接見ればよいと言うことです。光電子分光は、超伝導状態の電子を、そのままの状態で物質の外に引っ張り出し、その性質を調べることができます。他の実験ではなかなかできません。

**岩本：**超伝導がなぜここで重要かと言うと。。。。

**高橋：**１９８６年に高温超伝導体が発見されるまでは、超伝導というと極低温の話で、液体ヘリウム、4K、マイナス270℃ですが、もう我々の住んでいる世界とはかけ離れた極低温の世界の話だと思われていました。ところが、高温超伝導体では超伝導転移点が160Kくらいまで上がっています。そうすると、沸点が77Kの液体窒素が使えます。液体窒素というのは空気中にある窒素を液化したもので、ほとんど無尽蔵にあります。非常に安い。ですから、非常に安い冷媒を使って超伝導を作ることができるので、大きな省エネルギーになります。一つの例を言いますと、今、石油をアラビア半島で汲み上げてタンカーで運んできています。これは大変なエネルギーと時間を消費しています。ところが、超伝導ケーブルを利用すれば、向こうで石油を燃やして発電して、それを送電ロスなしで日本まで送るということができるようになります。大変な省エネになります。

**岩本：**なるほど。一杉先生からもそう伺いました。

**高橋：**実はそういう構想は既にあって、JSTで始めていると聞いています。

**岩本：**それはすごい経済効果ですね。

**高橋：**それはもう計り知れないほどの経済効果ですね。ですから、超伝導がエネルギー施策として非常に重要視されているのは、そういう理由です。

**岩本：**だから、今、AIMRの目指すグリーンマテリアルにつながってきますね。

**高橋：**その通りです。電気抵抗がゼロですから、送電損失がありません。大きな省エネルギーになります。

**岩本：**そういうことですね。

**高橋：**水力発電にしても、ダムで発電した電気を町に持ってきた段階で、もう既に１０％ぐらいも損失していると言われています。それがゼロになりますから、これは画期的なことです。

**岩本：**そういうことですか。それで、先ほどの鉄系高温超伝導体で言えば、先生がおやりになったのは、まさにそういったことですね。

**高橋：**ええ。しかし、鉄系超伝導体の場合は、まだ超伝導転移温度が低いです。

**岩本：**むしろ抑制する原因を明らかにしたということですね。

**高橋：**そうです。それを除いてやれば、超伝導転移温度は上がると提案しました。

**岩本：**高温超伝導になるのを何が邪魔していたのですか。

**高橋：**磁気的なものが存在しているということを見つけたのです。

**岩本：**これは「ネイチャーコミュケーションズ」に出たのですね。
(http://www.nature.com/ncomms/journal/v2/n7/full/ncomms1394.html)

**高橋：**そうです。

**岩本：**すばらしいですね。

**高橋：**超伝導に絡んで言いますと、２０世紀は半導体の世紀と言われているのに対し、２１世紀は超伝導体の世紀だとされています。超伝導を使っていろんなものができてくると言われていますね。

**岩本：**そうですね。しかし、超伝導というのは、全く別な人に言わせると、あまり進歩していないのではないかとも言われますが。

**高橋：**いや、むしろ私は、超伝導は大きく進歩して、既に私たちの日常生活に入り込みつつあると思っています。高温超伝導体を使った超伝導ケーブルは既に商業ベースで生産販売されていますし、その試験線がニューヨークで敷設されて日常的に使用されています。今後は、電力消費を最大限に押さえ込んだスマートグリッドの中核技術として、私たちの生活になくてはならないものになると思います。また、ご存じのように、東京−大阪間に建設が決まったリニア中央新幹線は、超伝導を用いた磁気浮上を利用しています。このように、多くのところで超伝導は活用され始めています。

**岩本：**そういうことですね。

　新材料トポロジカル絶縁体の電子スピンの直接観測に成功というのも、これも大きく取り上げられましたね。

**高橋：**そうですね。トポロジカル絶縁体は、現在、非常に注目されている物質です。今までの電子デバイス、このコンピューターもそうですが、電子機器というのはすべて電子の持つ電荷の働きで動いていたのです。ところが、電子というのは、電荷とは全く異なるもう一つの性質を持っています。それがスピンで、いわば磁石です。電子自体はぐるぐると自転していますから、自転の右左の方向によって、上向きまたは下向きの磁場が発生します。言ってみれば、電子は、N極を上または下に持った小さな磁石と見ることができます。そうすると、スピンも電荷と同じように情報を伝えることができます。電荷がプラスとかマイナスとか言いますが、スピンもアップとかダウンとかで、情報を伝えることができるのですね。この電子のスピンを使う電子デバイスがスピントロニクスです。エレクトロニクスに対してスピントロニクスです。

**岩本：**電荷に着目するのがエレクトロニクスとすれば、スピンに着目して上とか下というのをスピントロニクスというわけですね。

**高橋：**スピントロニクスの特徴は、消費エネルギーがエレクトロニクスに比べて桁違いに小さい点です。エネルギー的には、電荷に比べたら二桁から三桁ぐらい小さいです。今、パソコンは長い時間使っていると、かなり熱くなりますね。それはエレクトロニクスを使っているからで、スピントロニクスを使えば、そういうロスは無くなります。

**岩本：**これもまさにグリーンですね。

**高橋：**今、大型計算機は運転中に大変な高熱になってしまうので、オーバーヒートを防ぐために大型空冷装置で冷やしていますが、そのために大電力を消費しています。しかし、スピントロニクス計算機なら、その必要もありません。このスピントロニクスの材料として、トポロジカル絶縁体が注目されています。なぜかといいますと、トポロジカル絶縁体を用いると、電子のスピ

ンを揃えることができるからです。

**岩本：**トポロジカル絶縁体というのは、どういうものなのですか。

**高橋：**普通の物質では、電子のスピンがばらばらになっていて、その方向をコントロールするのが難しいのですが、トポロジカル絶縁体の表面では、電子のスピンが決まった方向に揃っています。けれども、どの物質がトポロジカル絶縁体かというのは簡単には分かりません。理論計算で予測はできますが、実際は、その電子状態をスピン状態まで分離して観測して始めてわかります。その意味で、スピンアルペスが大変有効になるのです。

**岩本：**そうか、トポロジカル絶縁体かどうかというのを見るためにはスピンの向きが揃っているかどうかというのを見るのですね。

**高橋：**そうです。電子のスピンが揃っているかどうかを見てやれば良いのです。ここで、まさにスピンアルペスの出番なわけです。

## 融合研究への抱負

**岩本：**AIMRというのは融合研究を一丸となって推進していますが、今伺っただけでも先生のご研究というのは、もちろん、BMG、有機物、デバイスにも関係しますし、いろいろな分野にも関係してくるわけですね。

**高橋：**そうですね。私自身、今は超伝導体を研究していますが、学生の頃は有機物もやっていましたし、実は生体物質を研究したこともあります。生体物質も光電子分光の研究対象になります。私が研究したのは、視神経にあるロドプシンという物質で、その光応答中心であるレチナール分子周辺の電荷分布を光電子分光で研究しました。面白い結果が得られたので何編かの論文を書くことができました。おそらく生体物質を光電子分光で研究した最初の論文ではないかと思っています。

**岩本：**いろいろな広がりがあるのですね。

**高橋：**AIMRの中では、たくさんの方がいろんな物質を作っておられます。金属にしても、またソフトマテリアルにしても、すべてアルペスの研究ターゲットになります。何か面白そうな物質があったら是非教えて頂いて、融合研究を積極的に進めたいと思っています。

**岩本：**そうですね。むしろほかの分野の方,どんどんいらしてくださいという感じですね。

**高橋：**是非お願いします。

**岩本：**今、先生の場合には理学研究科にずっといらしてAIMRに入られて、これでもう４年ぐらい経ちますね。AIMRそのものの雰囲気はどう思われますか。

**高橋：**そうですね。もう少しPI同士のコミュニケーションがあると、もっといいかなと思いますね。

**岩本：**そうですね。去年ぐらいからようやくPIを集めて会議を開催していますし、また新棟の完成でかなり変わることを期待しています。

**高橋：**私もそう期待しています。

**岩本：**結局論文では名前をお互いに知っているけれども、せっかく同じ組織の中にいるのだか

らもっと相互交流があってもよいということですね。

**高橋：**そうですね。WPIができて、例えば宮崎先生のところとスピントロニクスに関係したグラフェンで共同研究を始めていますし、BMGグループからは金属ガラス試料を頂いて測定しています。そういう意味では幾つかの新しい融合研究が始まっています。

**岩本：**ああ、そうそう。宮崎先生もスピントロニクスの分野で、またトンネル磁気効果が御専門でいらっしゃる。

**高橋：**はい。

**岩本：**そういう意味でスピンということではつながっている。

**高橋：**試料をいただいたり、あげたりということも実際やっています。

**岩本：**そうすると、先生もこれからは片平キャンパスの方に頻繁に来られるわけですから余計融合研究にかかわられますね。

**高橋：**そうですね。スピンアルペスの装置は全部片平に持って来ましたので、ぜひ皆さんと一緒に研究をしたいと思っています。

**岩本：** 話は変わりますけれども、３月の震災とか余震では、アルペスは大丈夫だったのですか。

**高橋：**真空装置のつなぎ目の部分がいくつか壊れましたが、幸いなことに、エネルギー分析器やスピン検出器などの装置の中心部には大きなダメージはないようです。

**岩本：**そうですね。つなぎ目とか、それはどうしても弱いですね。

**高橋：**今は、片平に移したスピンアルペス装置の放電や真空リークなどの修理を行っている段階で、できるだけ早く元の高分解能での測定を再開できるよう最終調整を行っています。

### 若手研究者への期待

**岩本：**さっき相馬先生の名前が出ましたけれども、先生のところでは、相馬先生が今、助教でWPIのメンバーとしてはほかに。。。。

**高橋：**助教の菅原君とポスドクの荒金君、そして、博士課程の院生として高山さんがいます。

**岩本：**そうですね。なかなか皆さん、僕らが見ていると、一生懸命、頑張っていますね。

**高橋：**人数が少ないということもあって、２－３人分働いてもらっています。

**岩本：**あと外国人の方というと。

**高橋：**以前、ピアー・リシャー君が助教として居ましたが、彼は中国の方に引き抜かれてしまいました。

**岩本：**彼は本当にここから育っていったと言ってよいですね。

**高橋：**そうです。彼はここでよく働きました。

**岩本：**今は中国科学院の物理の教授ですか。

**高橋：**そうです。今は偉くなりましたね。彼はもともとカナダの出身で、ボストンに居てからこちらに来ました。

**岩本：**やはり先生のところのアルペスというのを見聞きしてそれで来たわけですね。

**高橋：**そうかもしれません。

**岩本：**彼は、頭脳循環の良い例ですね。

**高橋：**そうですね、今、研究室には、アメリカから来た修士課程の院生が１人います。イリノイの出身ですが、日本で勉強したいと言って、わざわざここに私費で来てくれました。

**岩本：**なかなか。じゃ、やっぱり先生のところに引きつけてられているのですね。

**高橋：**経済的にサポートしてあげたいのですけれども、学資を出す手立てがなくて、そこが今困っているところです。

**岩本：**なるほど。そうですね。先生方は特にAIMRの場合には若手の研究者、みんな真面目にやっているよというお話が多いんですけれども、一方では世間では、最近の若い者は覇気がないとか、外に出ていこうとしないとか言われますが、そこはどうなのでしょうね。

**高橋：**そうですね、確かに昔ほどアグレッシブではなくなっているかもしれませんけれども。

**岩本：**でも皆さん、真面目ですよね。

**高橋：**ええ、そうですね。それに、やる気のある学生はいますよ。人数比にしたら昔ほどではないかもしれませんが、やっぱり何人かいます。ですから、そういった学生をちゃんと育てていくということですね。丁寧に育てて、本人が実力と自覚を持つようになったら、あとは自分でやっていきますよ。

**岩本：**丁寧に、ですか。

**高橋：**丁寧と言っても、そこは過保護になってはいけないと思います。本人はもともと研究とか開発に強いモチベーションを持っています。そういう人は、ちょっと後ろから押してやると、どんどん成長しますね。

**岩本：**確かにそういうモチベーションを持ってきた者を押す力具合というのが肝要ですね。

**高橋：**そこがなかなか難しくて、経験でしか言えないのですけど。大切なことは、本人のやる気をどんどん大きくすることだと思います。

**岩本：**そうしますと、若い人に対するメッセージというのはどういうことになりますか。

**高橋：**そうですね。研究室に来る学生に私が言うのは、「自分の実験データを取れ」ということです。「これは君の実験データだ。世界中、君以外だれも知らない」と。「これは君しか知らないのだから、君がやるしかない」ということを言います。それは私自身の経験からなのですけれどもね。研究の世界では、少なくとも世界中で同じものを見ている人は他にはほとんどいないはずだ。自分が世界で初めてこれを見ている、ということです。何とすごいことではないか、ということです。

**岩本：**おっしゃるとおりです。

**高橋：**だから、君のデータだから君がちゃんとやりなさいと、そういうことを私が学生の頃、先生に言われましたね。

**岩本：**それはおっしゃるとおりです。確かに自然科学の実験の場合には、それが同じことがまた次に起こるなんていうことはまずないわけですね。

**高橋：**君はもう世界の最先端を走っているんだ、フロントランナーなんだということが大切なのです。

**岩本：**おっしゃるとおりです。

**高橋：**そうですね。君はだから世界の一番トップを走っているんだと。

**岩本：**そうですね。まさにその一人一人がフロントランナーなんですね。

話は変わりますが、先生のところでは、毎年カレンダーを作っていらっしゃいますね。

**高橋：**ええ、毎年その年に得られたデータ画像を使ってカレンダーにして、世界の研究者に送っています。これがなかなか好評でして。もうかれこれ、６－７年続けています。

**岩本：**AIMRでも、これを参考にして何か考えますかね。

**高橋：**それはぜひ。

**岩本：**今日は、大変勉強になりました。難しいお話をやさしくご説明いただきどうも有り難うございます。これからも頑張っていきますので、よろしくお願いいたします。

２０１１年9月２9日

東北大学物理A棟　高橋研究室にて

事務部門長　岩本　渉

**Interview with Associate Professor Winfried Teizer,**
Junior Principal Investigator, WPI-AIMR

## "Academic Landscapes of Germany, the US and Japan"

***About Karlsruhe***

**Administrative Director Iwamoto (I):** Thank you for accepting the interview. You have spent so many years in the United States, but you are German, aren't you?

**Associate Professor Winfried Teizer (T):** I am Austrian by citizenship, but I grew up in Germany. I never lived in Austria.

**I:** Until university, had you been in Karlsruhe?

**T:** I had been in a small town in the suburbs of Karlsruhe.

**I:** I understand, so Karlsruhe is the nearest town to the French frontier, isn't it?

**T:** It is very close to France. You can go to France for dinner, easily. Just maybe 20 minutes drive.

**I:** And you entered the University of Karlsruhe?

**T:** Yes.

**I:** I heard the University of Karlsruhe is the oldest university in the field of technology in Germany?

**T:** That is right. It is the first German technical university. It was at the time modeled after the École Polytechnique in Paris. There has been a new development in Karlsruhe recently. The university and the federal research center located in the outskirts of Karlsruhe merged to become one unit (the Karlsruhe Institute of Technology). It is rather unusual in Germany, because you have a state-sponsored university and a federal research center, with administrative structures that are very difficult to bring together.

So far, from what I have heard, the experiment is going quite well and I think people are generally happy with the outcome.

**I:** In other words, it is a fusion between a university as an academy and a rather policy-oriented federal research center?

**T:** So it is a win-win situation, because the university has access to very good students.

And the research center has a very good research infrastructure where these students can do very nice research projects. This combination was the result of a project in the German academic landscape very similar to the WPI project.

**I:** I see.

**T:** There was what they called the "Excellence initiative". And Karlsruhe was one of the first three universities that won. The other two were the major universities in Munich. Those three universities won the first competition. And Karlsruhe won with this concept of fusion.

**I:** I heard that the University of Karlsruhe is one of the nine elite universities in Germany.

**T:** That is right. But it is more than "one of the nine". It is one of the first three. In Karlsruhe, the people like to focus on this.

Historically, this area of Germany in the $19^{th}$ century was comparably poor. Now, it is the opposite. It is now a kind of high-tech center of Germany. There have always been developments in the Karlsruhe area which were technology-oriented for a long time. You can go back, for example, to Heinrich Hertz—he found electromagnetic waves in Karlsruhe.

**I:** I understand.

**T:** Then, as another major development there has been the Haber-Bosch process, which was done in Karlsruhe. And outside the chemistry building in Karlsruhe, you can still see the original reactor that was used to first synthesize ammonium. So there has been a long history of technology and development.

**I:** I see.

**T:** Now, you have major high-tech companies in the area. For example, near Karlsruhe, Hewlett-Packard and Siemens have facilities in Karlsruhe. A little bit north of Karlsruhe, there is SAP, one of the major business software companies.

**I:** After graduating from Karlsruhe University, you went to the University of Massachusetts Amherst, didn't you?

**T:** Yes, the typical Diplom system used to take five years from high school in Germany. And in my third year, I decided to go to the United States for a one-year exchange. Baden-Wuerttemberg and Massachusetts have an exchange program.

**I:** I see.

**T:** I went with this exchange program for one year to the United States, planning to come back to Germany and continue my studies in Germany, but life turned out different.

**I:** Why?

**T:** The United States was very attractive for me. I met people I really liked to work with. And while I was living in the United States, I finished my degree in Karlsruhe by flying back once in a while. I passed exams and also did my thesis research in the United States. That was at the time very fortunate—Karlsruhe was very progressive about this. It allowed me to do my thesis externally.

**I:** Fantastic.

**T:** And I handed it in English, which was very nice and very convenient, because I could basically use the work I was already doing in the United States anyhow.

**I:** So it was not necessary to translate your thesis into German?

**T:** That is right. I think it was a pilot project at the time, but now this is becoming more popular among universities.

***Research in the New World***

**I:** It is good. So, when you were at the University of Massachusetts Amherst, was your specialization physics?

**T:** Yes, that is right. I was in the physics department. As a graduate student I did my PhD in experimental low-temperature physics, especially, in condensed matter physics with a specialty for low temperatures.

**I:** Who was your professor at that time?

**T:** Bob Hallock. He is quite well known in the community of helium research. Helium is a very interesting system. At low temperature, it shows some extraordinary properties, most importantly superfluidity.

**I:** Yes.

**T:** And he is specialized in the films of helium on various surfaces.

**I:** I see.

**T:** It turns out that it is actually a little bit more complicated because there are helium-4 and helium-3, two isotopes that behave quite differently in terms of their superfluid behavior. And then you can also make mixtures of the two, at which point it becomes even more interesting. So, his specialization is that type of film research.

**I:** After the University of Massachusetts, you spent several years in California, didn’t you?

**T:** Yes, I went to University of California San Diego, where I did a postdoctoral research position with Bob Dynes who is quite well known in the field of superconductivity.

**I:** I see.

**T:** He is a very interesting person. As you know, usually scientists are somewhat introverted. They are very good at what they are doing, but they do not have the ability to show it to regular people.

**I:** Unfortunately true. I understand.

**T:** He is one of the rare exceptions, because in addition to being a great scientist, he is also a great communicator. You can see that incredible things are possible when these two things come together.

**I:** I see.

**T:** In his case, before he went to UCSD, he was the Director of Chemical Physics at Bell Laboratories, and his group was very influential and important for solid state science. As leader of this group, so he was doing administrative work in addition to his scientific research.

**I:** It is very exceptional to be a great scientist and at the same time a great communicator.

**T:** Administrator or manager, too in his case. But as you know, what happens often is that scientists work as scientists and then at some point they become more and more managerial.

**I:** That is right.

**T:** Often they ultimately forget the science. Basically, they cannot do both, so they engage so much in administration that the science gets less and less in their work.

**I:** Yes.

**T:** In his case, the interesting thing was that even in positions where almost nobody is able to still do science, he could still make sure that he was doing science on a daily basis. When I started working with him at UCSD, he was the Chancellor (Head) of the university.

