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[Special Interview]

What are the roles that universities and AIMR should play in order to solve the various issues confronting society?

Tadafumi Adschiri

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

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Hiroshi Komiyama

Chairman, Mitsubishi Research Institute,
Chairman, Platinum Society Network, and Special Adviser, University of Tokyo

Toward a Sustainable Society

What are the roles that universities and AIMR should play in order to solve the various issues confronting society?

How sustainable societies really are fluctuates greatly, as the world faces problems with energy and food. In the case of Japan, these problems are further compounded by economic issues. To resolve such problems, innovation is necessary in order to create new societies. Research institutes, including universities, should play a leadership role in this innovation process. What should our future vision of Japan look like?

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Text : Atsumi Takebayashi
Photo : Yasufumi Nakamichi

The age of saturation

Adschiri: You raised three points related to the realization of a sustainable society. The first is recycling; that is, thorough material recycling. The second is to raise energy efficiency by three times from the current level. The third is to double the degree of natural energy utilization from its current level.

Komiyama: These three points are key factors when considering the idea of a sustainable society from the aspects of resources and energy. However, it is important to take note of one more perspective with regard to the future society; that is, the concept of saturation.

Adschiri: Does that refer to a society overflowing with things?

Komiyama: I was born in 1944. Those about five years older than I am have experienced starvation. Even though I never experienced it, I did experience greed. In other words, there were many things that I desperately wanted. The first was a black-and-white television, and when I was a student, I wanted a car. Prof. Adschiri, you were born in 1957, so these feelings may be foreign to you.

Adschiri: Now that you mention it, my childhood days coincided perfectly with the period of rapid growth in Japan. Black-and-white television became color television. Although car ownership was a status symbol before, gradually it became more and more commonplace during this time. I remember the rapid changes that entered our everyday lives.

Komiyama: In Japan today, statistics show that one in every two people owns a car. We have also nearly reached a state of saturation with regard to our lifespans. The average life expectancy of human beings was in the 20s up till the 1900s. This became 31 years in 1900, and now exceeds 70 years. We have truly hit a saturation in all aspects of our lives. Upon reaching saturation, it becomes cheaper to recycle, so we will naturally move on to become a recycling society.

Adschiri: If a society that has been focused on the pursuit of things is now satisfied and has reached its turning point, doesn't that mean that the standard of our values will also change significantly?

Komiyama: The next value that people will demand from now will be "quality." For example, we also seek quality in movement. If we take health into consideration, bicycles are a good choice; if we take the environment into consideration, then electric tricycles are a good idea. We consider such high-quality societies to be "platinum societies."

Adschiri: Quality is also desired in regard to the energy that supports societies. Does that mean improving the efficiency of energy conversion, and introducing natural forms of energy?

Komiyama: Solar power and geothermal energy are energy forms that can be used infinitely. Technology is evolving incredibly fast. Most recently, there was a call for bids for constructing a 1 million kW-class power plant in South America. Bids were put in for a thermal power plant and a solar power plant, but the bid was awarded to the solar power plant.

Adschiri: That is a good sign that natural energy technology is here. If we improved the energy efficiency of everyday goods, energy demand would also fall. In light of that, all aspects of our lives could be met by natural energy by the year 2050. That is Prof. Komiyama's theory. When that happens, we will then face the problem of how to transition from the existing systems.

The need for transition management

Adschiri: For systems in society that are already in place, it may not be easy to inject new investment for transitioning to natural energy if it does not offer truly significant advantages.

Komiyama: However, if we consider the costs, natural energy will become more and more advantageous to us in the future. On the one hand, nuclear power plants, for instance, call for the need to put in place measures for dealing with radioactive waste as well as counterterrorism measures. In transition management, we need to include in our discussions costs that have not surfaced as of now.

Adschiri: Cost performance is important not only in energy production, but also in energy consumption. Prof. Komiyama, you are among the first to convert your house into an "eco-house." You introduced the use of solar power generation into your home about 10 years before, is that right?

Komiyama: That was actually 12 years ago, and I have already sufficiently recouped my costs. It's a misconception that solar power generation is difficult to maintain. At my house, we do not have to do any maintenance work. The solar cells are made of glass on the outside and stone on the inside, and can last almost forever.

Adschiri: We are witnessing even further improvements to the efficiency of solar power generation, and energy costs are likely to fall in tandem with the growing adoption of solar power generation facilities in the future.

Komiyama: It is likely that by 2050, renewable energy will hit saturation. To say that it may become free of charge may be an exaggeration, but it is possible that we may be able to use it just by paying a low maintenance cost. Moreover, this energy is completely clean. How can we make the transition to a new system? That will really call for transition management.

Technological fusion

Adschiri: Naturally, technology is the key, and we must incorporate the evolution of technology into our computations when we make economic forecasts and think about the future of energy.

Komiyama: Although the evolution of technology has been assessed fairly accurately since more than 10 years ago, reality constantly surpasses our expectations. A 1kW solar cell cost 6 million yen in 1992, but today costs in the neighborhood of 200,000 yen.