**I:** Great!

**T:** During this time, he still had a lab and he still was there every day. Then, after I left, he became the President of the University of California system, so that is arguably the highest public education job in the United States. Still he had a lab.

**I:** So then, you moved to Texas A&M and I heard that there you founded the material science group.

**T:** Well, no. I was one of the founding members of a material science and engineering program that bridges between the College of Science and College of Engineering which were usually secluded from each other at Texas A&M.

**I:** I see.

**T:** But what I did found was the Center for Nanoscale Science and Technology which is a center that focuses on making small lithographic structures, so basically tiny, tiny lithographic devices, just like Professor Esashi is doing here at Tohoku University.

***Research in AIMR --- Kinesin and Single molecule magnet***

**I:** From November 2009 you joined AIMR as what we call Junior PI. You come here regularly for three months to Sendai?

**T:** Every summer, my primary base shifts from Texas to Sendai, so from June to August, my primary base is here in Sendai. In addition to that, I come for short trips like right now.

**I:** That’s right.

**T:** These short trips are for about ten days on average.

**I:** I see. But, so, from June to August, you direct the research with postdocs at AIMR. When you are in the United States, how do you communicate with them?

**T:** Besides e-mail, we have Skype and mostly it is through Skype that we have meetings. As a matter of fact, in America, we have a special conference room that is set up for virtual meetings. Two or three staff in Sendai essentially participate in our group meeting over the internet. We found one time slot that works well for both sides and that is 6 o'clock in the evening in Texas, which is—depending on the time of year—8 or 9 o'clock here, in the morning.

**I:** Wonderful.

**T:** And it works. We have at least one meeting every week where we do this. In addition to this big meeting of everybody, we have specialized meetings on certain topics where you just spontaneously communicate by Skype. Somebody just sees someone online, saying "Oh, he is there on the other side," and you ask him and you quickly talk.

**I:** I see.

**T:** Sometimes, there is a need to prepare for some conference maybe, and somebody needs to give a practice talk. So then I ask them, "Can you please prepare a practice talk?" and then they give a practice talk over the internet.

**I:** It's very convenient. Here you have three postdocs.

**T:** Yes, that is right. My group is quite international, composed of a Brazilian, a Korean, and a French.

**I:** Very worldwide. Can you tell me what your research themes at AIMR are?

**T:** It focuses on two topics, actually.

The first project is one on which we already did some work in the United States before joining AIMR. Together with a colleague there, we have a collaborative group studying kinesin, which is a motor protein, so a protein that can walk. Inside the body, it actually does that. There are little tubules inside the body, which serve as roads along which the kinesin walks.

**I:** The kinesin itself exists naturally?

**T:** In the body. As a matter of fact, as long as you quickly secure the material from the brain of the cows that have been slaughtered, it is usable for experiments. Now, for some of our materials we actually synthesize this artificially, most of the time, but you can use natural material for this.

**I:** What is the dimension of kinesin?

**T:** There are different types of kinesin, but it is tens to hundreds of nanometers.

**I:** Very tiny. But as you said, you can fabricate artificial kinesin?

**T:** You can basically make it by genetic manipulation.

**I:** I see.

**T:** You essentially grow it in bacteria. We do it here in collaboration with Dr. Umetsu in Prof. Kumagai's lab in Aobayama. And one of our postdocs is mostly working in Aobayama.

Essentially what they do is they use E. coli bacteria, in which they introduce the seeds of these kinesin and then as they multiply, it creates more and more. And ultimately, you can extract it from this process.

**I:** I see. How can we use it for application?

**T:** Inside the body its job is to transport large objects inside the cell. Small thing, like for example salt ions, just get transported by diffusion. They essentially move around through thermal motion. But large objects do not do that. Once they get beyond a certain size, they cannot move diffusively. So the body has to have an organized process of how to move them. The kinesin's job, among others, is that it walks along these tracks—so on one side, it has feet that walk and on the other side, it has a port. And at this port, you can attach cargo.

**I:** I see.

**T:** And inside the body, these organelles can attach and then move. So that is the job inside the body. Now, our goal is to use that motion process on a chip surface where we create structures that force this motion process to go in a certain direction.

**I:** I see.

**T:** So we can utilize it. We basically would like to take the natural process out of the body and put it into an artificial environment where we have complete control.

**I:** It is really biomimetic.

**T:** Yes, absolutely. So, I think this process has a lot of potential, because kinesin converts chemical energy to mechanical through walking.

**I:** I see.

**T:** And the possibility to have on a chip something that can suddenly create motion in a directed way is a unique concept that can be used for devices. It is our goal to make sure that we understand how it works, and once we understand, we will use it for devices.

**I:** So it is a biomaterial.

**T:** That is right. It is what is called bio-nano now, because you have a bio-component, but in order to use it properly, you should make very small tracks so that you can have directed transport. And so these are nano-trakcs.

**I:** I see.

**T:** It is a combination of nano and bio. And that is what makes it interesting. Our expertise is, among other things, as I mentioned before, electron beam lithography, so we can make very narrow or small devices. That allows us to define the chip surface so that this motion can occur.

**I:** Very great. So this is one subject. And what is the second?

**T:** When I came to Sendai for the first time, I talked to people about what is available here. I immediately realized that there is something I am interested in, but it did not happen for a while. And this was the low temperature Scanning Tunneling Microscope (STM) that our colleague, Dr. Hitosugi is running. During my postdoc with Bob Dynes, we also had a low temperature STM, a simpler one. When I talked to his group, they were building the system at AIMR at the time, and they had not tested it yet.

**I:** I understand.

**T:** The system was ideally suited for an experiment we always wanted to do and we could not, because our systems in the US did not have the same capability.

**I:** I see.

**T:** But the one at AIMR does. The research subject we are thinking of is called a single molecule magnet. These are again large molecules—typically the weight corresponding to 2,000 hydrogen atoms, and these molecules have a special property: a very large unidirectional magnetic moment.

**I:** More concretely?

**T:** So one single molecule has a large magnetic moment that is well defined. That is very unusual, because for example if you take the classical magnetic materials, like iron, nickel and cobalt, one atom is not magnetically stable by itself. It basically does not have a stable moment.

**I:** I see.

**T:** When you make a large iron system, many of the neighboring irons interact with each other. And this interaction is what stabilizes the magnetic behavior of the atom. So, you do not have individual components which by themselves are stable in those materials.

**I:** I understand.

**T:** In single molecule magnets, you do. You have individual molecules, which under proper conditions, are stable. Now, I was hiding one fact—one of the proper conditions is that you have to have low temperature.

**I:** This is the only condition, isn't it?

**T:** That is right. That is the important condition for this. That allows potentially very interesting applications, because you can think that if you have a molecule that has a stable moment, that one molecule can store information. And it can store information in the sense of long-term storage or computational information.

**I:** I see.

**T:** Some people think quantum computing is a possibility with these molecules. Dr. Hitosugi's lab has this special STM, which in addition to low temperatures, can also apply a strong magnetic field, and actually in different directions. Therefore this setup is particularly suitable for an experiment with single molecule magnets, because the magnetic behavior is strongly dependent on the precise alignment of the magnetic field. You have to have control of how

you align the magnetic field. And this allows experiments which are not possible in many places in the world, I think.

**I:** You find AIMR is an ideal place on this point.

**T:** This instrument is quite special.

**I:** It is interesting. So, how do you utilize this single molecule magnet for the real world?

**T:** Well, at the moment, the question is, "In the future, how would you use it?" And the answer is that in principle, you use it for magnetic information storage and computation. Now, you immediately realize that you have to go to low temperature to do this, which is not really so good in everyday life. For some very specialized applications maybe you can, but not for everyday.

**I:** Not now.

**T:** However, chemists are working very hard to create new single molecule magnets, which have higher temperature ranges, where this type of property is available, so it is possible that if you study the existing ones at lower temperature, you learn a lot later. Because of new chemical innovations and new molecules, it will be possible to use it at higher temperature. And then you will have very similar types of properties, at low temperature and high temperature—and then it becomes suddenly a very interesting widespread application.

**I:** Very interesting. So, you conduct the two themes of research. Do you benefit from spirit of fusion research in AIMR?

**T:** Particularly the kinesin project is so broad in expertise that honestly I do not think there is anybody in the world that in one person has all the expertise to do that. You have to take a team of people from very different areas and make them work together. That is the only way to do it. I mean, if you think about right now, the people who are working on this—there are physicists, chemists, chemical engineers, and biomolecular engineers.

**I:** I see.

**T:** As you see, it is the definition of a fusion research project, basically. You have to do it in such a style. Otherwise, I think it cannot work.

**I:** That is right. And do you think AIMR offers good conditions for fusion research?

**T:** I think so. One of the things that attracted me most about AIMR when I first came here was the fact that, for example at the tea time, you come together in a very relaxed manner and meet and talk with people whom, in your regular work week, you would never talk to.

**I:** That is right.

**T:** Because they are from areas that you have nothing to do with, you get a chance to talk and sometimes when you talk, you come up with an idea where interests get joined and you think about it and you give criticism and make suggestions. And that spirit, I think, is quite important. The idea of pushing this type of activity is really well placed here, because I think it is missing in many other places in the world.

**I:** I see.

**T:** For example in our Materials Science and Engineering program at Texas A&M, there is no regular event where people come together and talk loosely like that and join new ideas. You basically have a list of people and you know what they are doing and if you want to do something with the others, you can contact them.

**I:** That's right.

**T:** But the spontaneity is not there.

**I:** Of course, we can see on the Internet what their research projects are, etc. but a personal contact is missing. I hope the construction of this new building is also helpful.

**T:** Yes, you know, last summer, I had two graduate students from Texas A&M here in Sendai. One of them worked with Prof. Itaya and the other with Prof. Adschiri. So, those kinds of interdisciplinary interactions are possible because you share the floor with somebody from a quite different area. I think in this new building it looks to me like this type of interaction will be even more important.

***Interest in Japanese culture***

**I:** By the way, what was your first contact with Japan or Japanese science?

**T:** To be honest, my first interest in Japan was not through science. It was "aikidō".

**I:** You practice it?

**T:** I did at that time. I then developed the interest in Japan through that, and then when I traveled to Japan, I started considering that maybe there is a possibility to work in Japan afterwards. Then, ultimately, I became interested in the science. Obviously, the other aspect of this is that my wife is Japanese, because around that time, I met her.

**I:** How old were you when you began aikidō?

**T:** Well, I was like 21 years old or so.

**I:** Good.

**T:** I was interested—even in San Diego I still practiced a little bit, but then at some point it floated away gradually. I still like the idea, but I just do not take the effort anymore to do it.

**T:** Now, I have at least two more major interests about Japan. For some time I enjoy Japanese *onsen*. I have been to many, many *onsen*. And this reminds me of Germany. As you know, Baden-Baden is near Karlsruhe.

**I:** It is in your region, indeed.

**T:** It takes only 20-minute from my hometown to drive there.
And you know that the state that I am from was called "Baden."

It is now called Baden-Wuerttemberg. Until World War I, it was called Baden—which in German means "to bathe" and that is because there are so many hot springs.

**I:** I see.

**T:** Therefore, I have always been interested in hot springs. The Japanese hot spring culture is something that is more advanced than anywhere else, and so I am really quite fascinated by that.

**I:** But the way of enjoying hot springs in Japan is totally different from Germany.

**T:** It is.

**I:** Because in Japan, you are in a low tub unlike a swimming pool.

**T:** I had to learn many things.

**I:** Yeah, I think that it is difficult for the beginners. So you enjoy the hot springs in Japan. There are so many around Sendai.

**T:** Oh, it is very nice. Before I came to Sendai, my major playground in this respect was Izu Peninsula, but now obviously I am exploring more onsen here in Tohoku.

**I:** Splendid!

**T:** So that is one thing. When I arrived in 2009, I asked myself before my arrival, what I always wanted to do in Japan, but I never had a possibility to do, because I never had a long enough visit to really study it? And after thinking for a while, I came to the answer. And that was "sadō".

**I:** Sadō?

**T:** Then, I started practicing sadō for the first time. And that is maybe the most interesting revelation about Japan to me.

**I:** So it is tea ceremony.

**T:** But you know, people in the West call it "tea ceremony" but it is not really a good translation, I think.

**I:** Perhaps.

**T:** Because it implies that it is a very strict ceremony.

**I:** Very formal one.

**T:** It sounds very formal, but the spirit behind it is not really a ceremony. So I think the direct translation from the Japanese is actually the better one—like the "way of tea."

**I:** Exactly.

**T:** But for some reason the Western people do not use it. I guess, because they do not get the feeling of what it means, but usually, when I talk to people in the West, I usually call it the "way of tea."

**I:** You are right. As you know, in Japan, even jūdō, aikidō, sadō—all "-dō" means a way.

**T:** Kendō, too.

**I:** That is right. And it is not at all a kind of ceremony or some style. It is because, I think Japanese people always make an analogy to the "way" and we think one must make a spiritual progress along this way.
**T:** To some goal.
**I:** Indeed. And always to reach a certain goal spiritually, we should make an effort on this way, etc. It is interesting to make this analogy with road or way.
**T:** Yes, that is right. It is interesting.
**I:** Perhaps rather than me, you can catch the essence of Japanese culture.
**T:** Well, I am not sure about that.
**I:** Very great. So now your hobby is a way of tea.
**T:** In Japan, that is my major hobby.
**I:** So, you practice it in Sendai?
**T:** Yes.
**I:** Oh, really. So do you follow some master?
**T:** Well, most of the time I spend with Tohoku University students who are in a club.
**I:** I see.
**T:** But I have also meanwhile purchased whatever is needed and taken it to the United States. So in my house in America, I can also do it there.

***Science and society***

**I:** Last week we organized Katahira Festival (Katahira Matsuri in Japanese), open campus to the citizen. Did your lab participate in it with some demonstration?
**T:** Yes, for the demonstration, we purchased some materials and made some displays here, but I brought others from the United States. My department has a great outreach show at Texas A&M. We spent many years doing lots of events. Every year, we have an event where there are 5,000 or 6,000 people coming, mostly kids, and we have lots of different shows. And so I decided that maybe I should show a few of the things which can easily be transported.

**I:** I see.
**T:** So we did a presentation of low temperature effects.
**I:** Great. And did many visitors come to see your lab for experiment?
**T:** Yes, I was very happy with it.
**I:** Immediately after the earthquake, you sent us an e-mail with photos of the outreach event

in Texas A&M.

**T:** That is right. There was a big outreach event two weeks after the earthquake.

And so several people, including my wife decided that one should have a table there for donation to the victims of the Tohoku region.

**I:** I am very grateful for it. Generally speaking, we must inform what our activities are to the citizens, but also to attract the younger ones.

**T:** That is right. I think there are two missions, which are very important. Exactly like you said, the first one is that in many countries there is a big problem of motivating young people to get excited about science and technology. In the United States, a few years ago, there were almost no American students who wanted to do science and engineering and there were almost entirely foreigners. Now, it has changed a little bit, but it is still a difficult situation.

**I:** That is right.

**T:** In my opinion, smart young people should think normally that science is the number one choice for a career. But recently, smart young people thought that they should go to work on Wall Street or at some insurance company.

**I:** That is right.

**T:** I am sure that these jobs are also very interesting and you earn a lot of money—but I think if you are smart, you should consider science as your number one choice to go to. And that is the message that we have to get across. And I think for that you have to start very early. So, for example, at Katahira Matsuri, you have seen little kids maybe five or six years old come and stand there. Once some display starts, it fascinates them. And they can play around for minutes—you cannot know what is going on in their minds, but those moments may be very important.

**I:** That is right.

**T:** We do not know right now, but that moment may be the moment where the child decides to become a scientist.

**I:** I agree with you, because even in Japan 20 years ago when our economy was growing, most people wanted to go to the insurance or bank and traditionally many people wanted to become a government official, etc.

**T:** Yes.

**I:** But on the other hand, fortunately Japan has a strong tradition of esteem of technology. And so I think perhaps the Japanese situation is not so bad, but we should always make an effort to attract the children, because sometimes their parents think that science and technology are where your hands become dirty after the experiment and you cannot gain much salary, etc. However, through this kind of discovery of the charm of science at the small age, we can change the mindset of the citizen.

**T:** Absolutely. It is crucial and it really can make a big difference for our future.

Now the second reason in the end is very egotistic—but it is an important reason also.

**I:** Egoistic?

**T:** Science is in most cases supported by taxes. And it is mostly paid by regular people on the street that do not really come into our building, usually. They do not really come in, unless you have an event like Katahira Matsuri. Then they come in once every two years. And so, if we think egoistically as scientists, to continue doing research, we need to make sure that people understand that we are doing interesting thing and that there may be some benefit to them finally.

**I:** That means we do interesting and useful things.

**T:** Useful things, yeah. And ultimately our efforts are helping the country to advance.

**I:** That is right.

**T:** If people lose that belief, they will at some point say that there should be no more tax money for this.

**I:** That is right. So in this sense it is not egoistical, but it is rather related to the accountability for the contribution to society.

**T:** It is in some sense altruistic as you say, "Well, we were trying to make sure that we contribute to social advancement." But at the same time, it is also egotistic in a sense that scientists love what they are doing.

**I:** Yes, certainly.

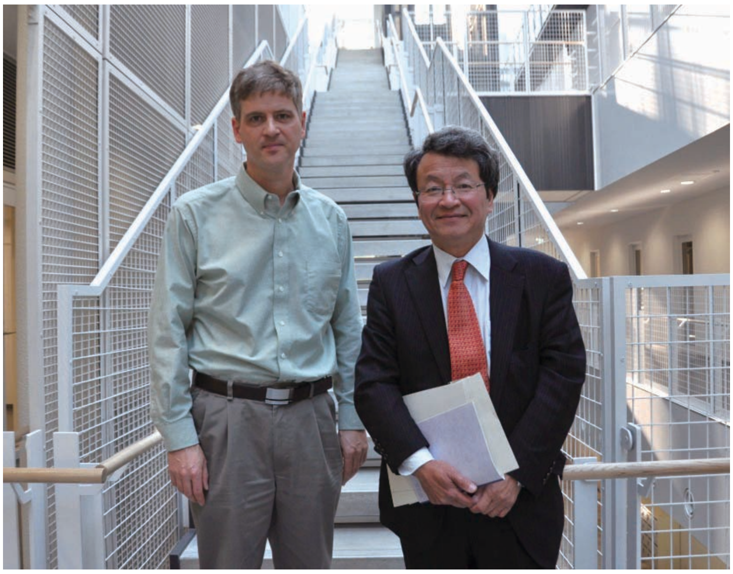
**T:** We want to continue what we are doing and we may not have the opportunity unless we are carefully making sure that everybody understands that they have a benefit from it.

**I:** This is an important message.

The next week I go to Tokyo to attend the Program committee for interim evaluation. I hope that the outcome of the evaluation is positive.

**T:** Absolutely. I am hoping that what has been started here will continue and, to be frank, five years is not a very long time if you start something new, so it is very difficult to make an assessment after five years. The trajectory that I have seen here is definitely a very good one. You see it converging toward a very beneficial goal.

**I:** I think so. Thank you for taking time. Have a nice stay at AIMR.



Interviewer: Administrative Director, W. Iwamoto

*At Teizer Laboratory, WPI-AIMR Main Building*

*October 12$^{th}$, 2011*

# News Update

## Completion Ceremony of the WPI-AIMR Main Building

The Completion Ceremony of the WPI-AIMR main building was held on 7 December 2011 to celebrate the inauguration of the new facility with the participation of 70 guests and almost all researchers of WPI-AIMR working in Sendai.

The Ceremony, preceded by the beautiful choir of the Tohoku University Männerchor OB, began with a speech by the President of Tohoku University, Dr. Akihisa Inoue, who indicated the new facility as a symbol of the resurrection of the intellectual power of the University after the disaster of March 11th. Dr Hiroyuki Abé, Counselor to the President of the Japanese Science and Technology Agency (JST) and the former President of the University, made a speech referring to the discussions on the genesis of the WPI Program at the Council for Science and Technology Policy of which he was Chief Executive Member. Mr. Hayashi Towatari, Deputy Director-General, Research Promotion Bureau of MEXT, gave an address encouraging AIMR researchers while insisting on the importance of the fusion research “under one roof”. Dr. Toshio Kuroki, as Program Director of the WPI Program, made a speech with expectation of the new orientation of WPI-AIMR.

The reception was organized at the spacious atrium hall of the main building, to congratulate the creation of the new research environment. After congratulatory remarks by Dr. Junichi Nishizawa, Adviser of the Sophia School Corporation and the former President of Tohoku University, and Dr. Yoshihito Osada, Program Officer of the WPI Program, the participants enjoyed the beautiful opening of the new main building. In the course of the reception, the process of the construction of the main building was reported on and Certificates of Appreciation were presented by the Center Director, Professor Yoshinori Yamamoto, to the builders and the providers of the equipments.

The main building, with a total surface of 9,000 $m^2$, was completed with only four months’ delay in spite of the Great East Japan Earthquake. The cost of construction, which amounts to 2 billion yen, was provided by MEXT from the 2009 supplementary budget. The new main building houses 11 PIs’ laboratories and staff rooms, the laboratory for fusion research, space for free discussion and the multi-purpose room for outreach activities such as the science café. Tohoku University, as host institution, has contributed to the improved research environment through provision of the space for the Mathematics Unit and the library. This enables almost all researchers of AIMR to work together at the Katahira campus and it is expected to further the fusion research across different fields at AIMR more than ever.

# Memorandum of Understanding on Academic Exchange with Fraunhofer Institute for Electronic Nano Systems ENAS (Germany)

WPI-AIMR has concluded a Memorandum of Understanding (MOU) on academic exchange with Fraunhofer Institute for Electronic Nano Systems (FhG ENAS) (Germany) on November 8, 2011.

The MOU was signed between Yoshinori Yamamoto (Director, WPI-AIMR) and Thomas Gessner (Institute Director, FhG ENAS) and Georg Rosenfeld (Division Director of Corporate Development, FhG) in the presence of Emiko Okuyama (Mayor of Sendai), Hans-Jörg Bullinger (President, FhG) and Toshio Iijima (Executive Vice President, Tohoku University), the other persons concerned, at the signing ceremony held in Sendai.

As the largest organization for applied research in Europe, the FhG, founded in 1949, is a semi-private organization and consists of more than 80 research units in Germany, including 60 institutes. Their research fields focus on people's needs such as health, security, communication, energy and environment under the theme of "The conducted research spreads over a wide field of latest topics reaching from microelectronics to life sciences".

The FhG ENAS is focusing on smart systems integration by using micro and nano technologies and the main research areas of FhG ENAS are clearly visible in the structure of the institute. Six departments belong to FhG ENAS as provided below.

- •Multi Device Integration (MDI)
- •Micro Materials Center (MMC)
- •Printed Functionalities (PF)
- •Back-end of Line (BEOL)
- •System Packaging (SP)
- •Advanced System Engineering (ASE)


Prof. Thomas Gessner, who is Institute Director of the FhG ENAS, has worked for

WPI-AIMR as a Principle Investigator (PI) of Device/Systems Group (MEMS Materials Research Laboratory) since its establishment in 2007. He has strongly promoted "MEMS bonding technology with metallic glass and nanostructured metals" through the fusion research between MEMS and Bulk Metallic Glasses with Prof. Masayoshi Esashi, Principle Investigator of the WPI-AIMR, and has built essential important relationships between FhG ENAS and WPI-AIMR for its past activities.

The research exchange among two parties is very actively promoted. Dr. Yuching Lin from FhG ENAS has worked as an assistant professor of WPI-AIMR since October 2008 and she has studied "Metallic glassy thin films for system integration" through the fusion research between MEMS and Bulk Metallic Glasses, and three young researchers from FhG ENAS have also worked as visiting scientists of WPI-AIMR.

With this MOU, it is expected that these two parties will not only participate in active academic exchanges but also further collaboration research in the field of MEMS.

WPI-AIMR has been strongly promoting a relationship with foreign institutes since its establishment in 2007. Another recent example is the Agreement with the Particulate Fluids Processing Centre (PFPC) of Melbourne University signed on October 26th. This is a fruit of the discussions at the ACIS-WPI Workshop held in February 2011 in Tasmania, Australia.

Fraunhofer Institute for Electronic Nano Systems ENAS
http://www.enas.fraunhofer.de/EN/index.jsp

PFPC of Melbourne University
http://www.pfpc.unimelb.edu.au/

# "Green materials synthesis with supercritical water"

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**This review was amongst the top ten accessed articles of the online version of *Green Chemistry*.**

Concept of "Green materials" has two view points, process and materials. Essential is to design the products and processes so as to minimize the use and generation of hazardous substances, disposal and promote the use of safe, environment-benign substances, including solvents, and to design energy efficient processes/system. For aspect of materials, contribution of products to minimize environmental problems ($CO_2$ emission, environment-cleaning catalyst etc.), 2) recycling of materials to resources, 3) holistic life cycle assessment of the materials, and 4) combined multiple technological and operational systems for reduction of energy and resources should be also considered.

Supercritical fluids (especially, water and $CO_2$) technology is expected to contribute for green materials synthesis with the green sustainable chemistry route, especially for nanomaterials. For the fabrication of nanomaterials, the important point is the control of surface energy of nanomaterials or hetero-interface. As shown in Table 1, many supercritical fluid technologies were proposed to solve the problems, so far. Extraction with supercritical fluid can be applied for drying the semiconductor pattern, without forming the gas-liquid interface, namely capillary force, so that the collapse of fine patterns does not occur. In supercritical fluid, diffusivity is faster than in liquid, and since the reaction is less than first order so that Thiele modulus is approached to unity, namely uniform and conformal deposition is possible with increasing productivity. This review paper summarizes the green aspect of the supercritical fluid technologies(especially for supercritical water), including functional materials synthesis, complete solvent recycle, no use of organic solvents, nontoxic substances etc.

Supercritical water can form a homogeneous phase with inorganic and organic substances and also, water itself works as an acid or base catalyst. Supercritical hydrothermal process developed in WPI-AIMR, Tohoku University, contributes to greener society through the use of water instead of organic solvent to produce various functional materials that are used to minimize the emission of $CO_2$. In addition, because the processes are quite fast, the supercritical hydrothermal process can treat much larger amount of reactants and products as compared with conventional processes. The surface control of nanoparticles in supercritical water is a key to fabricate hybrid materials with polymers, which can be used for greener materials (high heat transfer materials, high RI film etc.). Supercritical hydrothermal condition provides the synthesis of organic modified nanoparticles that is required for those materials. Green processes involving chemical recycling of waste polymers and a combination of hydrothermal synthesis and supercritical water oxidation are another important aspect of greener process. Thus, the commercialization of such processes greatly contributes to the greener society.

**Table 1** Green aspects of supercritical fluid technologies for material processes

| Process | Advantages of SCFs | Green aspect |
|---|---|---|
| Extraction/Fractionation | Selective solubility/No residual solvent | No organic solvent, complete solvent recycle |
| Cleaning | Good solvent power | No VOCs, no toxic organic solvent |
| Drying | No capillary force | Increasing production yield |
| Polymerization | No residual solvent | No organic solvent |
| Hydrothermal synthesis | No organic solvent needed<br>Nanoparticle synthesis | No organic solvent, High heat recovery |
| Plating | Good solubility of $H_2$ in $scCO_2$ | No wastewater generation |
| Biomass conversion | No acid/base catalyst needed | Simple process without heavy wastewater generation |
| Recycling | No acid/base catalyst needed | No secondary contamination, less wastewater treatment |
| Recovery of materials by SCWO | No mass transfer resistance | Valuable inorganic compound can be recycled |
| Heavy metal extraction (Radioactive metals) | Selective extraction of uranium | No secondary contamination |
| Dyeing | Easy penetration of dye | No wastewater generation |
| SCF Deposition | No capillary force | Increasing production yield |

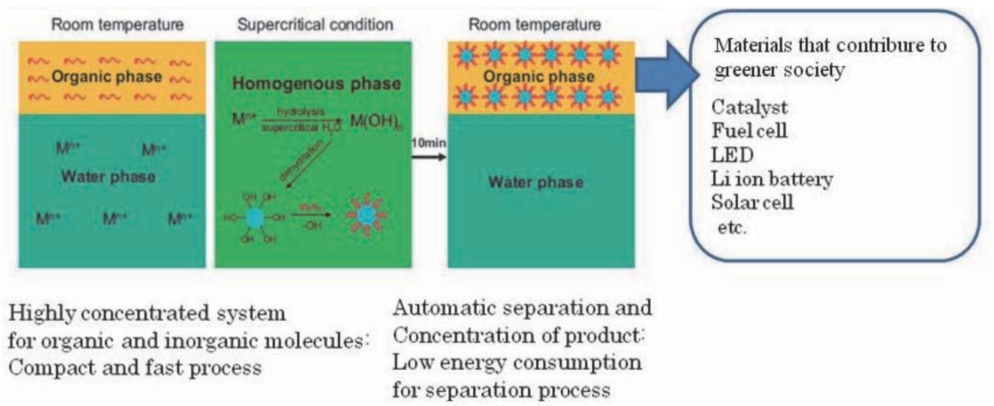


**Figure 1** Green process for green materials

# "Effect of metallic Mg insertion on the magnetoresistance effect in MgO-based tunnel junctions using $D0_{22}$-$Mn_{3-\delta}Ga$ perpendicularly magnetized spin polarizer"

T. Kubota,[1] S. Mizukami,[1] D. Watanabe,[1] F. Wu,[1] X. Zhang,[1] H. Naganuma,[2] M. Oogane,[2] Y. Ando,[2] and T. Miyazaki[1]

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**This paper was selected as Research Highlights in *Journal of Applied Physics*.***

"Spintronics" has been achieving great interests for the capabilities of various new device applications [1]. Non-volatile spin transfer torque (STT) writing type magnetoresistive random access memory (MRAM) is one of a promising spintronic device. Magnetic material with high perpendicular magnetic anisotropy (PMA) is indispensable for realizing giga-bit-class high density MRAM. Among various PMA compounds, tetragonal $D0_{22}$ type $Mn_{3-\delta}Ga$ alloys are attractive. Uniaxial anisotropy constant ($K_u$) of $D0_{22}$-$Mn_{3-\delta}Ga$ ($\delta$ = 0.6) films is the order of $10^7$ erg/cm$^3$ [2] which is high enough to achieve 10-year retention of a memory bit for STT-MRAM sells. And magnetic damping constant of ordered Mn-Ga alloys are much smaller than other PMA materials [3], which can benefit to reduce the writing current of a magnetic tunnel junction (MTJ). In addition, it was theoretically expected that spin polarization of transport electron in bulk $D0_{22}$-$Mn_{3-\delta}Ga$ [4] and TMR ratio in a $D0_{22}$-$Mn_3Ga$/MgO/$D0_{22}$-$Mn_3Ga$ MTJ [5] were also high enough to apply Spin-RAMs. As well as these attractive physical properties, $D0_{22}$-$Mn_3Ga$ is a both rear earth and noble metal free PMA material unlike conventional ones (i.e., $L1_0$-FePt, TbFeCo, etc.). Thus, $D0_{22}$-$Mn_3Ga$ alloy in spintronic device can play important role to create so called the *Green material based society* from the aspects of both reducing power consumption and resource of rare-elements.

We have succeeded in fabricating $D0_{22}$-$Mn_{3-\delta}Ga$ epitaxial thin films [2] and observing tunnel magnetoresistance (TMR) effect in MTJs using $D0_{22}$-$Mn_{3-\delta}Ga$ electrode and MgO tunnel barrier [5]. To achieve further understanding concerning the interfacial effect on the TMR effect, we investigated the effect of Mg-layer-insertion at the Mn-Ga/MgO interface in this article.

Figure 1 (a) shows a schematic stacking structure of the MTJs. All the layers were prepared by magnetron sputtering technique onto MgO (001) single crystal substrate. Epitaxial growth of the Cr/$D0_{22}$-$Mn_{3-\delta}Ga$/MgO/CoFe layers was confirmed by transition electron microscopy. Thickness of the inserted Mg layer ($t_{Mg}$) was varied to modify interfacial density of states (DOS) at the Mn-Ga/MgO interface.

Fig. 1 (b) is the TMR curves with different $t_{Mg}$. Firstly, TMR ratio was increased with increasing $t_{Mg}$ up to 0.4 nm, which is considered due to suppressing contamination (i.e., Mn-oxides) at the interface. Increasing $t_{Mg}$ more than 0.6 nm, TMR ratio was decreased monotonically. Interestingly, here, sign of the TMR ratio was changed in an MTJ with $t_{Mg}$ = 1.2 nm, and the magnitude was increased at the $t_{Mg}$ = 1.4 nm. The dependence of the TMR ratio is attributed to be relating to band dispersions of both Mn-Ga and CoFe electrodes, considering the results of bias voltage dependences of tunneling conductance and TMR ratio. In addition, change of the sign in the MTJs with thick Mg insertion is possibly attributed to quantum well states within an Mg layer [6]. Tuning of TMR ratio by the quantum well states have potential of enhancing the TMR ratio. Our result is an important first step for realizing memory bit using $D0_{22}$-$Mn_3Ga$ for the STT-MRAM devices.

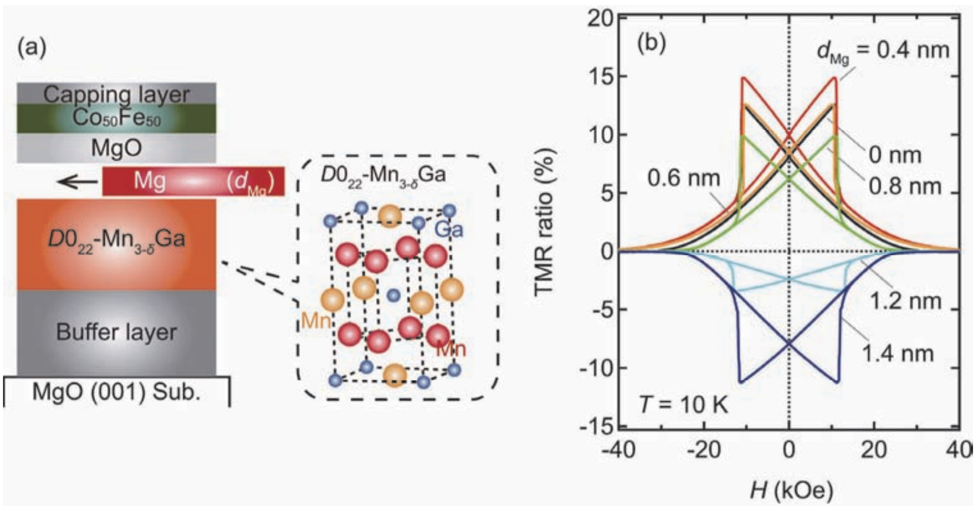


Fig. 1 (a) Schematics of stacking structure of the prepared MTJ devices and crystal structure or $D0_{22}$-$Mn_3Ga$ alloy. (b) TMR curves of the $D0_{22}$-$Mn_3Ga$ MTJs with different Mg thickness

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# "Interface effects on perpendicular magnetic anisotropy for molecular-capped cobalt ultrathin films"

Xianmin Zhang, Shigemi Mizukami, Takahide Kubota, Qinli Ma and Terunobu Miyazaki

WPI Advanced Institute for Materials Research, Tohoku University

**This paper was selected for publication in *Virtual Journal of Nanoscale Science & Technology*.***

Organic spin valve (SV) devices using π-conjugated organic semiconductors as spacers have been attracting much research interest, owing to low processing costs and their long spin diffusion lengths [1,2]. Interface between molecular layer and ferromagnetic metal plays an important role in determining spin injection and detection efficiency of organic SV devices. Investigation and understanding of the interface interactions are essential for fundamental science and future organic devices [3]. A very thin Co film (~1nm) shows strong perpendicular magnetic anisotropy (PMA), depending on buffer and capping layer materials. Most of the PMA originates from the electron orbital anisotropy inducing at the interfaces, and therefore can be potentially used as a probe to explore the interface interaction.

In our papers [4,5], we investigated the on-top interface effect on PMA of very thin Co (0.5-1.8 nm) layer in the Pt/Co/molecule system using five typical molecular semiconductors: pentacene (Pc), 8-hydroxyquinoline-aluminum ($Alq_3$), fullerene ($C_{60}$), 5,6,11,12-tetraphenylnaphthacene (rubrene) and copper phthalocyanine (CuPc). The PMA of the $Alq_3$, rubrene, and $C_{60}$-capped films was almost same as each other, though they were smaller than that for CuPc and Pc-capped films. Figure 1(a)-(e) shows the magnetic curves of Co (0.7 nm) with different organic capping layers. Figure 1(f) is the dependence of out-of-plane coercivity on Co thickness with different capping layers. This study contributes to design organic SV devices because the magnetoresistance is switched by the different coercivities of electrodes.

We found the PMA of Co was relatively smaller if molecular capping layer was of amorphous structure compared to crystal structure and analyzed the possible mechanism for the dependence of PMA on organic capping layer. The alteration of PMA and coercivity for ferromagnetic Co ultrathin films by varying organic capping layers correlate with the difference in structure of capping layers. Stacking structure in molecular layer might be affected by the interactions between Co and organic molecule at the interface because it determines an initial growth of molecular stacking. The difference of crystal structural in $C_{60}$, $Alq_3$, and rubrene layers compared to CuPc and Pc layers, reflects their different bonding with Co at the interface. Accordingly, this influences the spin-orbit interaction of interfacial Co. Our work clearly indicates the magnetic properties of ferromagnetic metal can be markedly infected by organic molecule depending on the nature of organic molecule. This likely opens a new window to deeply understand the ferromagnetic metal-organic interface physics and will contribute to develope advanced substances for future organic spintronics.

This work is collaborated with Dr. Hiroshi Naganuma, Dr. Mikihiko Oogane, and Prof. Yasuo Ando in Tohoku University and financially supported by the WPI-AIMR fusion research project.

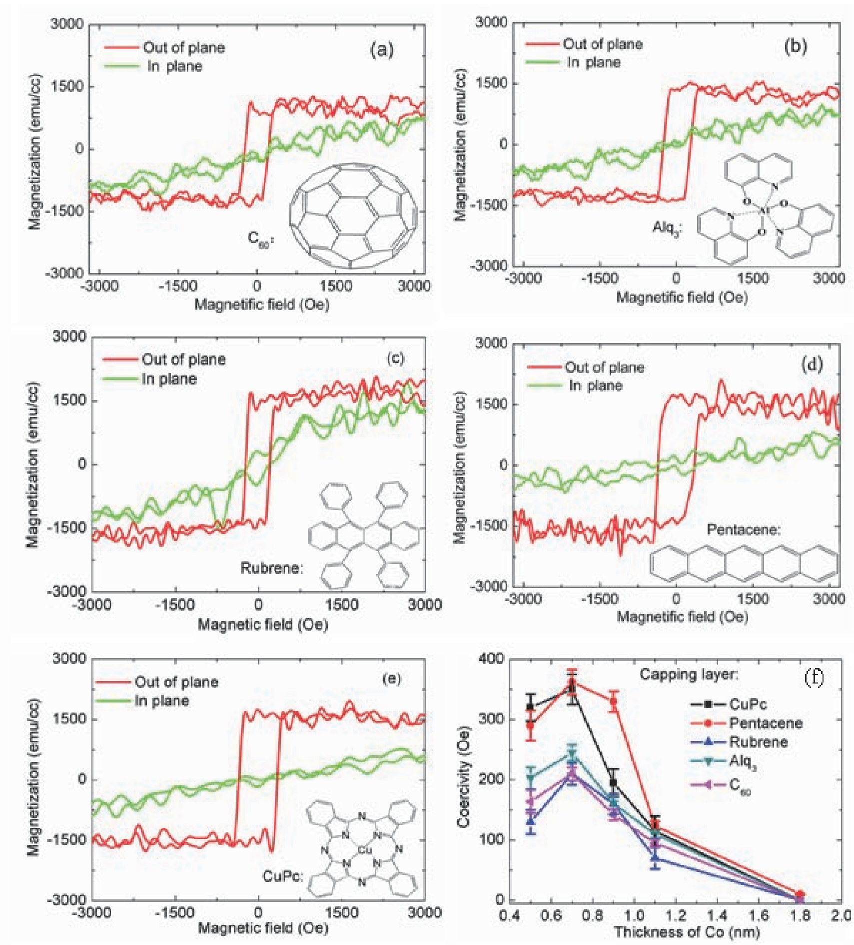


Fig. 1. (a) - (e): Magnetic curves of 0.7 nm Co with different organic capping layers. The inset was the molecular structure. (f) Dependence of out-of-plane coercivity on Co thickness with different organic capping layers.