Adschiri: I think there's two forms of new technology. The first is the assembly of technology. We bring in things we need and things we don't have enough of from elsewhere. In the course of our history to date, I think advancements in technological development were made based on this concept of assembly, which somehow propelled us forward. However, as we began to tread the paths of cutting-edge technology, we seem to have encountered problems that we cannot solve with that concept. We need another style of technological innovation going forward, as well as to integrate knowledge and wisdom from entirely different disciplines.

Komiyama: If we combine the ideas of integration with saturation, the result would be fusion.

Adschiri: We talked about recycling earlier, and we also experienced this during the development of supercritical recycling technologies. Factories that produce polyurethane generate waste matter during the production process. We know that when this reacts with water, it returns to its original form of raw material. Even so, because we are dealing with waste matter, it is not cost-efficient to use organic solvents or catalytic agents to ensure that water and organic matter are mixed evenly. Here, we faced the limitations of chemistry. However, physical chemists emerged, and showed us what to do. If we raise the temperature and pressure slightly, we can solubilize water and oil homogeneously. Furthermore, water scientists also taught us the "dream-like" fact that under those conditions, water molecules themselves act as a catalyst. Of course, ultimately, the process engineers were the ones who created an actual working plant based on these concepts. Hence, I believe that the integration of completely different perspectives and ideas created this chemical recycling technology for waste.

Komiyama: The issue is that people do not take action if we simply say, "Let's integrate." Organizations aiming to achieve such integration have sprung up in various places across Japan, including the University of Tokyo, but I think they are not working how we expect them to.

Adschiri: At AIMR, we are also striving to create new forms of science and technology through the fusion of mathematics and materials science. However, even when we were initially told to integrate, we did not know what to do. After all, there is no common language for these disciplines. Nevertheless, at some point, we invited those who knew the language of both disciplines to join us, and we called them the "Interface Unit." When we began to understand each other's languages, we got to immerse ourselves in that discipline and engage in discussions. Although the process is slow, a new fusion discipline is now gradually emerging. I think that the key to creating innovation still lies in integration.

Komiyama: Universities have a core responsibility, and innovation can be realized through collaboration between universities and corporations. For example, the University of Tokyo and Toshiba are conducting research on comprehensive health screening systems for regular use, through the use of ultra-compact sensors. The realization of such initiatives is made possible because they bring together and fuse cutting-edge research in fields ranging from sensing, including MEMS (Micro Electro Mechanical Systems), communications, and materials, to medicine.

Creating innovation originating from Japan

Adschiri: Even so, Japan is still described as being poor in innovation. What are we lacking in?

Komiyama: Why did innovation occur in Silicon Valley? This is because America did not drag the past into the new world.

Adschiri: Earlier, we talked about the importance of transition management in Japan's shift toward renewable energy. Does this mean that we need something else besides technological innovation?

Komiyama: Innovation is creative destruction. Creation begins when we destroy the present state of things. However, when the foundations are as strong as they are in Japan, it is difficult to destroy them. In that case, we can build a Silicon Valley and create innovation there.

Adschiri: However, as you have noted in your book, Japan is a developed country with many problems, and we also have a track record of having solved most of the problems. We have technological prowess, and the soil is fertile for solving problems. Wouldn't it be a good idea to harness this and put it to use around the world?

Komiyama: It is true that Japan has conquered the challenges of the energy crisis and pollution. Even so, problem-solving is a different matter from innovation.

Adschiri: Innovation is not only a matter of technology, but also involves changes in social system at the same time. Innovation in sectors where social systems are already in place may prove to be difficult for Japan.

Komiyama: There was a lady at the University of Tokyo who achieved a breakthrough in the development of artificial hearts. Although she attempted to put this to practical use, there were too many regulations in Japan and she could not make any progress. She moved to the United States and started a venture business, and carried out joint development with Johns Hopkins University. This technology was later used at the University of Tokyo Hospital.

Adschiri: Despite having technological prowess, we meet resistance when we attempt to apply these to practical use in society, and so commercialization does not go smoothly. After developing fundamental technology, it might be a good idea to continue with practical application of the technology overseas.

Komiyama: One of the venture businesses originating from the University of Tokyo is the humanoid robot development named "SCHAFT." This was acquired by Google at an enormous sum. Although we do not know how the results of this project will be used in the future, from a national perspective it is a great pity.

Adschiri: Another technology exists that was put to practical use based on the results of supercritical reaction research on nanoparticle synthesis. We disseminated this to the world more than 20 years ago. However, Korea was one of the first to achieve commercial viability for this technology. This material technology is already installed in society. It is possible to incorporate the newest and best things from an empty base.

Komiyama: Globalization is truly advancing by leaps and bounds, and the speed of transmission of information among human beings is moving beyond the "invisible hand of God." Information spreads across the globe instantaneously, which can be taken advantage of and used against others.

English proficiency as the key to internationalization

Adschiri: In research and development activities that take into account overseas expansion, it is important to be conscious of internationalization. This is also one of Japan's weaknesses.

Komiyama: For now, the key lies in English. Of course, researchers read and write theses and papers in English. However, they cannot assume that they are fluent in English just because they can do that. The level of English proficiency required for internationalization is far above that level.

Adschiri: Everything is conducted in English at WPI, and we have no problems at all when it comes to discussing technology in English. This is particularly true for the young. That is why we have been successful in creating a fusion scientific discipline, as I mentioned previously. However, it is true that when the faculty comes together to talk about creating a new culture in WPI, they appear to have much less to say.

Komiyama: I did not struggle with English either when I was a researcher. However, when I became the president of a university, I had to engage in complicated conversation and negotiations overseas. If we are unable to do those things, we cannot achieve true internationalization. The weakness of Japan's diplomacy may also stem from the English negotiation abilities of our diplomats.

Adschiri: If we look ahead till about the year 2050, I imagine that automatic simultaneous translation services provided through our smartphones and other such devices may help us break down the language barrier.

Komiyama: I hope that it can evolve to an extent that allows us to use it even for whispered conversations at a dinner banquet. Until that day arrives, I hope that we can recruit many young people who do not face any problems with English to propel us forward.

Expectations for AIMR to develop platinum materials

Adschiri: With regard to future expectations, what is demanded of organizations like AIMR?

Komiyama: First, the wonderful thing about AIMR is the concept of using mathematics as a tool. For example, as a result of using mathematics as a tool for physics, improvements were made in the area of integration. I think it would be good to also actively apply mathematics to materials science.

Adschiri: With regard to materials, what are your thoughts on the future direction of research?

Komiyama: Materials underpin all things. I was also engaged in the research of thin film in the past. This was for application in the field of information technology, and the future purpose of this technology, as far as we could see, was energy conservation. Materials ultimately became a key point in our efforts to make the transition to renewable energy.

Adschiri: We call these "green materials." Green materials are essential in order to achieve the 2050 vision that you have spoken about.

Komiyama: I also hope that the terms "sustainable," or rather, "platinum materials" will be used (laughs). On a more serious note, if we limit ourselves to the concept of "green = environment," that scope is too narrow. In contrast, platinum is a word that expresses the state of society going forward. New technology and integration are necessary in order to bring forth a platinum society, and I have high expectations for AIMR to play a role in this.

Tadafumi Adschiri

Born in Niigata Prefecture in 1957. Completed the doctoral course specializing in chemical and energy engineering at the School of Engineering, the University of Tokyo (Doctor of Engineering). Served as assistant in the School of Engineering at the University of Tokyo, and assistant as well as assistant professor at the School of Engineering at Tohoku University. Took on the position thereafter of Professor at the Institute of Multidisciplinary Research for Advanced Materials at Tohoku University. Has been Principal Investigator at AIMR since 2007.

Hiroshi Komiyama

Born in Tochigi Prefecture in 1944. Completed the doctoral course specializing in chemical engineering at the School of Engineering, the University of Tokyo (Doctor of Engineering). Served as assistant, assistant professor, professor, and Dean of the School of Engineering at the University of Tokyo, and as the President of the University of Tokyo from 2005 to 2009. Appointed thereafter as Chairman of the Mitsubishi Research Institute.