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# “Unexpected mass acquisition of Dirac fermions at the quantum phase transition of a topological insulator”

T. Sato[1], Kouji Segawa[2], K. Kosaka[1], S. Souma[3], K. Nakayama[1], K. Eto[2], T. Minami[2], Yoichi Ando[2], and T. Takahashi[1,3]

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**This Paper was published in *Nature Physics*, and the experimental data measured by Takahashi group were selected as its cover design.***

The three-dimensional (3D) topological insulator is a novel quantum state of matter where an insulating bulk hosts a linearly-dispersing surface state, which can be viewed as a sea of massless Dirac fermions protected by the time-reversal symmetry (TRS). Breaking the TRS by a magnetic order leads to the opening of a gap in the surface state [1] and consequently the Dirac fermions become massive. It has been proposed theoretically that such a mass acquisition is necessary for realizing novel topological phenomena,[2,3] but achieving a sufficiently large mass is an experimental challenge. In this news, we report an unexpected discovery that the surface Dirac fermions in a solid-solution system $TlBi(S_{1-x}Se_x)_2$ acquire a mass *without* explicitly breaking the TRS[4]. We found that this system goes through a quantum phase transition (QOT) from the topological to the non-topological phase, and by tracing the evolution of the electronic states using the angle-resolved photoemission, we observed that the massless Dirac state in $TlBiSe_2$ switches to a massive state before it disappears in the non-topological phase.

Figure 1 shows the series of ARPES data around the Brillouin-zone center measured

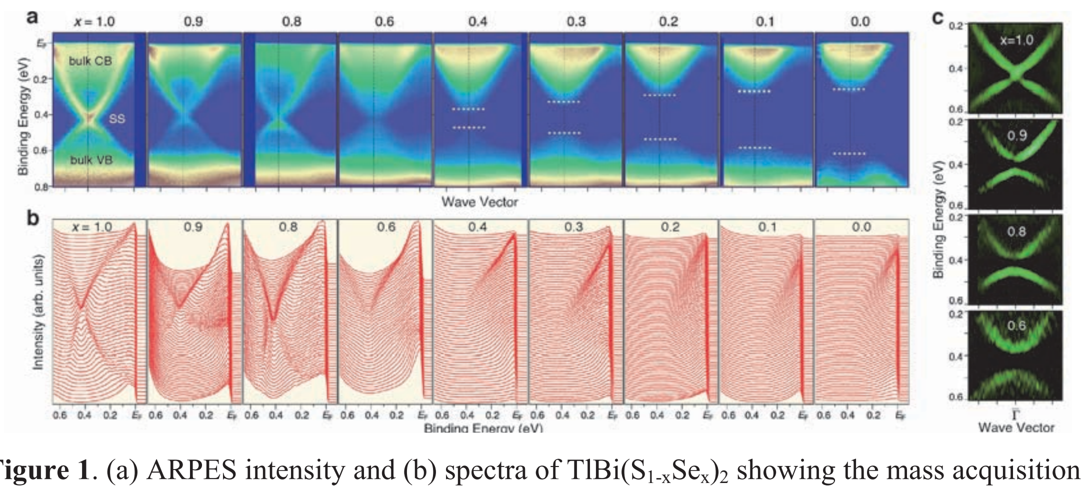


**Figure 1**. (a) ARPES intensity and (b) spectra of $TlBi(S_{1-x}Se_x)_2$ showing the mass acquisition of surface Dirac fermions. (c) Second-derivative intensity for $x$ = 1.0-0.6

for various sulfur concentrations $x$. We found a finite energy gap at the Dirac point in $0.6 \leq x \leq 0.9$, while such an energy gap is absent in $x = 1.0$. This indicates that the massless Dirac fermions transform into a massive state by simply replacing Se with S in the crystal.

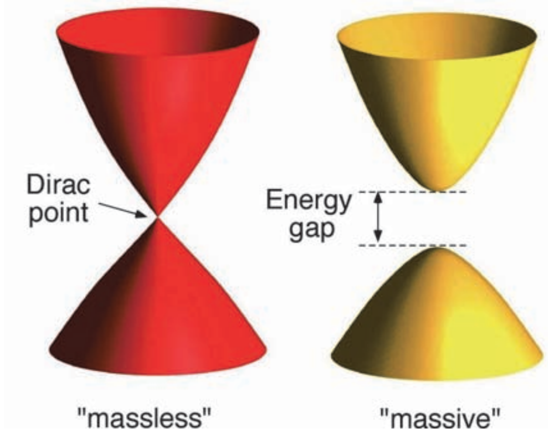


**Figure 2**. Masless and massive Dirac fermions observed in $TlBi(S_{1-x}Se_x)_2$ at x = 1.0 and 0.9, respectively

The mass acquisition of the Dirac fermions indicates that the Kramers degeneracy is lifted, which means that the TRS must be broken on the surface. Given that there is no explicit TRS breaking, the only possibility is that a *spontaneous* symmetry breaking takes place upon the S substitution, which reminds us of the Higgs mechanism in particle physics. Therefore, $TlBi(S_{1-x}Se_x)_2$ may serve as a model system to bridge the condensed-matter physics and particle physics. The exact mechanism of the mass acquisition is not clear at the moment, but an interesting possibility is that it originates from some exotic many-body effects that can lead to an electronic order, although a simple mechanism like the spin-density wave does not seem to be relevant. When the top and bottom surface states coherently couple and hybridize, the Dirac gap can open,[5] but the sufficiently large thickness (> 10 μm) of our samples precludes this origin. Another possibility is that critical fluctuations associated with the QPT are responsible for the mass acquisition, but it is too early to speculate along this line. From the application point of view, it is remarked that the Dirac gap of $TlBi(S_{1-x}Se_x)_2$ is much larger than that in magnetically-doped topological insulator $Bi_2Se_3$ [1], and more importantly, it is tunable with the S/Se ratio. This indicates that $TlBi(S_{1-x}Se_x)_2$ is a prime candidate for device applications that require a gapped surface state.

The paper, “Unexpected mass acquisition of Dirac fermions at the quantum phase transition of a topological insulator”, was published in Nature Physics (November issue, 2011), and the experimental data measured with the world-highest resolution angle-resolved photoemission (ARPES) spectrometer constructed by Takahashi group are used as the cover design to demonstrate the importance of the paper. Also on the cover page, the expression of “Unexpected mass” was used to highlight the impact of the present research. In this work, the group found that Dirac electrons at the surface of topological insulator acquire the mass without explicitly breaking the time-reversal symmetry. This result suggests existence of a condensed-matter version of the "Higgs mechanism" which proposes that materials acquire the mass with the spontaneous symmetry-breaking at the beginning of universe. Thus the present result would shed light on the basic problem common in particle, materials, and cosmic physics. In the application point of view, the present success to give a mass to Dirac electrons opens the possibility for developing highly efficient, high-speed spintronics devices with topological insulators. (http://www.nature.com/nphys/journal/v7/n11/covers/index.html)

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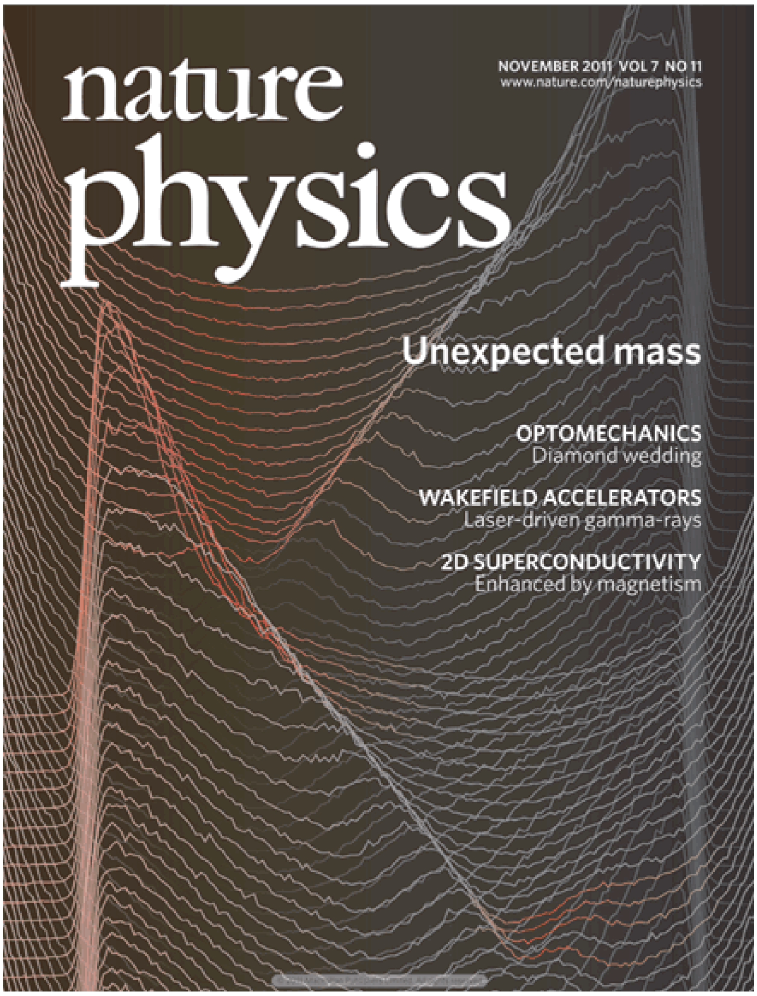

# "Atomic structure of nanoclusters in oxide-dispersion-strengthened steels"

A. Hirata[1], T. Fujita[1], Y. R. Wen[1], J. H. Schneibel[2], C. T. Liu[2], and M. W. Chen[1,3]

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**This paper was published in *Nature Materials*.***

The huge earthquake devastated the Fukushima nuclear power plants and caused large scale radioactive pollution last March. There is a pressing need to improve the safety of reactors in the plants as well as the whole system. Oxide dispersion strengthened (ODS) steels have been strenuously developed as a promising material for fission and fusion reactor applications [1]. The reason is that ODS steels exhibit an excellent high temperature strength, stability and expansion resistance in comparison with conventional steels. Nanoscale oxide clusters densely dispersed in the ODS steel contributes effectively to the excellent high-temperature mechanical properties. It was suggested that the nanoclusters possess a characteristic chemical composition differently from normal oxides and include a lot of atomic vacancies [2-4]. However, the structural detail is still open to question. Therefore it is highly necessary to perform detailed structural analysis for the oxide nanoclusters in the ODS steel.

The ODS alloy was synthesized by mechanical alloying of the Fe-14Cr-3W-0.4Ti (wt. %) alloy powder, with 0.25 wt. % $Y_2O_3$ powder, followed by canning in an evacuated jacket and hot extrusion. Then the hot-extruded ODS ingot was annealed for 1 hour at 1000°C for the formation of nanoclusters. Nanoscale observation for the ODS steel was performed using a JEM-2100F scanning transmission electron microscope (STEM) equipped with double spherical aberration correctors.

Figure 1 (a) shows a low-magnification STEM images of the representative microstructure of the 14YWT ODS sample used in this study, together with a closeup image of a nanocluster. To observe the oxide particles clearly, we employed the HAADF (high angle annular dark field)-STEM technique by which the regions with lower-density and/or including lighter elements (e.g. oxide in the steel) are emphatically imaged as darker contrast, vice versa. In the closeup HAADF image [inset of Fig. 1 (a)], a small oxide nanocluster can be seen as a dark contrast and dotted contrasts corresponding to atomic columns in the nanocluster are clearly different from those in the bcc-Fe matrix. To understand the contrast of the nanoclusters, we tried to construct plausible structural models for the nanocluster by fitting to the experimental HAADF-STEM images [5]. A lot of possible models were prepared by combining handmade method and molecular dynamics simulation, and then provided to the HAADF-STEM image simulation. Finally we proposed the structural model with a defective NaCl structure fully coherent with the bcc matrix structure [Fig. 1 (b)].

The defective oxide structure in the ODS steel is totally different from particle structures in conventional particle-dispersion materials. The nanoclusters in the ODS steel are multicomponent, include a lot of vacancy, and have a defective structure fully coherent with the matrix. It has been reported that the oxide nanoclusters are extremely stable and capable of keeping the nanoscale sizes as well as high number density even at high temperatures near the melting point [4]. It is obviously difficult to understand the phenomenon only with the macroscopic thermodynamics. In any case the anomalous chemical and structural features are highly responsible for the extraordinary stability, although we need further theoretical consideration on it. Therefore the ODS steel can be regarded as a novel material state providing the superior high-temperature mechanical properties.

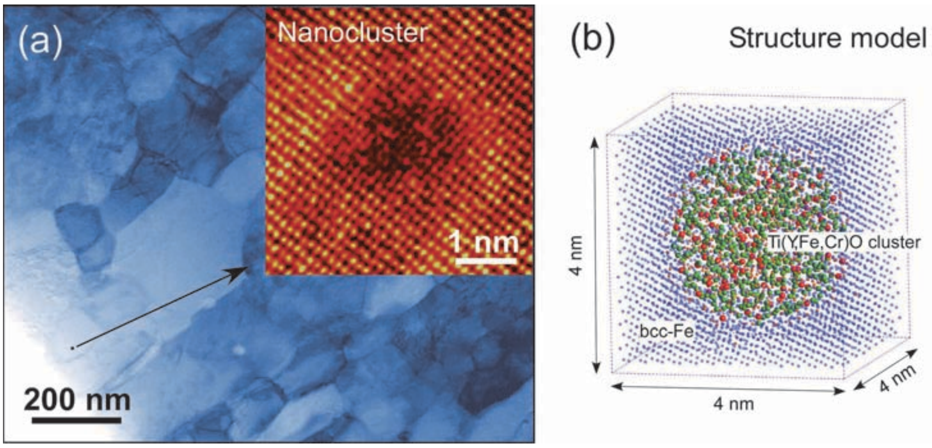


Fig. 1 (a) Microstructure of the ODS steel and closeup of the nanocluster. (b) Structural model of the nanocluster.

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# "Atom-Resolved Imaging of Ordered Defect Superstructures at Individual Grain Boundaries"

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The presence of defects, even at very low concentrations, can significantly affect the properties and functionality of materials [1]. This is especially pronounced for polycrystalline materials where there are often complex interactions between the extended grain boundary defects and atomic scale point defects. Inevitably, no matter how carefully a material is prepared, trace impurities, typically at the level of parts per million (ppm), are always present. In polycrystalline materials, such impurities often segregate to grain boundaries [2,3] where their concentrations can be enhanced by many orders of magnitude. This, in turn, can driven structural transformation of grain boundaries and lead to modification of material properties, *e.g.* mechanical or electronic. Therefore, considerable effort has been directed towards identifying multi-component structure of grain boundaries at the atomic scale in order to better understand as well as predict properties of polycrystalline materials.

Unfortunately, experimental methods capable of resolving the structure of a buried interface with both atomic and chemical resolution are extremely scarce. For example, most scattering or spectroscopy techniques yield only an ensemble average over a given sample volume and scanning-probe microscopies can only image atomic defects close to surfaces. Transmission electron microscopy (TEM), on the other hand, is one of the few methods that are able to fulfill this role. In particular, the development of advanced TEM methods, including aberration corrected high-angle annular dark field, scanning TEM, electron energy-loss spectroscopy, and annular bright-field, it is now becoming possible to obtain atomic scale, chemically resolved images [4] which can provide insight into how impurities and defects actually interact and rearrange in grain boundaries. However, many previous TEM studies of grain boundaries have imaged interfaces from one direction only, providing little direct information on its two-dimensional structure.

In the Letter, by taking the example of a grain boundary in MgO, we show that advanced electron microscopy techniques combined with first principles theoretical calculations can provide three-dimensional images of complex multi-component grain boundaries with both atomic resolution and chemical sensitivity. The unprecedented resolution of these techniques allows us to demonstrate that, even for the simple rocksalt oxide MgO, grain boundaries can accommodate complex ordered superstructures comprised of several types of defect species such as Ca impurities, Ti substitutions, Mg vacancies, Ca interstitials, and Ca vacancies (Fig. 1). These results point to the existence of new effects associated with interactions of defect with grain boundary in ceramics, and demonstrate that atomic scale analysis of complex multi-component structures inside materials is now becoming possible [5].

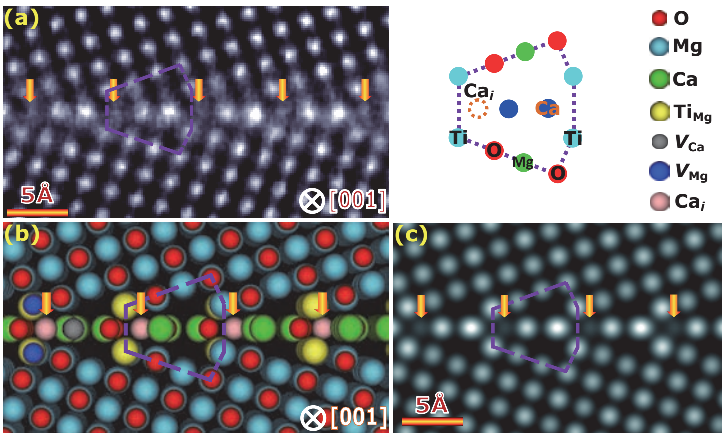


Fig. 1 (a) Atomic-resolution high-angle annular dark field image viewed from [001]. (b) Theoretically determined stable grain boundary structure. (c) Simulated image obtained using determined grain boundary structure showing good match with the experimental image in (a).

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# “Single molecule detection from a large-scale SERS-active $Au_{79}Ag_{21}$ substrate”

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Detecting and identifying single molecules are the ultimate goal of analytic sensitivity. Single molecule detection by surface-enhanced Raman scattering (SM-SERS) depends predominantly on SERS-active metal substrates that are usually colloidal silver fractal clusters [1,2]. However, the high chemical reactivity of silver and the low reproducibility of its complicated synthesis with fractal clusters have been serious obstacles to practical applications of SERS, particularly for probing single biomolecules in extensive physiological environments.

Recently, we have succeeded in fabricating a large-scale and free-standing SERS substrate for single molecule detection [3,4]. Our robust substrate is made with wrinkled nanoporous $Au_{79}Ag_{21}$ films [3] (Fig 1(a)) that contain a high density of electromagnetic “hot spots” with a local SERS enhancement larger than $10^9$. The excellent SERS performance of the wrinkled nanoporous film comes from its heterogeneous nanostructures including nano-pores, nano-tips and nanogaps, which give the substrate a broad-spectrum of plasmon frequencies for a wide range of molecule detection. The most active sites locate at the narrow broken ridges of the wrinkled nanoporous film (Fig 1(b)). Interestingly, in these complex plasmonic structures, rows of tip-to-tip nanoantenna can be frequently observed along the ridges of the wrinkled film, which are responsible for giant Raman scattering enhancement [4]. We have demonstrated that SM-SERS can be achieved for both resonant (R6G) and nonresonant (DNA base: adenine) molecules.

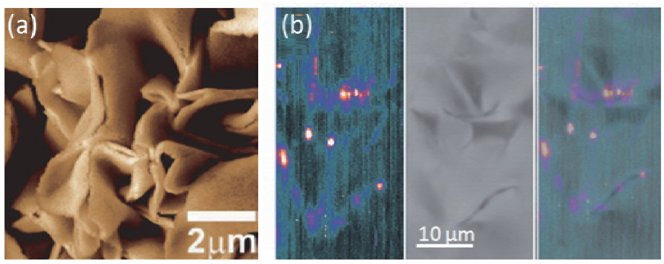


Figure 1 (a) SEM image of a wrinkled nanoporous film. (b) Single molecule detection. Typical Raman map of DNA adenine molecules ($10^{-9}$ M) (left), corresponding optical microscopic image (middle), and their overlay image (right).