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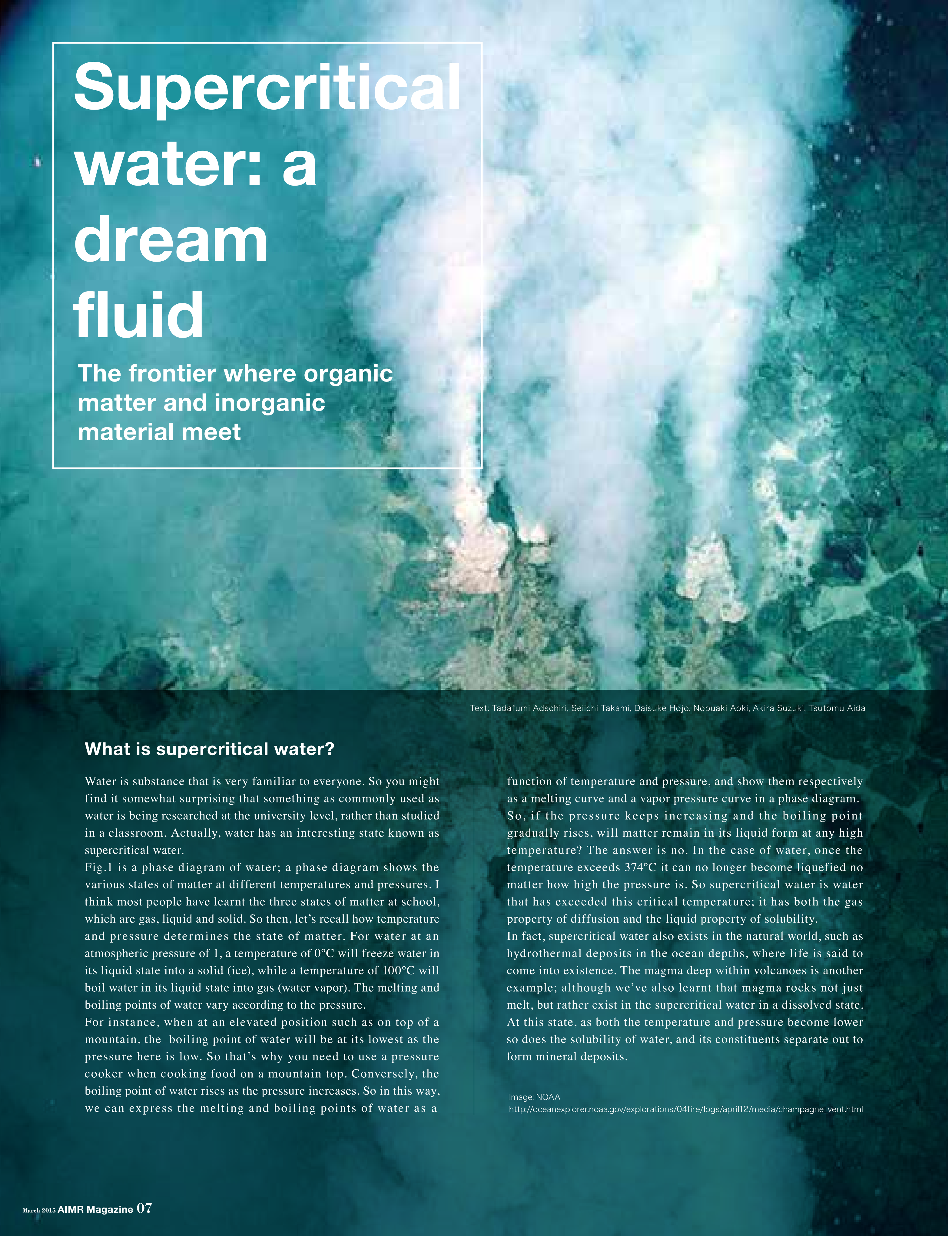


Supercritical water: a dream fluid

The frontier where organic matter and inorganic material meet

Text: Tadafumi Adschiri, Seiichi Takami, Daisuke Hojo, Nobuaki Aoki, Akira Suzuki, Tsutomu Aida

What is supercritical water?

Water is substance that is very familiar to everyone. So you might find it somewhat surprising that something as commonly used as water is being researched at the university level, rather than studied in a classroom. Actually, water has an interesting state known as supercritical water.

Fig.1 is a phase diagram of water; a phase diagram shows the various states of matter at different temperatures and pressures. I think most people have learnt the three states of matter at school, which are gas, liquid and solid. So then, let's recall how temperature and pressure determines the state of matter. For water at an atmospheric pressure of 1, a temperature of 0°C will freeze water in its liquid state into a solid (ice), while a temperature of 100°C will boil water in its liquid state into gas (water vapor). The melting and boiling points of water vary according to the pressure.

For instance, when at an elevated position such as on top of a mountain, the boiling point of water will be at its lowest as the pressure here is low. So that's why you need to use a pressure cooker when cooking food on a mountain top. Conversely, the boiling point of water rises as the pressure increases. So in this way, we can express the melting and boiling points of water as a function of temperature and pressure, and show them respectively as a melting curve and a vapor pressure curve in a phase diagram.

So, if the pressure keeps increasing and the boiling point gradually rises, will matter remain in its liquid form at any high temperature? The answer is no. In the case of water, once the temperature exceeds 374°C it can no longer become liquefied no matter how high the pressure is. So supercritical water is water that has exceeded this critical temperature; it has both the gas property of diffusion and the liquid property of solubility.

In fact, supercritical water also exists in the natural world, such as hydrothermal deposits in the ocean depths, where life is said to come into existence. The magma deep within volcanoes is another example; although we've also learnt that magma rocks not just melt, but rather exist in the supercritical water in a dissolved state. At this state, as both the temperature and pressure become lower so does the solubility of water, and its constituents separate out to form mineral deposits.

Image: NOAA
http://oceanexplorer.noaa.gov/explorations/04fire/logs/april12/media/champagne_vent.html

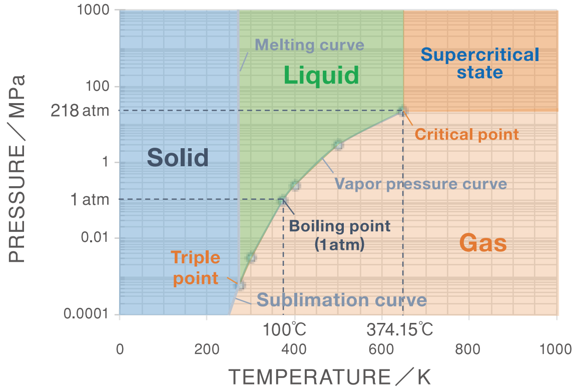


Fig. 1: Phase diagram of water

Synthesizing nanoparticles using supercritical water

We started researching supercritical reactions around 25 years ago, with the idea of trying to recreate on land a state of high temperature and pressure, such as that of hydrothermal deposits in the ocean depths, and using it in various reactions. This has led to a range of studies covering biomass conversion, waste recycling, organic synthesis, and nanoparticle synthesis, of which several have already been industrialized. Now I will introduce our research on nanoparticle synthesis.

So what are the merits of using supercritical water in reaction field? Water can be called the only natural solvent that exists on earth. In its solvent state water has supported life on earth and the earth itself, and hence is also the gentlest solvent in the earth's environment. What's even more amazing is that in its supercritical state, water actually mixes together with oil and the water molecules themselves function as an acid and base catalyst. So using supercritical water as a reaction solvent eliminates the need to use toxic organic solvents and catalysts. Another fascinating aspect of supercritical water is that in its state of being between a gas and a liquid, the equilibrium and speed of a reaction varies substantially with only the slightest change of temperature and pressure, and this also gives rise to unique reactions that aren't normally observed.

Let's recreate the same environment of producing mineral deposits in a laboratory. In its supercritical state, the density and dielectric constant of water declines considerably, and subsequently the degree of solubility also rapidly falls, which brings about a high degree of saturation. The higher the degree of supersaturation, the easier it is to obtain even smaller metal oxide particles. This is similar to when a sudden drop in temperature causes supersaturated water vapor, which is above the saturation pressure of water, to instantly condense and become a fine mist. Using this method in our lab, we've been able to successfully synthesize metal oxide nanoparticles of about 10 nanometres (1 nano is 1/1,000,000 of a millimetre).

So now let's add oil (a surfactant) to the nanoparticle synthesis reaction. In its supercritical state, water mixes together evenly with oil; and as the synthesis of inorganic nanoparticles occurs, they also react with organic molecules. As a result, these organic molecules bind to the surface of metal oxides to produce organically-modified nanoparticles of 10 nanometres of less in size. In our lab, we have successfully synthesized metal oxide nanoparticles and organic-modified nanoparticles using a small high-pressure container or a flow reactor, as shown in Fig. 2.

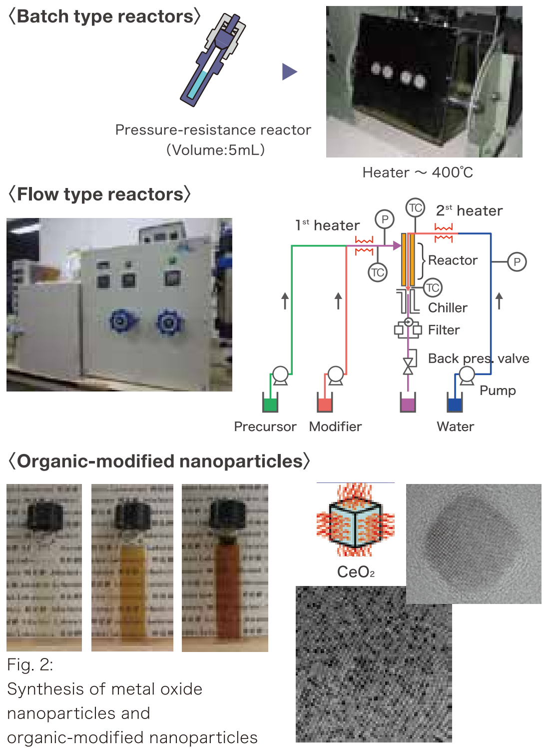


Fig. 2:
Synthesis of metal oxide nanoparticles and organic-modified nanoparticles

What are the applications for organic-modified nanoparticles?

The synthesized organic-modified nanoparticles are covered by organic molecules, which gives them a high affinity with organic solvents. Also, when placed inside organic solvents, each nanoparticle disperses and scatters to form a fluid-like state. So what are the applications for this type of organically-modified nanoparticles?

These nanoparticles also disperse in a high concentration within polymers as well as organic solvents, which allows for the synthesis of hybrid materials comprising polymers and nanoparticles. However, they don't only disperse; we now know that increasing the volume of ceramic nanoparticles - even to a weight fraction greater than 80 vol % - will make them flow just like a solution. This has produced a new material that can be described as fluidic ceramics. As a result, we have been able to create a workable "dream material" with the properties of electrical insulation and high thermal conductivity. We call this "super hybrid material".

Nanoparticles that disperse in a high concentration while still flowing can also be used as ink. Nowadays we are seeing advancements in the development of printing technology for drawing electric circuits and molding them by 3D printing. The key point in the development of this technology is elucidating the principles that explain why the fluidization of nanoparticles occurs. We are working with mathematicians at the AIMR to tackle this challenging question.

We also discovered another interesting fact; using supercritical methods might allow us to control the shape of nanoparticles. Generally, crystal growth occurs so that the unstable surface of a crystal is not exposed. So looking at the shape of crystals, it explains why identical material looks quite similar to one another; and also, why the most stable surface of the crystal is always exposed. So we’ve learnt that using supercritical methods may enable us to control the exposed surface of nanoparticles.