This large-scale gold-based SM-SERS substrate with superior reproducibly, facile synthesis and excellent stability may open new avenues for a wide range of applications in life science and environment protection where single molecule detection and identification are critical. Considering the chemical inertness and biocompatibility of the gold-rich alloy, the single-molecule SERS substrate may allow direct visualization of single biomolecules and their assemblies under native physiological conditions for improving our understanding of the behaviour and interaction of individual biological molecules.

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## WPI 6 Institutes - Joint Symposium
## “Leading Science and Your Future”

The WPI 6 Institutes Joint Symposium “Leading Science and Your Future” was held under the auspices of the International Institute for Carbon-Neutral Energy Research ($I^2$CNER; new WPI Center established in 2010) of Kyushu University at a great hall of the Fukuoka Bank’s head office in Fukuoka City. The symposium was attended by more than 600 participants, high school students, and the general public, mostly from Kyushu/Yamaguchi areas.

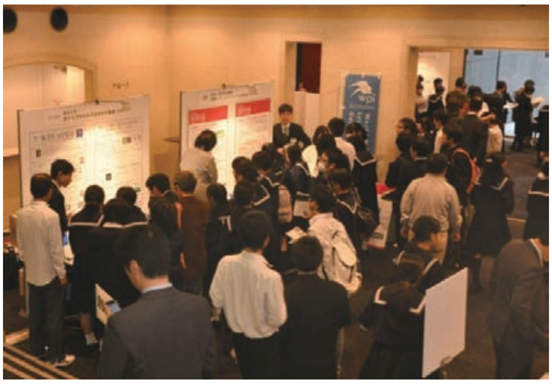
The day officially began with opening remarks from Dr. Setsuo Arikawa, President of Kyushu University, and a keynote lecture presented by Toshio Kuroki, WPI Program Director, sending an encouraging message to the young audience. And then, Prof. Petsos Sofronis, Director of $I^2$CNER and Prof. Seiji Ogo, Principal Investigator of $I^2$CNER, gave lectures followed by five WPI research center (AIMR･IPMU･iCeMS･IFReC･MANA) presenters who each introduced their center’s research. They also expressed hopes and dreams for the young peoples’ future.

In the presentations, Prof. Motoko Kotani, a deputy director of the AMIR, in her lecture entitled “Giving Shape to Your Dreams”, presented in a comprehensible way how human beings have invented new materials and made use of them for society, taking an example of the space shuttle.

The panel discussion was held after five WPI research center presentations, coordinated by Ms. Junko Edahiro, an environmental journalist, and there were active questions and answers between 12 panelists, high school students, junior high school students, and lectures.

In the area of the booths, the posters of research activities of WPI 6 institutes were put up and lectures and the staff provided explanations and demonstrated to young people. Many young people asked lead scientists many questions and communicated with them.

The AIMR and MANA set up a joint-booth with materials science under the theme of “Let’s Experience with Pleasure! -Familiar Materials Science-”, and Dr. Susumu Ikeda, a deputy administrative director of AIMR, demonstrated the experimentation on “Investigation of Materials Properties using Polarized Lighting Plates” to many young people. Some high school students, who were interested in the lecture by Prof. Kotani, eagerly asked her about mathematics. The advertising campaign for Materials Science Idea Contest -Challenger to the Future-” was also conducted in the course of the event.



# The $7^{th}$ Katahira Festival

Katahira Festival (Katahira Matsuri in Japanese) was held at Katahira Campus of Tohoku University on October $8^{th}$ and $9^{th}$.

Since 1998, Katahira Festival has been held every two years and organized by Tohoku University's six research institutes and research center (Institute for Materials Research, Institute of Development, Aging and Cancer, Institute of Fluid Science, Research Institute of Electrical Communication, Institute of Multidisciplinary Research for Advanced Materials, and Center for Northeast Asian Studies). It is for the first time that WPI-AIMR joined Katahira Festival.

This Festival is held to promote public understanding for the research outcomes of Tohoku University in the scientific field. Besides this, Tohoku University Archives introduce Tohoku University's history and traditional buildings.

AIMR opened 9 booths under the theme of "Nano Expo" at the WPI-AIMR main building completed at the end of July. AIMR's events are as follows:

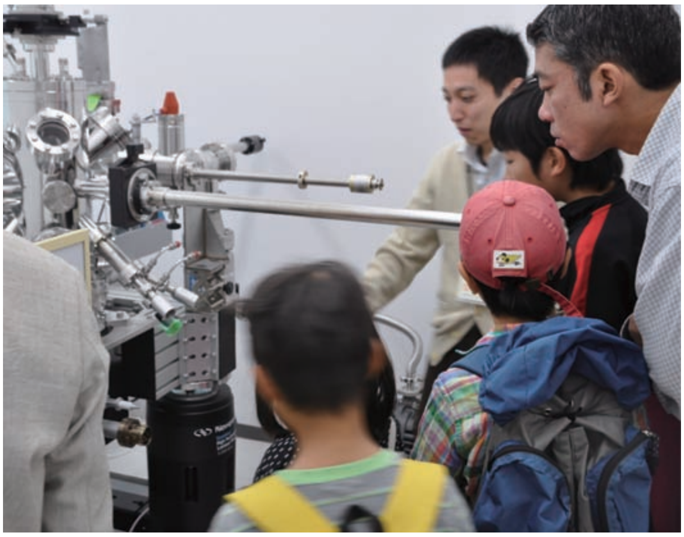
1) Visiting AIMR's laboratories with up-to-date equipment ("Atom and Molecule Lab Tour")
2) A tiny mirror using MEMS ("Mirrors smaller than ants")
3) A liquid magnet using fluid magnetic quality ("Let's play using liquid magnet")
4) Experiment for looking at electricity ("The world of electrons observed by light as a probe")
5) A rubber with varied properties ("Precious experience with wonderful rubber")
6) A drop of water which is insoluble in water ("Wonderful water")
7) Low temperature show using liquid nitrogen ("American low temperature show")
8) Experiment for simulating the movement of molecules on a computer ("Atoms and Molecules in a computer")
9) Making slime especially popular among children ("Let's make Slime")

These events are managed by AIMR young and foreign researchers. About 2,500 participants enjoyed events together with staff members and listened attentively to their explanations, and also asked several questions concerning the mechanism.

**The Special Lecture by Prof. Toshio Nishi**

As one of the official events of Katahira Festival, the Special Lecture by Professor Toshio Nishi (WPI-AIMR) was held on October 8th at the Life Science Project

Research Laboratory. In his lecture entitled “Science of Rubber Bearings for Seismic Isolation”, Prof. Nishi talked about the fundamentals and applications of rubber bearings and showed many examples how the rubber bearings work at the moment of the earthquakes. About sixty people attended this lecture and they asked many questions after the talk.



(Katahira Festival)

See appendix for more photos

(Lecture by Prof. Nishi)

# Award Information

| Name | Position | Group | Name of Award | Awarding Organization | Date of Award |
|---|---|---|---|---|---|
| Shinya Nakano | Research Assistant | Soft Materials | Poster Award of The 63th Divisional Meeting on Colloid and Interface Chemistry | Divisional Meeting on Colloid and Interface Chemistry (DMCIC) | September |
| Ali Khademhosseini | Junior PI | Device/System | Pioneers of Miniaturization Prize 2011 | The Royal Society of Chemistry's "Lab on a Chip Journal" | October |
| Ali Khademhosseini | Junior PI | Device/System | Presidential Early Career Award for Scientists and Engineers (PECASE) | The White House, the USA | October |
| Yuichi Ikuhara | PI | Materials Physics | Fellow, the American Ceramics Society | The American Ceramics Society | October |
| Ali Khademhosseini | Junior PI | Device/System | The 2012 Biotechnology and Bioengineering Daniel I.C. Wang Award | Biotechnology & Bioengineering Journal | November |
| Shinya Nakano | Research Assistant | Soft Materials | Poster Prize Runner-Up | 12th Australia-Japan Colloid & Interface Science Symposium | November |

## The Fourth Series of WPI-AIMR Joint Seminars FY2011

The topics of the Fourth WPI-AIMR Seminar Series of Fiscal Year 2011 are "Cooperation between Materials Science and Mathematical Science" and composed of two parts, i.e., (1) "Mathematical (Math-Mate) lecture + discussions", and (2) "Materials science presentation + discussion" meetings. The first half of the seminar is assigned to lecture/presentation, and the latter half to questions/ (panel) discussions. Initial several Seminars should be introductory to form a common understanding among WPI staffs on the aim/problems of the collaboration with mathematics.

As for the part (2), the speakers are chosen from younger/senior researchers mainly from WPI-AIMR and they provide topics concerning on the following questions;

[1] How does he/she expect the cooperation with mathematics or mathematical science?

[2] What does he/she expect from the concept of "Functon（see below）" for creating a novel research strategy of materials science?

[3] How can his/her research topics be seen from the view point of Functon?

Proposals of a presentation at the Seminar providing any opinions and related topics by research members at WPI-AIMR will be most welcome. But Committee members of Seminars may ask research members to give a talk at one of the Seminars at any occasion.

Please remind that the participation to this Seminar Series is mandatory.

**＊＊＊ about Functon ＊＊＊**

Definition of the concept of "Functon" itself is the important theme which will be discussed through this seminar series. Here is a starting point for you to think of it by yourself.

**What is Functon（"機能子" in Japanese and Chinese）?**

Functon is a constituent element of materials showing a certain definite function or property, and every material is composed of one or many kinds of assembled functons. The size of functons ranges over from the size of atom/molecule to macroscopic size. Functons often take spatial or temporal nesting structures, i.e., the structures like matryoshka (Russian doll); higher rank functon is formed as an assembly of lower rank functons.

**Why Functon?**

Functon is a central concept introduced at WPI-AIMR to create a novel research strategy of materials science. Namely we consider materials science can be performed without going back to atom/molecule, but by introducing the concept of minimum function unit, i.e., functons. Working on functons, materials science can be effectively executed with a help of mathematical science. So far existing materials science remained the science of matter where properties of matter is solved in turn from the lower to higher rank, i.e., from atom/molecule level to macroscopic level, which therefore treats ordinary (non-inverse) problems in terms of mathematics. However, a true materials science should treat an inverse problem to finding out necessary functons to create novel materials with desired function. Mathematical science should play important role for that cooperating with materials science.

**Functons as a target of mathematical sciences**

Mathematical science, of which important tool is the concept of functon helping a bridge with the materials science, is needed for solving the difficult inverse problem. It should solve how to combine complicated multilayer functon systems for the inverse problem. Furthermore the mathematical science is also expected to help developing materials as sensitive but robust, and those with multi-functions responding environment change. Mathematics is also necessary for the control of rare events, and for device processes utilizing pattern formation and so on. These can be also achieved with the help of the concept of functons.

**Establishing the concept of Functon**

Elucidation of easy processes forming higher rank functons from the lower rank functons, even from those of atoms/molecules level, and forming functons in artificial materials, which are related with non-equilibrium open systems, phase transition and nucleation core, interface processes, and self-organization, have been major topics of individual materials science so far. However, to create a guiding principle of innovative materials science, it is essentially important to explore and establish a general concept of "Functon", and with its bolster, establishing a strategy of a novel materials design by solving the inverse problem.

# Report on the 3rd Seminar

**Taro Hitosugi and Kazuto Akagi**

July 29, 2011

Topological Crystallography
— Commemorating the fourth centennial anniversary of the publication of Kepler's pamphlet “New-Year's gift concerning six-cornered snow” (1611) –
Prof. Toshikazu Sunada (Meiji University)

One-dimensional exotic-nanocarbon: Electrons in a Riemannian space
Prof. Jun Onoe (Tokyo Institute of Technology)

In this seminar, two talks were given by Profs. Sunada and Onoe, both encouraging our efforts to help materials scientists think of the possible collaboration with mathematics.

In the first lecture, mathematician Prof. Sunada gave a brief history of crystallography, a practical science that originated in the classification of the observed shapes of crystals, to provide the audience with a mathematical insight into modern crystallography. Then the talk went in to the formulation of a minimum principle for crystals in the framework of discrete geometric analysis, and predicted a new crystal based on K4 structure.

He expects the synthesis of the predicted material, and emphasized that topological crystallography vigorously interacts with other fields in pure mathematics and also with materials science.

The next speaker, a materials scientist Prof. Onoe, talked about their observation of Riemannian geometrical effects on the electronic properties of materials such as Tomononaga-Luttinger liquids, which were previously theoretically predicted by their group. They have examined a one-dimensional metallic $C_{60}$ polymer with an uneven periodic peanut-shaped structure using *in situ* high-resolution ultraviolet photoemission spectroscopy.

Their successful combination of materials science and mathematics was quite impressive, and suggests one of the ways of research in WPI-AIMR.

# Report on the 4th Seminar

**Kazuto Akagi**

August 26, 2011

"A map of mathematics for materials scientists"
Kazuto Akagi

"Why mathematics?"
Prof. Masatsugu Shimomura

In the past three seminars, we had several Math-Mate talks and open discussions on what we are aiming for through the fusion with mathematics. This attempt looks basically going well so far, but it is also true that we cannot well imagine "what really becomes possible by collaboration with mathematicians", still now. Therefore, two talks introducing how to interact with mathematics were given at this timing.

In the former part of the talk by Akagi, the world of mathematics was overviewed with simplified explanations on each field. Next, an example was introduced how chaos theory helped to analyze and stabilize the behavior of a furnace based on very limited numbers of monitoring data and a simplified physical model. Materials scientists are more or less familiar with the basic scientific framework (e.g. classical mechanics, thermodynamics, electromagnetics, statistical mechanics, quantum mechanics) and use it in their thinking. In the same way, we need to know minimum level of knowledge about the framework of mathematics (= a map of mathematical world) though we need not do mathematics itself, he said.

In the second talk, Prof. Shimomura gave a talk on "why mathematics" based on his experiences of collaboration with mathematicians in the field of biomimetics. One of the impressive examples was the biomimetics database aiming for contribution to other wide scientific and engineering fields including materials science. It is based on the digital image processing technology developed by Prof. Haseyama (Hokkaido Univ.), which helps us recognize buried similarity or relevance in enormous data one after another. As Prof. Nishiura says, mathematics is a ubiquitous tool.

# Report on the 5th Seminar

**Kazuto Akagi**

October 6, 2011

"Protein Structure and Topology"
Prof. Hiroaki Hiraoka (Kyushu University)

In this seminar, applications of computational homology to analysis of proteins were shown. In particular, compressibility of proteins was chosen as an example of structural properties, and it was successfully correlated with some topological properties such as robust "hole" in the protein modeled by van der Waals balls.

The lecturer used Homology groups as algebraic tools to study such geometrical "holes". In this framework, "simplicial complex" is given as an input data, and various geometrical properties such as connectivity ($H_0$), loop ($H_1$), cavity ($H_2$), n-dimensional hole ($H_n$) are obtained as outputs. Here, "simplicial complex" is a connection of tetrahedrons whose faces are shared by each other. They say pixel processing in computer graphics is similar to this transform to "simplicial complex".

He says that recent progress on computational homology allows us to easily treat them by using computers, and emphasizes that this approach is widely applicable to various targets, not only realistic objects but also abstracted ones including n-dimensional data structures. Some people seemed to be inspired to use it for analysis of the relation between structure and property in BMG systems. My approach to aqueous solution systems focusing on the structure of hydrogen-bond network can be sophisticated using this method. Indeed, abstraction of the topological structure from our research objects in materials science should be one of the helpful approaches to clarify the nature in them.

# Report on the 6th Seminar

**Susumu Tsukimoto**

October 27, 2011

"Cantor sets meet the brain"
Prof. Ichiro Tsuda (Hokkaido University)

In this seminar, the talk were given by Prof. Tsuda who is an authority on chaos in complex systems and is recently studying on chaotic dynamics of the brain, entitled "Cantor sets meet the brain" and were followed by open discussions in order to have a clue for bridging between materials science and mathematics in WPI-AIMR.

Prof. Tsuda first introduced Libchaber's thesis which clearly described how a mathematical theorem takes part in an actual proof in laboratories. Then, he talked about the research example of this thesis, which is on a "mathematical model" for archicortex proposed to explain the formation of episodic memories in the brain base on the network structure of the hippocampus which provides fields for the creation of internal time connecting the past, present, and future. The theoretical model showing that the hippocampus plays a role in formation of dynamic memory via multiple time-scales interactions was presented in this seminar. He talked about the study with a similarity between the structures of hippocampal CA3 and CA1 and of two variables constructing a skinny baker's map, which is a typical two-dimensional chaotic map. The structure gave a hint to make a mathematical model of the hippocampus which is responsible for the formation of episodic memory. By correlating between experimental and mathematical studies of the network structures, chaotic behaviors were observed in hippocampal CA3, and also a Cantor set in hippocampal CA1. This example could suggest a promising relationship between mathematical and experiment studies of dynamic behavior in the brain science.

Following his talk, we organized open discussions, which were led by Dr. Tsukimoto. At first, Prof. Tanigaki asked a question on the experimental measurements of signals in neuron. In order to make effective collaborations between mathematics and materials science, Dr. Nakajima asked the speaker about possibility of Cantor set and/or other mathematical models to apply to materials science field as well as brain science.

# Report on the 7th Seminar

**Ken Nakajima**

November 25, 2011

"Simulation study of a local glass transition temperature in polymer thin film"
Dr. Hiroshi Morita (AIST)

In this seminar, Dr. Morita introduced their study on a local glass transition and a polymer chain dynamics in polymeric materials using coarse-grained molecular dynamics (MD) simulation. According to his talk, the dynamics of the polymer chain in the confined geometry is different from that of the bulk, and these situations can be observed in many materials. Recently, Prof. Tanaka and co-workers in Kyushu University measured the glass transition temperature ($T_g$) near the substrate and it became larger as the analytical depth from the substrate became smaller and smaller. Furthermore, $T_g$ of filler-contained polymeric materials were also measured by them and the feature of $T_g$ was considered as a relation to $T_g$ near the substrate. To clarify these problems, Dr. Morita conducted the coarse-grained MD simulation. He also briefly explained the coarse-graining technique and the simulation system of OCTA, which was developed by Prof. Masao Doi's group in The University of Tokyo, including Dr. Morita himself (http://octa.jp/).

After his talk, there were extensive questions and discussions. One arose from a researcher from the polymer group was the effect of the change in $T_g$ to mechanical properties. This is actually important and we reached the conclusion that we need a further collaboration with Dr. Morita. A researcher in the BMG group put a question about the $T_g$ change at surfaces. This is because it would be very interesting if this effect is also seen in BMG materials. Dr. Morita pointed out the possible parameters for this phenomenon. We will be able to study this point in the near future. Another question was the inhomogeneity recently observed in BMG and polymer surfaces by researchers in WPI-AIMR. He seemed to be interested in it. He will check his data in more detail in terms of inhomogeneity and will give us a report on it soon.

This time, he tried to talk the glass-transition phenomena as a generalized problem seen in many different types of materials and the audience agreed his point.

# Research Prospect

# Nanoporous Metals as Green Catalysts for Molecular Transformations

Naoki Asao

WPI Advanced Institute for Materials Research, Tohoku University

## 1. Introduction

Molecular metal catalysts (**A**), such as $AuCl(PPh_3)$ and $Pd(PPh_3)_4$, have been used for many molecular transformations as homogeneous catalysts [1]. However, the use of heterogeneous catalysts offers several advantages over homogeneous systems, such as ease of recovery and recycling, atom utility, and enhanced stability. While bulk metals (**D**) are catalytically inert materials, supported nanoscale metal particles (**B**) on suitable oxide show catalytic activities in a variety of molecular transformations [2]. On the other hand, the catalytic properties of unsupported metals, such as nanoporous metal materials (**C**), are still less explored. The nanoporous metal materials can be generally prepared by leaching less noble metals from the corresponding alloys through a route similar to that for the preparation of Raney nickel. For example, nanoporous gold is fabricated from Au-Ag alloy by means of free corrosion in nitric acid [3]. It has an open sponge-like morphology of interconnecting ligaments on the nanometer length scale. Our research focused on these nanoporous metal materials as promising green catalysts.