Nanoparticles have a large surface area per volume, so there are expectations for their use as catalysts as well; although, the stable surface of nanoparticles does not actually have a very high catalyst activity. Incidentally, organic-modified reactions start from the unstable surface of nanoparticles instead. So this means we can probably synthesize nanoparticles with an exposed unstable surface. After exposing the modified molecules and assessing the activity of the nanocatalyst, we were able to achieve reactions that can normally only be done at 400℃ or above at a low temperature of around 150℃ (Fig. 3).

These findings can potentially be used in various catalyst reactions. A technology that is particularly garnering attention these days uses this type of highly-active catalyst for producing an endothermic reaction (to produce hydrogen by the reaction of waste with water) at low temperatures. If such technology is viable, it will allow us to recover the lower temperature waste heat energy from exhaust gas, which we have so far been disposing of in large quantities. We are currently seeing technological advancements to tackle the energy problem, with a particular focus on natural energy such as solar cells, wind power and biomass utilization. The amount of this lower temperature waste heat energy is quite large; it is actually equivalent to the volume of natural energy currently being developed. Our work at the AIMR is focused on the creation of “green materials”, and we are currently in the process of developing a dream catalyst that precisely fits the description of a green material.

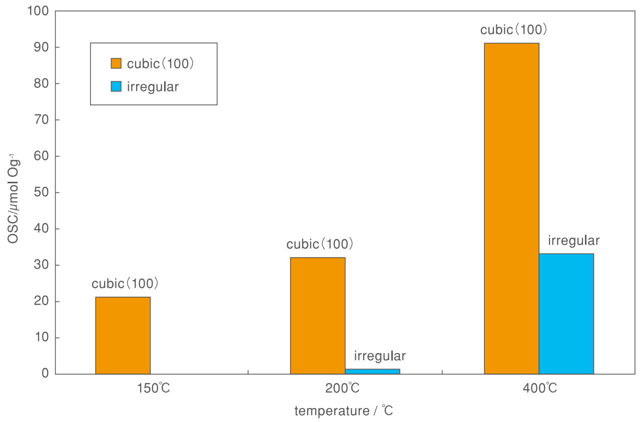


Fig. 3: Organic-modified nanoparticles with a controlled exposed surface are highly reactive, even at low temperatures.

NEWS & INFORMATION

AIMR holds Joint Workshop with University of Cambridge

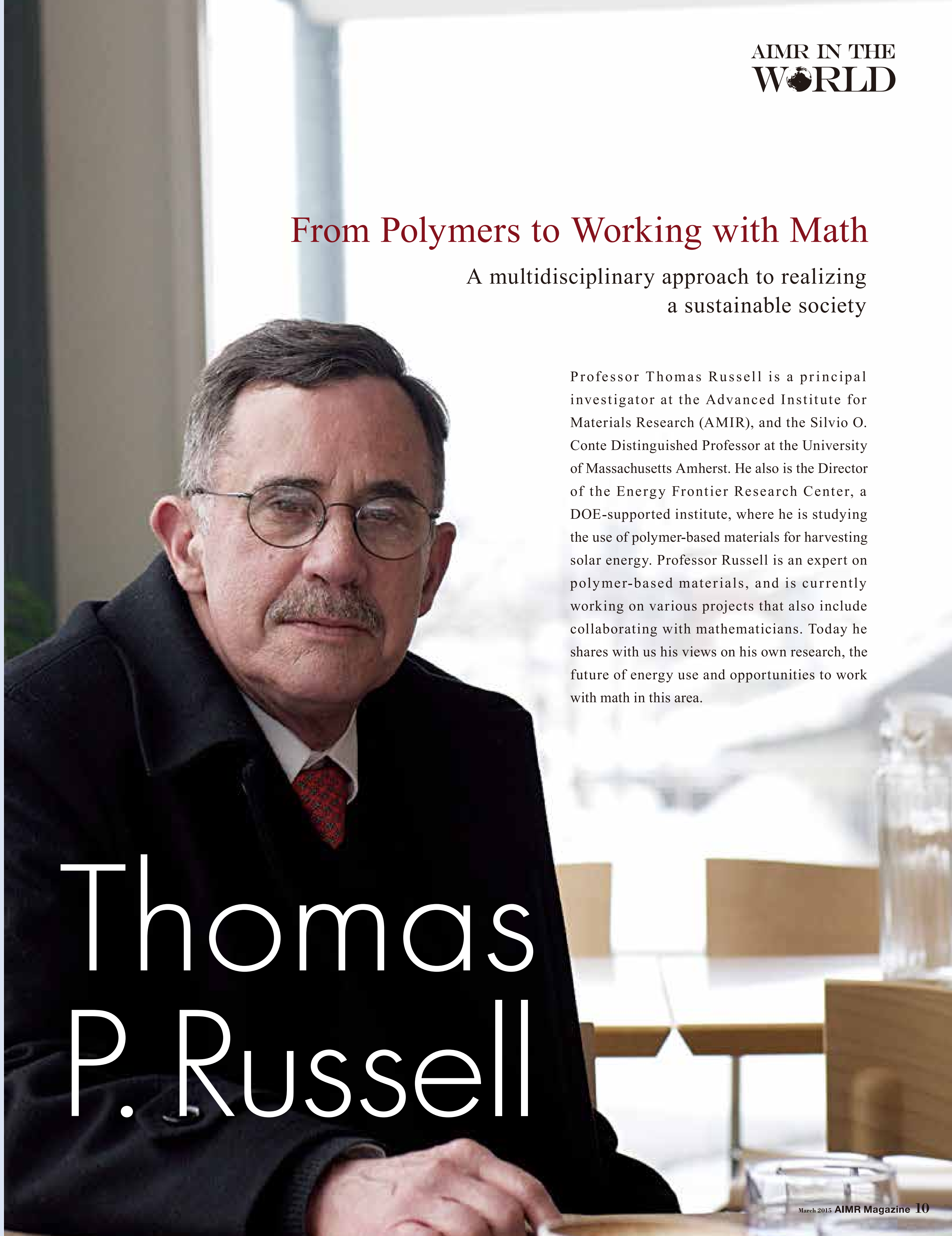
AIMR held a workshop on materials science jointly with the University of Cambridge in December 2014. This workshop, convening for the third time, took place at the Department of Materials Science and Metallurgy on 10 December. A total of 40 students from AIMR and the University of Cambridge participated in the workshop. After Director Motoko Kotani and Professor Alan Lindsay Greer delivered the opening remarks, keynote lectures were presented by three AIMR researchers (Associate Professor Taro Hitosugi, Professor Yasumasa Nishiura, and Professor Naoki Asao), as well as three professors from the University of Cambridge. In addition, young researchers and students from the University of Cambridge participated in the poster presentation session, and Specially Appointed Professor Masaru Tsukada provided an introduction of the researcher exchange program. In the afternoon, the participants were broken up into groups based on the respective fields of materials science, chemistry, and mathematics, and engaged in lengthy discussion. With this, the workshop ended on a high note.