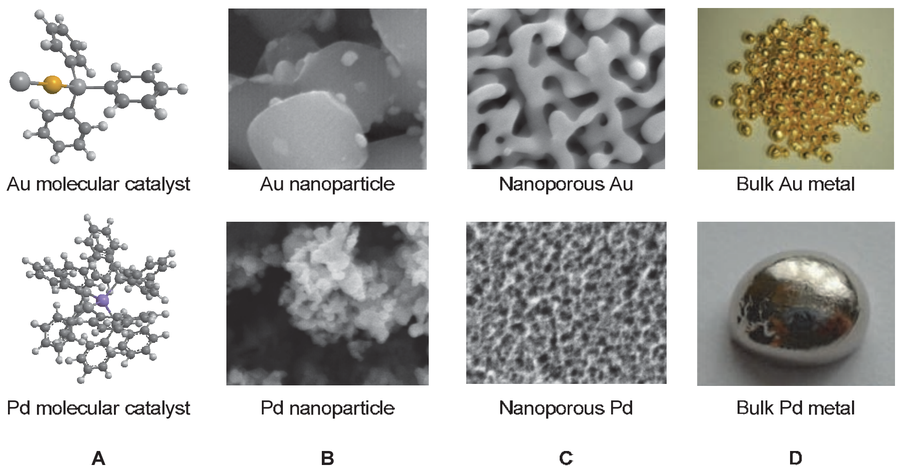


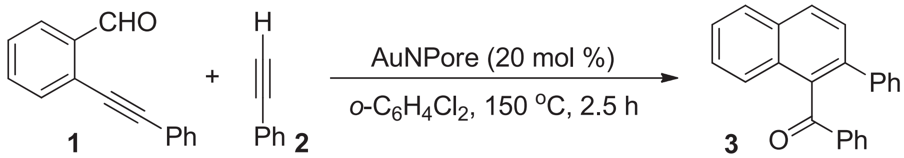

**Fig. 1** Four different types of morphology of gold and palladium.

## 2. Results and discussion

### 2.1 AuNPore-catalyzed benzannulation

We initially examined the catalytic activity of the nanoporous gold by use of the

[4+2] benzannulation reaction between *ortho*-alkynyl benzaldehyde **1** and phenylacetylene **2** as a model reaction, which has been previously reported by our group with homogeneous gold catalysts [4]. The reaction proceeded with 20 mol % of AuNPore-1, having around 25 nm pore size, at 150 °C for 2.5 h, and the desired product **3** was obtained in 62 % yield together with a small amount of decarbonylated naphthalene derivative **4** (Scheme 1). On the other hand, any reactions did not take place in the absence of the catalyst or in the presence of the non-dealloyed $Au_{30}Ag_{70}$ thin plates. These results clearly indicated that the nanoporous structure of the catalyst is necessary for this transformation [5].




| Entry | Average pore size | | Yield of **3** (%) |
|---|---|---|---|
| 1 | AuNPore-1 | 25 nm | 62 |
| 2 | reuse 1 | | 61 |
| 3 | reuse 2 | | 60 |
| 4 | AuNPore -2 | 30 nm | 61 |
| 5 | AuNPore -3 | 40 nm | 12 |
| 6 | AuNPore -4 | 60 nm | trace |
| 7 | AuNPore -5 | 100 nm | 0 |

**Scheme 1** AuNPore-catalyzed benzannulation reaction between *ortho*-alkynyl benzaldehyde **1** and phenylacetylene **2**.

AuNPore can be recovered simply by picking up with tweezers because the catalyst is a bulk metal. Therefore, unlike ordinary heterogeneous catalysts, any cumbersome work-up procedures, such as filtration or centrifugation, are not required. The catalyst can be reused several times and the chemical yields of **3** were constantly good in each case (entries 1-3). We found that the catalytic activity of the nanoporous gold was highly dependent on the pore size in this transformation. AuNPore-2, having around 30 nm pore size, exhibited the similar activity with AuNPore-1 (entry 4). However, the chemical yields were dramatically decreased with catalysts having more than 40 nm pore sizes (entries 5-7).

### 2.2 AuNPore-catalyzed oxidation of organosilanes with water

These results mentioned above prompted us to further explore the feasibility of carrying out a wide range of molecular transformations with this material. Then, we next examined the oxidation of organosilanes with water, leading to silanols, which are useful building blocks for silicon-based polymeric materials as well as nucleophilic coupling partners in organic synthesis. Although several metal particles have been reported as catalysts for this transformation, there are some drawbacks in those cases, such as poor long-term stability, narrow substrate generality, formation of by-products, and complicated work-up procedure for separation of products from the catalyst [6]. We found that the nanoporous gold exhibited a remarkable catalytic activity in the oxidation of $PhMe_2SiH$ **5** and the corresponding silanol **6** was produced quantitaively under mild conditions together with the evolution of hydrogen gas (Scheme 2) [7]. The formation of by-products, such as disiloxane, was not detected at all by GCMS. The turnover frequency (TOF) of 3.0 $s^{-1}$ was achieved in this catalytic system. The catalyst can be used at least 5 times repeatedly and the product was obtained nearly quantitatively every time (entries 1-5). The turnover number (TON) reached up to 10700. SEM images of the AuNPore catalyst (Fig. 2) indicate that there is no difference on the surface of the catalyst before and after 5 times use.

$$\underset{\mathbf{5}}{PhMe_2Si{-}H} + H_2O \xrightarrow[\text{acetone, rt, 1 h}]{\text{AuNPore (1 mol \%)}} \underset{\mathbf{6}}{PhMe_2Si{-}OH} + H_2$$

| Entry | Catalyst | Yield of **6** (%) |
|---|---|---|
| 1 | fresh | 100 |
| 2 | reuse 1 | 98 |
| 3 | reuse 2 | 100 |
| 4 | reuse 3 | 99 |
| 5 | reuse 4 | 100 |

**Scheme 2** AuNPore-catalyzed oxidation of $PhMe_2SiH$ with water.

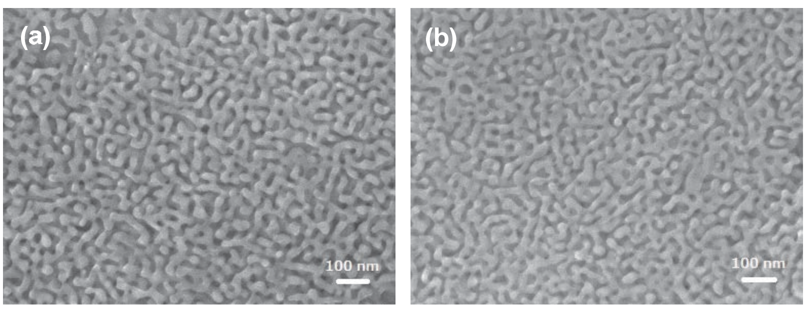
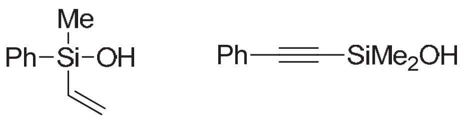



**Fig. 2** Scanning electron microscopy (SEM) images of AuNPore: a) before reaction, b) after being used five times for oxidation of $PhMe_2SiH$.

The catalytic oxidation reactions with a variety of organosilanes were conducted and representative examples are shown in Fig. 3. Not only aromatic silanes but also sterically hindered trialkylsilanes were oxidized effectively. The AuNPore catalyst was also applicable to the oxidations of tri-, di-, and mono-phenylsilanes, and the corresponding oxygenated products were obtained in high yields, respectively. Alkenyl- and alkynyl-containing silanes were oxidized smoothly without reduction of their multiple bonds by $H_2$ gas.

| | | | | |
|---|---|---|---|---|
| $Bu_3SiOH$ | $iPr_3SiOH$ | $Ph_3SiOH$ | $Ph_2Si(OH)_2$ | $PhSi(OH)_3$ |
| 95 % | 88 % | 99 % | 90 % | 80 % |




98 % 92 %

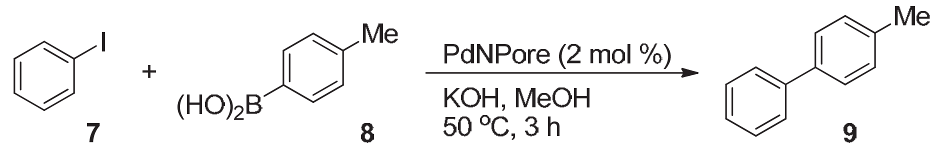
**Fig. 3** Representative examples for AuNPore-catalyzed oxidation of organosilanes.

Leaching test was conducted to clarify whether the disolved gold species in solvents take part in the current reaction system or not. After the catalytic oxidation of **5** was carried out for 10 min under the standard condition, AuNPore catalyst was removed from the reaction vessel. $^1$H NMR analysis of the mixture showed that **6** was produced in 48% yield at this time. While stirring of the mixture was continued in the absence of the catalyst for 50 min, further consumption of **5** was not detected at all. Then, the AuNPore was put back into the mixture. The oxidation reaction started again and finally **6** was obtained in 99% yield with 50 min. Furthermore, leaching of the gold in the reaction of **5** was not detected by inductively coupled plasma (ICP) analysis (<0.0005%). These results clearly indicated that the current transformation was catalyzed by the AuNPore catalyst but not by the dissolved gold species in solvents.

2.3 PdNPore-catalyzed Suzuki coupling

In parallel with the study on AuNPore, the catalytic property of nanoporous palladium (PdNPore) has been investigated. This material can be easily fabricated from metallic glassy ribbons $Pd_{30}Ni_{50}P_{20}$ [8] by electrochemical dealloying process [9]. The resulting PdNPore was used as a catalyst in the Suzuki-coupling reaction, which is one of the most important organic transformations in recent years [10]. The reaction of iodobenzene **7** with *p*-tolylboronic acid **8** using KOH as a base in the presence of 2 mol% PdNPore gave the corresponding biphenyl product **9** in a nearly quantitative yield

(Scheme 3, Entry 1). On the other hand, no coupling products were obtained in the presence of un-dealloyed (non-porous) metallic glass $Pd_{30}Ni_{50}P_{20}$ or in the absence of PdNPore [11].




| Entry | Catalyst | Yield of **9** (%) |
|---|---|---|
| 1 | fresh | 99 |
| 2 | reuse 1 | 94 |
| 3 | reuse 2 | 92 |
| 4 | reuse 3 | 95 |

**Scheme 3** PdNPore-catalyzed Suzuki-coupling reaction.

Recently, small palladium particles, consisting of gathering of palladium atoms, have been used as a solid state catalyst. However, a drawback of this catalyst is that it undergoes quite easy agglomeration under the reaction conditions, leading to deactivation of the catalyst. Hence, appropriate stabilizer or supporter is necessary to prevent deactivation by agglomeration. In contrast, PdNPore exhibited an excellent catalytic activity under mild reaction conditions without any supporter, ligand, or stabilizer. Although palladium black has been reported as an unsupported catalyst for Suzuki coupling reaction, nearly one-half equivalent of catalyst is necessary probably due to the poor catalytic activity. Recovery of ordinary heterogeneous catalysts often requires complicated treatment. In contrast, the recovery process in the current catalytic system is simple. Since the size of the catalyst is relatively large, the catalyst and the product can be separated easily by just removal of the liquid moiety by a pipette. The recovered catalyst was washed with MeOH several times and it was reused without further purification. Indeed, the product **9** could be obtained in excellent yield every time when the reactions were performed 4 times repeatedly. Furthermore, SEM images of the catalyst before and after 4 times run indicated the nanoporous structure was maintained well (Fig. 4).

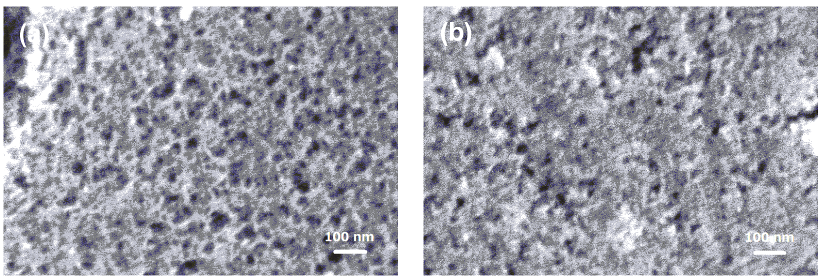



**Fig. 4** Scanning electron microscopy (SEM) images of PdNPore: a) before reaction, b) after being used four times for Suzuki coupling between **7** and **8**.

Since leaching of toxic palladium causes contamination of the final products with the dissolved palladium, catalytic systems with low leaching are highly desirable. Inductivity coupled plasma (ICP-AES) analysis did not detect the leaching of the palladium (< 0.0005%) during or after reaction of **7** with **8**. We next checked the leaching by conducting the reaction with the supernatant as follows: The reaction of **7** with **8** was carried out for 30 min under the standard condition, then a half amount of solution was picked up. $^{1}$H NMR analysis of the supernatant indicated that **9** was produced in 3% yield at this time. The supernatant was stirred in the absence of the catalyst for 3 h; the chemical yield of **9** at this moment was 24%. On the other hand, stirring of the residual reaction mixture having the catalyst for 3 h gave **9** in 93% yield. These results clearly indicated that dissolved Pd species existed and catalyzed the reaction but its activity was much lower than that of solid state of the catalyst due to the low leaching amount.

The Suzuki-coupling reactions using various aryliodides and arylboronic acids were examined and representative examples are shown in Fig. 5. The reaction proceeded smoothly even with sterically hindered 2-iodoanisole. The reactions of aryl iodides possessing electron-withdrawing groups proceeded faster than those having electron-donating groups. In contrast, the reactions of arylboronic acids possessing electron-donating groups proceeded faster than those having electron-withdrawing groups. Not only aryl iodides but also aryl bromides are suitable substrates.

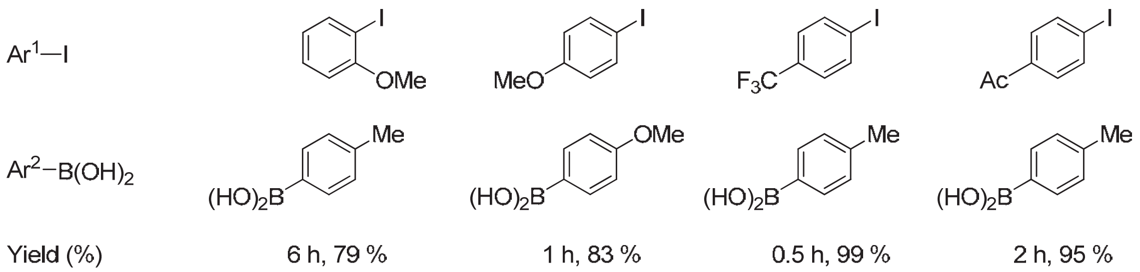
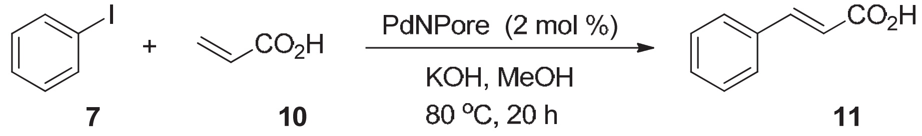



**Fig. 5** Representative examples for PdNPore-catalyzed Suzuki coupling.

2.4 PdNPore-catalyzed Heck reaction

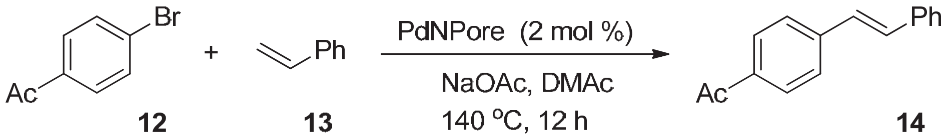
The material was next applied to Heck reaction, which is widely utilized in organic synthesis from small scale to the industrial process (Scheme 4) [12]. The reaction of iodobenzene **7** with acrylic acid **10** using KOH as a base in the presence of 2 mol % of PdNPore gave cinnamic acid **11** in 84 % yield (Entry 1). Addition of tetra-*n*-butylammonium iodide (TBAI) improved the chemical yield up to 94% (Entry 2). Since TBAI is known as a stabilizer of Pd particles, it might stabilize the dissolved Pd species even in the case of the current catalytic system. On the other hand, no coupling products were obtained at all in the absence of PdNPore catalyst or in the presence of un-dealloyed metallic glass $Pd_{30}Ni_{50}P_{20}$ ribbon [13].




| Entry | Additive | Yield of **11** (%) |
|---|---|---|
| 1 | - | 84 |
| 2 | TBAI | 94 |

**Scheme 4** PdNPore-catalyzed Heck reaction.

Not only aryliodides, but also less reactive arylbromides were suitable substrates by using Köhler's condition (Scheme 5) [14]. Treatment of 4-bromoacetophenone **12** with styrene **13** in the presence of 2 mol % of PdNPore in *N*,*N*-dimethylacetamide (DMAc) resulted in the formation of **14** in a nearly quantitative yield (Entry 1). Heck reaction is well known to be catalyzed by Pd/C, which is one of the most accessible heterogeneous Pd catalysts. However, it has a serious limitation on the recyclability [14]. In contrast, our catalyst can be used at least 5 times. SEM analysis of the catalyst clearly indicated that nanoporous structures were maintained well even after 5 runs. Furthermore, any significant changes of the composition of the catalysts were not observed before and after reaction by energy-dispersive X-ray (EDX) analysis. These results clearly indicate that PdNPore is a robust and recyclable catalyst for Heck reaction.




| Entry | PdNPore | Yield of **14** (%) |
|---|---|---|
| 1 | Fresh | 99 |
| 2 | Reuse 1 | 99 |
| 3 | Reuse 2 | 99 |
| 4 | Reuse 3 | 99 |
| 5 | Reuse 4 | 99 |

**Scheme 5** PdNPore-catalyzed Heck reaction of bromoarene.

The representative examples are shown in Fig. 6. While the reactions of aryliodides were not influenced significantly by the electronic effect of the substituents on the aryliodides, the reaction speed of arylbromides was considerably dependent on the substituents on bromoarenes.

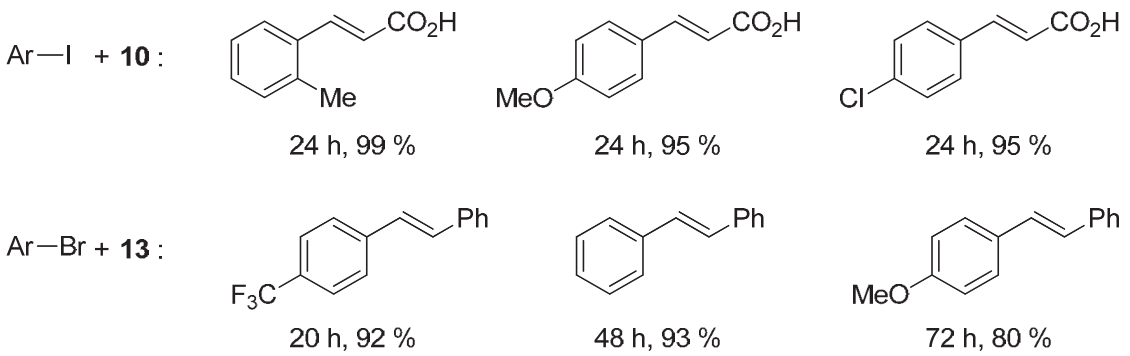



**Fig. 6** Representative examples for PdNPore-catalyzed Heck reaction.

We compared the leaching amount of Pd from PdNPore, Pd/C, and Pd black catalysts in the reaction of **12** and **13** by inductivity coupled plasma mass spectrometry (ICP-MS). On the basis of the average of specific surface areas of these catalysts, the leaching amounts of Pd per unit surface area can be calculated and the results are summarized in Table 1. Obviously, the leaching amount from the PdNPore catalyst is significantly smaller than those from the other two commercially available catalysts. This result clearly indicated that PdNPore has higher resistant property against leaching than the other two catalysts. Köhler reported that the Pd concentration in solution in the Pd/C-catalyzed reaction was highest at the beginning of the reaction and was a minimum at the end of the reaction by the reprecipitation of Pd onto the support [14]. It is worth mentioning that the leaching amount from the unsupported PdNPore is smaller than that from the supported Pd/C even at the end of the reaction.

**Table 1** Leaching amount of Pd at the end of the reaction with **12** and **13** by use of Pd NPore, Pd black, and Pd/C catalysts.

| Pd cat | Leaching amount in solution [μg] | Average of specific surface area [$m^2$/g] | Leaching amount per unit surface area [μg/$m^2$] |
|---|---|---|---|
| PdNPore | 0.57 | 13 | 43.8 |
| Pd black | 3.80 | 50 | 76.0 |
| Pd/C (10 wt%) | 48.2 | 83 | 580.7 |

## 3. Summary

We have demonstrated that nanoporous gold and palladium are promising nanostructured skeleton catalysts for molecular transformations. Any supports, ligands, or stabilizers are not required in these catalytic systems. The catalysts can be easily recovered by simple separation processes and the recovered catalysts were reusable without significant loss of catalytic activities. The exploration of new catalytic properties of a variety of nanoporous metals as well as designing and creation of novel types of nano-structured skeleton catalysts are in progress.


**Acknowledgements**

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# Exploring new spintronics materials via investigation of fast precessional spin dynamics using an ultrashort pulse laser

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## 1. Introduction

Since the discovery of giant magnetoresistance (GMR) by P. Grünberg and A. Fert [1,2] who obtained the Nobel prize in 2007, spintronics research field increased year by year. One big breakthrough is a finding of large tunnel magnetoresistance (TMR) at room temperature in magnetic tunnel junctions (MTJs) in 1995 [3,4]. The MTJs consist of a few nano meter thick insulating barrier sandwiched by ferromagnetic layers and exhibit, basically, a larger (smaller) resistance in parallel (anti-parallel) configuration of magnetizations. This implies that a MTJ can be used for a non-volatile magnetic random access memory (MRAM) element if a high or low resistance states is regarded as “1” or “0” digital memory bit.

Another interesting proposal was brought in 1996 into spintoronics is the so-called spin-transfer-torque (STT) effect [5]. Conducting electrons flowing through a fixed magnetic layer in a magnetoresistive device are spin polarized along the magnetization. When these spin-polarized electrons pass through another magnetic layer, the polarization direction may have to change depending on relative orientation. In this process, the magnetic layer experiences a torque associated with the transfer of spin angular momentum from conducting electrons. For large current, the spin torque amplifies the cone angle of spin precession and leads magnetization switching in the case that the spin torque overcomes magnetic damping. Thus, the magnetization of nano-scaled free layer is controllable by the flowing current direction.

Nowadays, the researchers in spintronics field are developing STT-MRAM utilizing the above two fundamental technologies. The features of STT-MRAM is not only non-volatility but also a large memory capacity and a high speed in reading and storing of digital memory, comparable to a dynamic random access memory (DRAM) and/or static RAM (SRAM), made of CMOS technology [6]. STT-MRAM is considered to be an important element of Normally-off computer as Green Technologies in near future. However, there are many subjects to be overcome for realization of such an ultimate memory. One of the important subjects is to develop the new magnetic materials with low magnetic damping as well as high perpendicular magnetic anisotropy, and also to clarify their mechanism.

## 2. Perpendicular magnetic anisotropy and magnetic damping

When the magnetic materials are patterned into several tens nano meter scale, that is comparable to the current CMOS technology node, magnetization direction fluctuates randomly against time, like as the Brownian motion of very small particle. Reducing of these thermal fluctuations of magnetization is crucial to make nano scaled memory because the thermal fluctuation of magnetization leads to lose a stored digital memory in MRAM. To avoid it, a magnetic material with a large perpendicular magnetic anisotropy is used in electrodes of MTJ. Thermal fluctuation of magnetization is stabilized significantly by high perpendicular magnetic anisotropy [7]. There have been several magnetic materials with high perpendicular magnetic anisotropy, so far, because such materials are also used in a storage media in hard disk drive or permanent magnet. Most of such magnetic materials have crystal structures with symmetry lower than a cubic, i.e., tetragonal or hexagonal. Artificial magnetic multilayer also shows perpendicular magnetic anisotropy owing to two dimensional structures [7]. Most of them contain various rare earth or noble metals. History of research on magnetic anisotropy is long [8] and the development of precise *ab-initio* calculation and progress of microscopic characterization based on X-ray reveals the mechanism of anisotropy in last two decade, but physics of magnetic anisotropy was not so clear yet.

In the elementary mechanics, we learn that a friction forces to stop an object moving in the air and this friction force is proportional to velocity of moving object. Such friction is a universal phenomenon that appears from microscopic to macroscopic scale. Large friction needs large power to drive the motion of object, but a finite friction is necessary to control it, thus friction control is very important technology to save the energy, as seen in a hybrid car. Similarly, magnetization also feels a friction inside magnets, so-called magnetic damping. In STT-MRAM, small magnetic friction is efficient to drive the magnetization motion with saving the power requiring magnetization reversal [6]. Origin of magnetic friction can be attributed to one electron spin relaxation phenomena related quantum-mechanical spin-orbit interaction [9], but there are a few data of magnetic damping in the magnetic materials with perpendicular magnetic anisotropy and the related physics is not yet understood fully.

Theories show magnetic friction and magnetic anisotropy originates from spin-orbit interaction, namely materials with large magnetic anisotropy might tend to show large magnetic friction. Therefore, it is a challenging task to explore new materials suitable to STT-MRAM.

## 3. Spin dynamics and all-optical time-resolved magneto-optical Kerr effect

The objectives of our studies are to get insight into physics of magnetic damping in magnetic materials with large perpendicular magnetic anisotropy and also to explore magnetic materials with both high perpendicular magnetic anisotropy and small magnetic damping. However, it is difficult to evaluate magnetic damping constant in such magnetic materials. A basic motion of spin in magnets is precession, which is similar to oscillation of a pendulum. Precession frequency is roughly proportional to the perpendicular magnetic anisotropy field. Precession frequency is several GHz for the usual ferromagnetic metals, e.g., iron, but it exceeds more than 100 GHz in the magnetic materials with high perpendicular magnetic anisotropy. “All optical pump-probe detection” is the current state of art technique for the investigation of spin dynamics [10]. All optical pump-probe detection is based on pump-probe technique with femto second laser. The motion of spins can be induced only by laser light pulse and any coils or inductances, which are required to generate pulsed magnetic field in the other techniques, are not involved in the set-up, so that one can achieve the ultimate time resolution better than hundred femto second. The equivalent frequency bandwidth of this measurement is more than 1 THz.

In 2008-2009, we have constructed the set-up of all-optical time-resolved magneto-optical Kerr effect (TRMOKE) using a standard optical pump-probe set-up with Ti: Sapphire laser and regenerative amplifier (wavelength of 800 nm, pulse width less than 100 fs) [11,12]. S-polarized probe light is normally incident on a film surface. A very small amount of rotation of polarization vector of laser light reflected from sample is

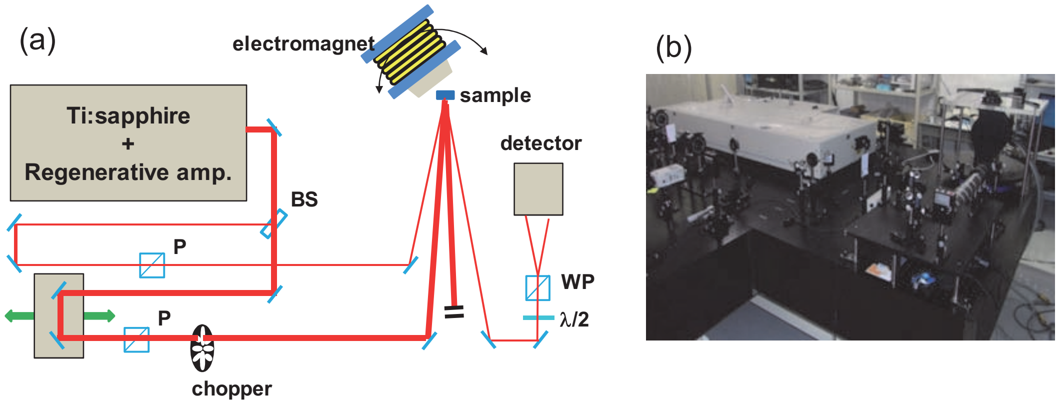


Figure 1. (a) Schematic illustration of optical set-up. P, WP, and BS correspond to a polarizer, beam splitter, and Wollaston prism as an analyzer. Thin and bold red lines are probe and pump beam path, respectively. (b) the photograph of optical set-up constructed in Integration laboratory in WPI-AIMR.

detected by a balanced detector after passing though analyzer (Wollaston prism) by polar magneto-optical Kerr effect (PMOKE). Intense pump beam is also focused to the sample overlapped and delayed by probe beam and time variation of magnetization was detected. Magnetic field can be applied up to 10 kOe and the field direction can be varied from in-plane to out-of-plane. Hereafter, we discuss the result of investigation of fast spin precession dynamics in various magnetic films with large perpendicular magnetic anisotropy.

## 5. Precessional spin dynamics in ultrathin films and multilayers exhibiting a large perpendicular magnetic anisotropy

As mentioned earlier, artificial layered materials have a large uniaxial magnetic anisotropy induced by symmetry broken at an interface. We investigated Co-based multilayered structure: Co/Pd [13] and Co/Ni [14], here we show representative results of very thin Co layer sandwiched by Pt layer [15].

Films were deposited on a naturally oxidized Si substrate using an ultra-high vacuum magnetron sputtering system at room temperature. Thickness of buffer and capping layer of Pt were 5 and 2 nm, respectively, and Co layer thickness was varied from 4 to

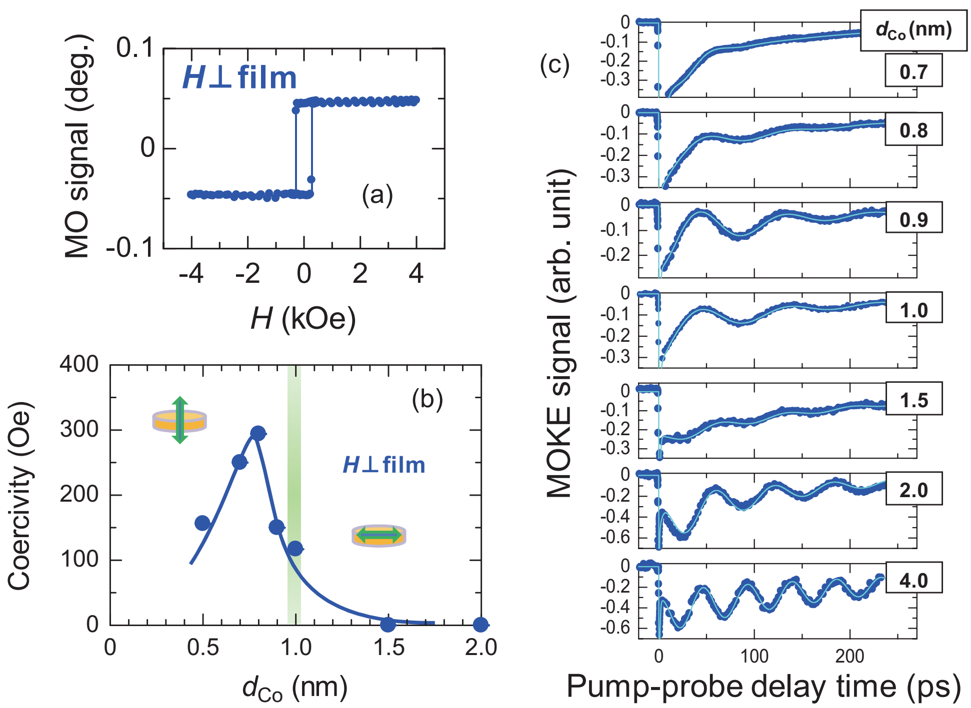


Figure 2 (a) Typical hysteresis curves for a Pt/Co/Pt trilayer film with Co layer thickness $d_{Co}$ of 0.8 nm. (b) Co layer thickness dependence of Coercivity, and (c) time-resolved magneto-optical Kerr effect signal for the films with different $d_{Co}$.

0.5 nm. A typical hysteresis loop for a film with Co layer thickness of 0.8 nm is shown in Fig. 2(a), in which a coercivity $H_C$ was ~ 300 Oe and an effective perpendicular magnetic anisotropy field $H_k^{eff}$ was 2.1 kOe. Figure 2(b) shows the coercivity as a function of Co layer thickness evaluated from PMOKE measurements, confirming that Pt/Co/Pt films was magnetized perpendicularly at Co layer thickness $d_{Co} < 1$ nm. Time-resolved magneto-optical signals for these films are shown in Fig. 2(c). Signal shows a rapid decrease in sub-ps time regime and then exhibits damped oscillation, those correspond to ultrafast demagnetization due to pulse heating and magnetization precession, respectively. Spin precession signals are observed clearly in all films, especially in case of perpendicularly magnetized films where cobalt layer thickness is comparable to a few atomic layers. Precession signal decays more rapidly in a film with thinner Co layer thickness, which implies magnetic friction acts more strongly on spins in a few atomic layers of cobalt. To determine magnetic damping quantitatively, the precession frequency $f$ and decay time $\tau$ for Pt/Co/Pt films were evaluated from the time-resolved data by fitting the damped harmonic function, and then the experimental data of $f$ and $1/\tau$ were analyzed by using Landau-Lifshitz-Gilbert equation, a basic equation of motion of magnetization:

$$\frac{d\boldsymbol{m}}{dt} = -\gamma \boldsymbol{m} \times \boldsymbol{H}_{eff} + \alpha \boldsymbol{m} \times \frac{d\boldsymbol{m}}{dt}. \qquad (1)$$

Here, $\boldsymbol{m}$, $\gamma$, $\boldsymbol{H}_{eff}$, and $\alpha$ are the unit vector of magnetization direction, the gyromagnetic ratio, the effective magnetic field, and the dimensionless damping constant. Extracted damping constant $\alpha$ increases, up to 0.4, with decreasing Co layer thickness, those values are by a factor of 10-100 larger than those in the ordinary magnetic materials, such as iron. This means that huge electric power needs to control magnetization direction of Co layer in these films.

### 6. Ultrafast precessional spin dynamics in Mn-Ga alloys

As mentioned earlier, some types of magnetic materials naturally forms atomically layered structure that leads to tetragonal distortion of crystal lattice, or some types of magnetic materials have hexagonal lattice. These crystal structures have an axial symmetry, leading a uniaxial magnetic anisotropy along c-axis. In case that those films are textured along c-axis, perpendicular magnetic anisotropy appears. A hexagonal CoCrPt and tetragonal FePt alloys are, respectively, the materials used in the storage media currently and possibly near future, so that we investigated magnetization

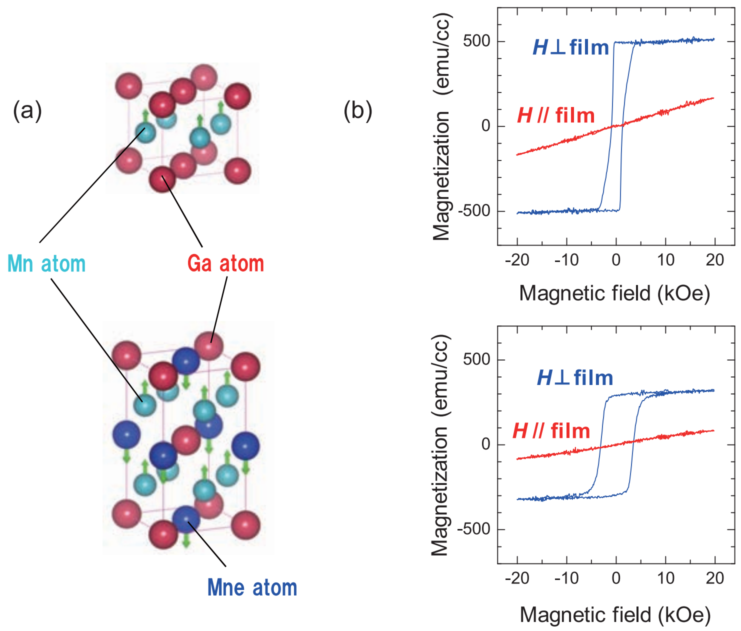


Figure 4. (a) Schematic illustration of crystal structure of $L1_0$-MnGa and $D0_{22}$-$Mn_3Ga$. (b) Typical hysteresis curves for the films having $L1_0$ or $D0_{22}$ crystal structures.

dynamics in those materials [16-18]. Here, we show only the recent result of Mn-Ga alloy films [19].

A Mn-Ga binary alloy has a tetragonal crystal structure and large uniaxial anisotropy [Fig. 1(a)], that is similar to that for a FePt alloy. This material contains no noble and rare-earth metals which are important constituents to gain high magnetic anisotropy, such as FePt or $Nd_2Fe_{14}B$. Curie temperature for Mn-Ga alloys is much higher than room temperature, and the large spin polarization has also been predicted in $Mn_3Ga$ [20], nevertheless those contain no magnetic elements, i.e., Fe, Co, and Ni. We succeeded, for the first time, to grow $Mn_{2.5}Ga$ epitaxial film using ultra-high vacuum magnetron sputtering technique and reported a huge uniaxial perpendicular magnetic anisotropy constant over 10 Merg/cc with low saturation magnetization ~ 250 emu/cm$^3$ [21]. High-TMR ratio has also been predicted by our group [22]. However, there are many open questions, especially magnetic damping constant.

Figure 4(b) shows the typical hysteresis loops for the Mn-Ga films with different composition with applying field of out-of-plane (in-plane) denoted by red (blue) curves. Both films show good perpendicular uniaxial anisotropy and very large effective anisotropy field $H_k^{eff}$, close to 10 T, was estimated from the hysteresis loops. Figure 5(a) shows the typical time-resolved magneto-optical Kerr signals for the films. Sinusoidal oscillations correspond to magnetization (spins) precessions about an

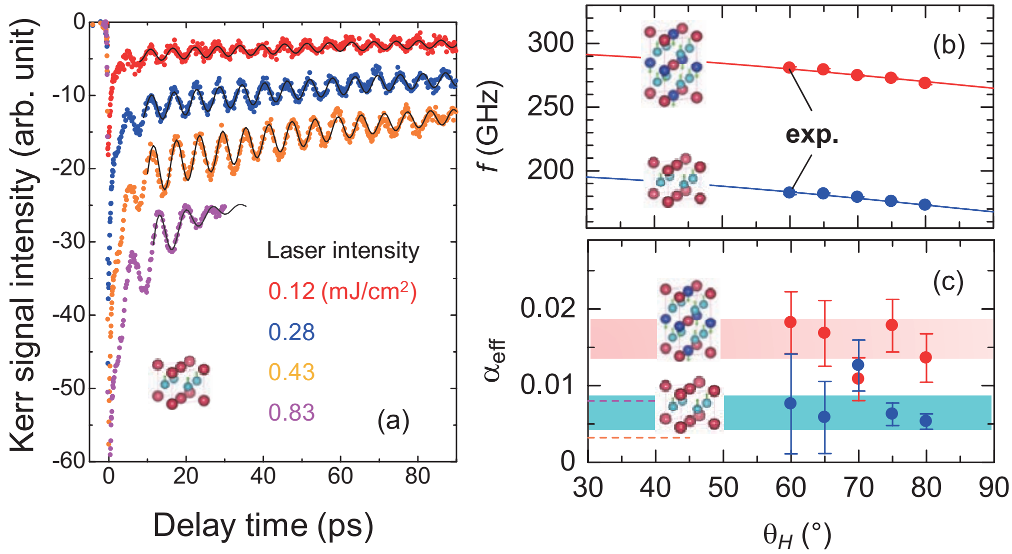


Figure 5 (a) Typical example of time-resolved magneto-optical Kerr effect of the Mn-Ga film with $L1_0$ structure. Magnetic field direction $\theta_H$ dependence of (b) precession frequency and (c) effective damping constant for $L1_0$ and $D0_{22}$ Mn-Ga films.

externally applied magnetic field. Spin precessions show ultrafast frequencies over 100 GHz with no remarkable decays, that have never been observed in metallic ferromagnets, so far.