Associate Professor Taro Hitosugi delivering his keynote lecture

The AIMR International Symposium 2015

The AIMR International Symposium 2015 (AMIS2015) was held at the Sendai International Center from 17 to 19 February 2015. Following the opening remarks delivered by Tohoku University’s President Susumu Satomi, Deputy WPI Program Director Akira Ukawa, and AIMR Director Motoko Kotani, the symposium kicked off with keynote lectures by six speakers including Professor F. Duncan M. Haldane from Princeton University, as well as lectures by 34 AIMR researchers and guest speakers from overseas.

The theme of this symposium was “A new horizon for materials science with mathematics collaboration” and a total of 268 participants from 13 countries, including the United States, China, Australia, and Germany, came together for a lively exchange of views on this theme after each lecture. The newly established Poster Award was presented to Assistant Professor Yoshikazu Ito and Assistant Professor Natsuhiko Yoshinaga, who claimed the honors from among 98 poster presentations.



From Polymers to Working with Math

A multidisciplinary approach to realizing a sustainable society

Professor Thomas Russell is a principal investigator at the Advanced Institute for Materials Research (AMIR), and the Silvio O. Conte Distinguished Professor at the University of Massachusetts Amherst. He also is the Director of the Energy Frontier Research Center, a DOE-supported institute, where he is studying the use of polymer-based materials for harvesting solar energy. Professor Russell is an expert on polymer-based materials, and is currently working on various projects that also include collaborating with mathematicians. Today he shares with us his views on his own research, the future of energy use and opportunities to work with math in this area.

Thomas
P. Russell

- Firstly Professor Russell, could you please tell us about your current research?

Professor Russell: I am currently researching organic photovoltaics, particularly polymer-based organic photovoltaics. I believe organic photovoltaics are part of the solution to the energy problem that mankind is facing. Our group has successfully acquired organic polymer-based devices with an exceptional power conversion efficiencies (PCEs) of >11%, which is the highest that has been reported to date.

- What specific area of organic photovoltaics are you focusing on?

Professor Russell: Our focus has been to optimize what's called the active layer, where light is absorbed and converted into electricity. This active layer is a mixture of carbon materials, namely fullerene C_{60}, and photoactive polymers. Key to the functioning of these devices is a bicontinuous morphology of the components with domains tens of nanometers in size, comparable to the diffusion of an exciton, a bound electron-hole pair. So, in addressing this issue, my co-researchers at the AIMR - Associate Professor Dr. Nakajima and Dr. Wang - used high resolution atomic force microscopy (AFM) to successfully look at the morphology at the surface which is in contact with the cathode and discovered the presence of crystals right at the surface, a key element in understanding the performance of thee devices..

We have also been able to develop interlayer materials, that enhance conversion efficiencies by several percent. Our research has enabled us to create devices capable of PCEs > 11%, which is exceptional. Six years ago, standard devices were regarded as working well with PCEs of 5%. Attempts to commercialize flexible devices with these materials failed. With more than a doubling of PCEs in such a short period, with the promise of further enhancement, commercialization is viable with extensive potential applications.

- You've also been involved in research using nanoparticles; can you please tell us more about that?