Precession frequency $f$ are extracted from the data are shown in Fig. 5(b) as a function of magnetic field direction. Experimental data of $f$ are well fitted to the data calculated from eq. (1) with adequate fitting parameters. The damping constants α are also extracted from the data [Fig. 5(c)], average values of 0.015 and 0.0075, respectively, for $L1_0$ and and $D0_{22}$ Mn-Ga alloys. First-principles calculations are also in qualitative agreement with these experimental results [19].

## 4. Discussion

The damping constants for various films with perpendicular magnwetic anisotropy are plloted as a function of the perpendicular anisotropy constant in Fig. 6. The reported materials with large perpendicular magnetic anisotropy show large damping constants as shown in Fig. 6. However, damping constants for Mn-Ga alloys are by a factor of ten smaller than known materials even though this materials have a large perpendicular magnetic anisotropy. As we mentioned earlier, the origin of both perpendicular magnetic anisotropy and magnetic damping relate to quantum mechanical spin-orbit interaction from the theoretical points of view [8,9]. Thus, the compatibility of small damping and large perpendicular magnetic anisotopry in Mn-Ga alloys is not only

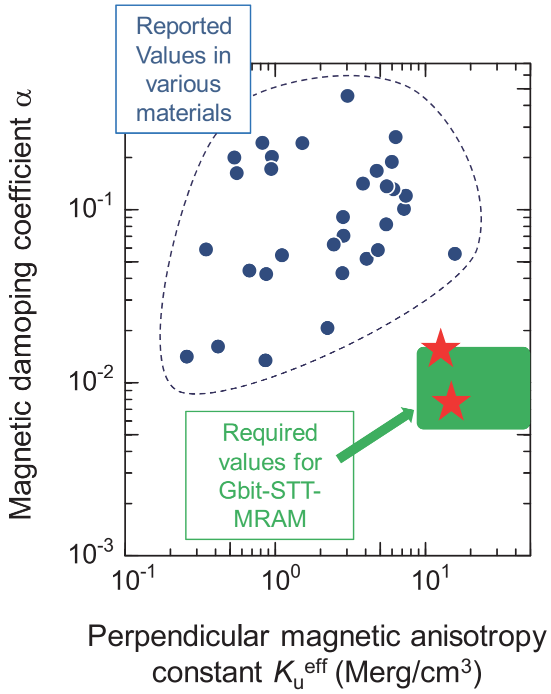


Figure 6 Magnetic damping constant α as a function of effective uniaxial perpendicular magnetic anisotropy constant $K_u^{eff}$ for various types of perpendicular magnetization films.

technologically but also fundamentally interesting. One reason of small damping is that this alloy has small density of states at Fermi level and no constituent of heavy elements [19,23]. Full understanding needs further investigations.

## 4. Summary and prospect

We have achieved the construction of set-up, the investigation of dynamics for various magnetic films with perpendicular magnetic anisotropy, and the discovery of excellent properties in Mn-Ga alloys. This finding contributes not only to develop STT-MRAM but also to form the new concept for designing *Green Spintronics Materials* with no heavy elements. The Mn-Ga alloys has potentially high spin polarization and exhibit high-TMR ratio, so that it is important to investigate spin transport properties of MTJ with Mn-Ga, such studies are in progress [24].

It is important to continue to explore materials with much better properties for STT-MRAM. Such new materials could be created by controlling atomic layer structure including light element as well as electronic structure around Fermi energy.

It is naturally considered that a high speed motion of spins, demonstrated in our optical experiments in the Mn-Ga films, can be applied to a high speed spintronics device. Such a new devices should be useful for nonvolatile logic application, that is one of the future directions of research.

**Acknowledgements**

We sincerely thank our colleagues; F. Wu, E. P. Sajitha, D. Watanabe, T. Kubota, X. Zhang, Q. Ma, M. Araidai, and Prof. M. Tsukada (WPI-AIMR), H. Naganuma, M. Oogane, and Prof. Y. Ando, and Prof. A. Sakuma (Department of Applied Physics), Y. Miura and M. Shirai (RIEC), and J. Walowski (Goettingen University). These studies were partially supported by NEDO Spintronics Nonvolatile Devices Project, Grant-in-Aid for Scientific Research from JSPS and MEXT, Grant for Industrial Technology Research from NEDO, FIRST Program from JSPS, Strategic International Cooperative Program "ASPIMATT" from JST, and Asahi glass foundation.

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**PROFESSIONAL EXPERIENCE:**

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| 2008-2009 | Senior Engineer, Hard magnetic materials laboratory, Moscow State Institute of Steel and Alloys, Russia |
| 2009-2011 | Senior Researcher, Hard magnetic materials laboratory, Moscow State Institute of Steel and Alloys, Russia |
| 2009-2010 | Docent (off-hour job), Material Physics Department, Moscow State Institute of Steel and Alloys, Russia |
| 2011-present | Research Associate, WPI Advanced Institute for Materials Research, Tohoku University |

**CURRENT RESEARCH:**

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- Thin magnetic, transparent, conductive films

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| 2011-present | Research Associate, WPI Advanced Institute for Materials Research, Tohoku University |

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2010-2011 Research Fellow, Fukui Institute for Fundamental Chemistry, Kyoto University
2011-present Assistant Professor, WPI Advance Institute for Materials Research, Tohoku University

**CURRENT RESEARCH:**

- Theoretical studies in Active Soft Condensed Matter including Hydrodynamics, Nonequilibrium and Nonlinear Physics, Polymers, and Biological systems
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2011-present Research Associate, WPI Advanced Institute for Materials Research, Tohoku University

**CURRENT RESEARCH:**

- Microfluidic platform for tissue engineering and drug delivery
- Biodevices for diagnosis of diseases

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| 1999-2002 | Post-Doc, University of Groningen, the Netherlands |
| 2002-2004 | Researcher, Institute for Material and Chemical Process, AIST |
| 2004-2007 | Researcher, Nanotechnology Research Institute, AIST |
| 2007-2010 | Researcher, Photonics Research Institute, AIST |
| 2008-present | Cooperated Associate Professor, Graduate School of Pure and Applied Science, University of Tsukuba |
| 2010-04-09 | Researcher, Research Center for Photovoltaics, AIST |
| 2010-2011 | Senior Researcher, Research Center for Photovoltaics, AIST |
| 2011-present | Senior Researcher, Research Center for Photovoltaic Technology, AIST |

**CURRENT RESEARCH:**

- Design and synthesis of functional π-conjugated organic materials
- Application of organic materials for molecular photovoltaic devices

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| 2005 | Ph.D., University of Leeds, UK |

**PROFESSIONAL EXPERIENCE:**

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|---|---|
| 2005-2009 | Research Fellow, University College London, UK |
| 2009 | Visiting Senior Research Fellow, Ångstrom Laboratory, Uppsala University, Sweden |
| 2009-2011 | Assistant Professor, WPI-Advanced Institute for Materials Research, Tohoku University |
| 2011-present | Lecturer, Department of Physics, University of York, UK |

**CURRENT RESEARCH:**

My research aims to understand the properties and functionality of nanoscale and nanostructured materials by developing and applying a range of theoretical and computational approaches. Current research topics include:

- Defect segregation and charge trapping at grain boundaries in polycrystalline materials
- Electronic and optical properties of metal-oxide nanocrystallites
- Dynamics, structure and properties of metallic nanoparticles in liquid and gaseous environments
- Electronic properties of supported metal clusters

# Global Intellectual Incubation and Integration Lab (GI$^3$ lab)

# $GI^3$ Laboratory

In order to strengthen international fusion/joint research and construct a world "visible center", we started "Global Intellectual Incubation and Integration Laboratory ($GI^3$ Lab)" program in 2009. The original target of $GI^3$ Lab was to establish a global stream of young bright brains (young and excellent researchers and students) gathering at WPI-AIMR from all over the world. Now, we expand the target of $GI^3$ Lab to senior researchers, integrating existing IFCAM visiting professorship.

Briefly stated, $GI^3$ Lab will accept following researchers.

1. Senior Researchers: Visiting Professorship and Associate Professorship
2. Junior Researchers: Visiting Scientists

## Ⅰ. Senior Researchers

Qualified researchers who may be interested in $GI^3$ visiting professorship should first contact the WPI-AIMR principal investigators (PIs) of the related research fields. Your contact PIs will initiate the further process to materialize the fusion/joint research.

(1) Tenure: For a period of one to three months.

(2) Financial: The salary varies, depending on the qualifications, based on the Tohoku University regulations. Roughly speaking, "full professor" receives 600,000 yen per month and "Associate Professor" receives 500,000 yen per month.

## Ⅱ. Junior Researchers

We accept excellent young researchers and students who belong to foreign PIs' laboratories as WPI-AIMR visiting scientists. The PIs who would like to send them to $GI^3$ Lab should first contact the host PIs of the related research fields. The contact PIs will initiate the further process to materialize the fusion/joint research.

(1) Tenure: For a period of minimum a couple of weeks to a maximum of three months.

(2) Financial: We support living cost of about 100,000 yen per month and actual cost for accommodation.

For details, contact General Affairs Section at WPI Office:
wpi-shomu@wpi-aimr.tohoku.ac.jp

## Global Intellectual Incubation and Integration Laboratory (GI³ Lab) - April 2011 to March 2012

### B. Junior Researchers and Students <Visiting Scientists>

| | Name | Host | Position | Term | | | | | | | Affiliation | Position | Nationality | Age | Research Topic |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | From | | | ~ | Through | | | | | | | |
| 1 | **FRÖMEL, Jörg** | Esashi (Gessner)* | Visiting Scientist | 2011 | 5 | 11 | ~ | 2011 | 12 | 5 | Fraunhofer ENAS, Germany | Deputy Department Manager | Germany | 34 | Application of metallic glass structures into silicon MEMS—using low temperature solid liquid interdiffusion based on gallium and indium to fabricate packaged devices |

Note: * indicates the name of PI who dispatched the scientist.

**GI$^3$ Activity Report of Jörg FRÖMEL**
**May 11$^{th}$, 2011 - December 5$^{th}$, 2011**
**Host: Professor Masayoshi ESASHI (Professor Thomas GESSNER)**

During my stay at the WPI-AIMR two main objectives could have been achieved. The scientific focus was on the development of a novel process to bond materials even with a highly different thermal expansion coefficient. Therefore the process temperature needs to be as near as possible to room temperature. The lowest theoretical applicable material combination is gallium and gold slightly above 30°C. It will form the $AuGa_2$ alloy that has a melting point of 491°C. Whereas the material system Au/Ga has already been extensively researched, there is to our best knowledge no application in micro devices yet. The reason is linked to the difficult process ability of the gallium. Many known processes in micro and nanotechnology cannot be used because of the low melting point of 29.8°C. Basically three different processes are needed to enable the application: deposition of gallium, micro structuring of gallium and the bonding process itself. During my stay at the GI3 lab I could successful develop a deposition process based on electroplating that allows the precise thin film deposition of gallium. With this process layers ranging from several 100nm to several µm can be realized now. The application in micro devices requires structuring of the gallium thin film within several 10µm structures. This could be achieved by using patterns of photosensitive polymers (resist) that are applied before the deposition process. Lastly with the deposited and structured thin films the bonding process could be successfully demonstrated at a temperature of 40°C. With this result the whole needed process chain is available now and the possibility to finally apply the Au/Ga SLID technology in micro devices is within reach. Currently a journal paper is being prepared based on the results of the research work.

Additional to the scientific objective also it was a target of the stay in Sendai to increase the cooperation between the WPI-Advanced Institute for Materials Research and Fraunhofer Institute for Electronic Nano Systems (ENAS). As a result on November 8$^{th}$ 2011 a memorandum of understanding could be signed by WPI-AIMR Director Prof. Yamamoto and Fraunhofer ENAS Director Prof. Gessner in presence of Mayor of Sendai Ms. Okuyama, Fraunhofer President Prof. Bullinger and Tohoku University Executive Vice President Prof. Iijima. It is anticipated to form even more stronger international relation between the two organisations in the future. During my stay I could acquire many new skills and experiences related to material science, micro technology and Japanese scientific environment.

I would like to thank Prof. Esashi, Prof. Yamamoto and Prof. Gessner for their support and giving me the opportunity to contribute to the research at the excellent WPI-AIMR.

# Announcement

# The 2012 WPI-AIMR Annual Workshop

The 2012 WPI-AIMR Annual Workshop will be held on February 20 through 23 in Sendai. The workshop will be composed of plenary sessions and parallel sessions, inviting world class researchers.

| | |
|---|---|
| Date: | Monday, February 20 – Thursday, February 23, 2012 |
| Location: | Sendai International Center (sessions) & Sendai Kokusai Hotel (reception, accommodation) |

In the process of realizing three major goals of the AIMR—(1) Invent and develop new functionally innovative Green Materials, (2) Establish a new system adequate as a World Premier Research Center, and (3) Strengthen international cooperation and construct a world visible center—the AIMR has been organizing the WPI-AIMR Annual Workshop since 2009. And now, we are announcing the 2012 WPI Annual Workshop which will be held from February 20, 2012, Monday, through February 23, Thursday, at Sendai Kokusai Hotel and Sendai International Center. This will be the fourth WPI-AIMR general workshop since its inauguration in October 2007 as a World Premier International Research Center.

The scientific scope of our workshop is "Cutting-edge Functional Materials for Green Innovation", reflecting our efforts to create Green Materials which contribute to "Energy Harvesting", "Energy Saving" and "Environmental Clean-up". The workshop will aim to provide a new direction of materials research, since the AIMR now promotes the collaboration between materials science and mathematics.

Plenary sessions and parallel sessions will be organized with presentations by world class researchers of the fields of AIMR research (four groups and a unit), which are the Bulk Metallic Glasses, Materials Physics, Soft Materials and Devices/Systems Construction groups and the Mathematics unit. For encouraging younger researchers and further discussing the fusion research projects, we also have poster sessions.

We would appreciate very much if you would join the workshop.

To participate in this workshop, please resister on the following website.

http://www.wpi-aimr.tohoku.ac.jp/workshop2012/

## Tentative Schedule

February 20 (Monday): Sendai Kokusai Hotel
17:00 – 19:00 Welcome Reception

February 21 (Tuesday): Sendai International Center
09:00 – 09:30 Opening session
09:30 – 11:00 Morning plenary session (Mathematics-Materials)
11:10 – 12:40 Morning plenary session (Bulk Metallic Glasses)
12:40 – 14:30 Poster session
14:30 – 16:00 Afternoon plenary session (Materials Physics)
16:10 – 17:40 Parallel sessions (Bulk Metallic Glasses & Soft Materials)

February 22 (Wednesday): Sendai International Center
09:00 – 10:30 Morning plenary session (General)
10:40 – 12:10 Parallel sessions (Device and Physics & Soft Materials)
12:10 – 14:10 Poster session
14:10 – 15:40 Parallel sessions (Bio-Device & Soft Materials)
15:50 – 17:20 Afternoon plenary session (General)
18:00 – 20:00 Banquet at Sendai Kokusai Hotel

February 24 (Thursday): Sendai International Center
09:00 – 10:30 Morning plenary session (Soft Materials)
10:40 – 12:10 Morning plenary session (Device/Systems)
12:10 – 12:20 Closing remarks

## Tentative list of Invited speakers (As of December 12)

Jean-Pierre Aimé, *Université Bordeaux 1*
Jean Bellissard, *Georgia Institute of Technology*
Derek Y C Chan, *University of Melbourne*
Masao Doi, *University of Tokyo*
Frank Ernst, *Case Western Reserve University*
Pavel Exner, *Academy of Sciences of the Czech Republic*
Claudia Felser, *Max Planck Institute for Chemical Physics of Solids*
Thomas Gessner, *Chemnitz University of Technology*
Katsumi Hagita, *National Defense Academy of Japan*
Buxing Han, *Chinese Academy of Sciences*
Liyuan Han, *National Institute for Materials Science*
Michelle Khine, *University of California, Irvine*
Tamiki Komatsuzaki, *Hokkaido University*
Yuri E Korchev, *Imperial College London*
Yutaka Matsuo, *University of Tokyo*
Yasumasa Nishiura, *Hokkaido University*
Takao Ohta, *Kyoto University*
Kosmas Prassides, *Durham University*
Keith Promislow, *Michigan State University*
David Joseph Srolovitz, *National University of Singapore*
Fred Wudl, *University of California, Santa Barbara*
Hiroaki Yoda, *Toshiba Electronics Korea Corporation*
Takeshi Egami, *University of Tennessee*
Todd Hunfnagel, *Johns Hopkins University*
Tingbing Cao, *Renmin University of China*
Matthew J. Rosseinsky, *University of Liverpool*
Youn Woo Lee, *Seoul National University*
Thomas P. Russell, *University of Massachusetts Amherst*

# Junior Faculty/Post-doctoral Positions

## Tohoku University
## WPI-AIMR

Effective October 1, 2007, Tohoku University created a new Research Institute, the Advanced Institute for Materials Research (AIMR), based on an initiative of the Japanese Department of Education (MEXT) for World Premier International Research Center Initiative (WPI) to bring together scientists involved in research on nano-science and technology.
In the 21st century, material science, broadly defined as the study of how complex/novel properties arise in matters/materials from the interactions of individual components, will comprise of inter-discipline collaboration.
(http://www.wpi-aimr.tohoku.ac.jp)
Over the next few years, as many as one hundred new appointments at the levels of post-doctoral fellows and junior faculty will be available. All innovative researchers are welcome as active promoters of basic/applied sciences in the fields of physical metallurgy, physics, chemistry, precision mechanical engineering and electronic / informational engineering.

We are continuously looking for excellent applicants throughout the year.
Please submit

1) **a curriculum vitae,**
2) **research proposal (<3,000 words),**
3) **summary of previous research accomplishments (<2,000 words),**
4) **copies of 5 significant publications, and**
5) **2 letters of recommendation**

by email to:
**aimr@wpi-aimr.tohoku.ac.jp**
All files must be submitted electronically in pdf or Word format.

*Applications from, or nominations of, women and minority candidates are encouraged.*
*Tohoku University WPI-AIMR is an affirmative action / equal opportunity employer.*

# WPI-AIMR
# Workshop Guideline

Tohoku University's new Research Institute, the Advanced Institute for Materials Research (WPI-AIMR) solicits several applications per year for International Workshops in the field of "broadly defined Materials Science."

Guidelines:

1) Organizers

Qualified research staff of academic institutions and public or private research establishments can submit the application for an international workshop to be held at WPI-AIMR or its Satellite branches, jointly with the WPI-AIMR principal investigator(s) whose research interest overlaps with the scope of the workshop.

2) Financial support

Under normal circumstances, WPI-IMR supports up to 2/3 of the workshop budget, while the organizer is expected to cover the rest.

3) deadline

The application must be received at least four months in advance to:

aimr@wpi-aimr.tohoku.ac.jp

All files must be submitted electronically in pdf or Word format.

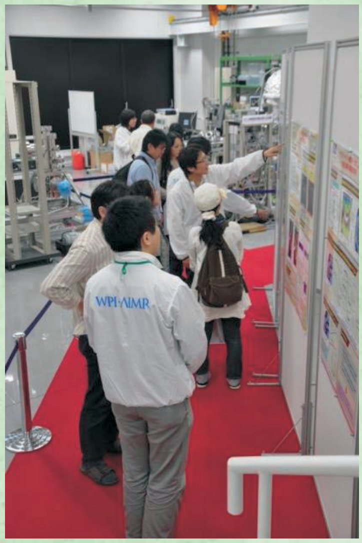
# Appendix

# Katahira Festival

**October 8-9, 2011**

# Katahira Festival

**October 8-9, 2011**




# Completion Ceremony of the WPI-AIMR Main Building

**December 7, 2011**




# Completion Ceremony of the WPI-AIMR Main Building

**December 7, 2011**

# WPI-AIMR Staff List

## (As of December 16, 2011)

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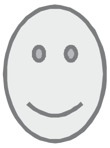
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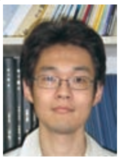

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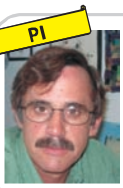

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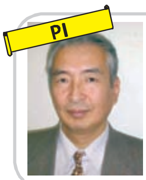


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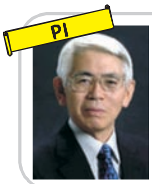


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