Professor Russell: As you have pointed out, another important research field for me is the study of nanoparticle surfactants. Normally, a water droplet that is mixed in with oil forms a spherical shape, to minimize the contact area between these two fluids that do not mix together. If you deform the drop with, for example, an electric field, the spherical drop changes to an ellipsoid and, if the field is removed, the drop returns to its spherical shape. If, though, we introduce nanoparticle surfactants to the drop, after we deform the drop into an ellipsoid and remove the field, the drop retains it ellipsoidal shape and does not relax to a sphere.

- So why does the droplet maintain this deformed shape?

Professor Russell: When the water droplet deforms into an ellipsoid, the volume does not change but the surface area increases and more nanoparticle surfactants locate on the surface of the droplet. So when the electrical field is switched off, the ellipsoidal droplet tries to return to a spherical shape which decreases the surface area. But, there are now too many nanoparticle surfactant at the surface. This is just likea large crowd of people in a room with the walls closing in on them. They become jammed up against each other, and are unable to move. This phenomenon of people getting stuck in a narrowing room represents an exceedingly interesting state of matter, which is referred to as a jammed system. This jamming actually prevents the droplet from relaxing to a spherical shape, so it stays deformed. So, we have actually structured the fluid, an interesting concept to say the least. Here we have a material with all the properties of a liquid, but the structural stability of a solid!

So where can you use this kind of technique? Let's say one fluid was an insulating material, such as a dielectric fluid, and the other was a conductor. Using nanoparticle surfactants to deform fluids, we can make a liquid electronic circuit. Now that's futuristic, but you have far reaching ideas to push the system to its limits.

My other research includes the study of self-assembly processes for generating 2D and 3D nanostructures from copolymers. We are increasing the complexity of molecules and the resultant morphologies where topological issues are important. This reduces to a geometric problem films, which I'm working on with mathematicians, like Professor Stephen Hyde from Canberra in Australia, who is interacting with AIMR, and Director of the AIMR Professor Motoko Kotani. I'm also involved in joint research with Associate Professor Nakajima and other colleagues on structural changes in glassy materials.

U.S. Energy Policy

- Professor Russell, you are currently serving as Director of Research on Polymer-Based Materials for Harvesting Solar Energy (PHaSE) at the research institute set up by the U.S. Department of Energy (DOE), while also conducting your own research on photovoltaics. Could you please elaborate on U.S. energy policy, and share your thoughts on the situation surrounding energy from here on?

Professor Russell: The U.S. Government, especially the DOE, is investing a substantial amount of money to encourage fundamental science and materials science, with the aim of achieving a sustainable society in the future; and solar energy is an important within this. So that's why we are researching polymer-based materials for use as photovoltaics. Polymer-based materials are effective, as they can be used to make highly functional and flexible devices, and as I mentioned earlier, they can reach PCEs> 10%.

However, we are still heavily dependent on oil, coal and other fossil fuels, so photovoltaics are only a very small part of the energy supply picture. Reducing our reliance on these fossil fuels is not just figuring out a solution only for my country, the U.S., and your country, Japan; it has to be a global solution. It's essential that we can have access to energy sources that won't pollute the air or generate carbon dioxides and carbon monoxides, or sulfides and other such substances.

For example, I think we will see all vehicles becoming electrical vehicles (EV) in time; that's inevitable if we want to realize a sustainable society. And so we see the U.S. is steadily rolling out recharging stations for EVs. Finding oil alternatives will be one of the core issues we need to address from hereon.

- However, achieving this sustainable society requires many other things, such as making people consciously reduce their energy consumption, and developing new materials for enhancing energy efficiency.

Professor Russell: That's right. I believe developing new materials or redesigning existing materials for improvement is also fundamental in terms of enhancing efficiency. We also need to come up with some innovative and new ideas for how we can actually conserve or generate energy from different sources, whether it be thermoelectric, photovoltaic or hydroelectric. I think all of these things will become extremely important.

Preparing to foray into other fields

- So what initiatives are required for developing these new materials that can change society?

Professor Russell: In my opinion, the number one initiative that the AIMR has seen success in is the math-materials science collaboration. I think it's actually quite innovative, and if, through this collaboration, we can extract the key issues and find solutions for them, then I believe it has the potential to be groundbreaking. As for myself, I'm working with mathematicians at the AIMR on research in areas such as the self-assembly process. However, these types of initiatives take a long time to generate fruitful findings. Also, mathematicians and materials scientists need to find a mutual area of interest to work on.

So in that sense, I think tea time at the AIMR is a great chance for the people working there to interact with each other. When you give a presentation, if it's not in the area that some of the audience are working in, you lose their attention; some people may listen and see if they can make a contribution or suggestion; or others may listen and say "Gee, what about this? I might know how to do this. I bet if we worked together on it, we could produce some truly interesting results." Sometimes the research themes match, and sometimes they don't. We cannot predict the rate of success or failure, but I think having people gather in the same room and talking to each other is really important.

When I was working at IBM in San Jose, we used viewgraphs (OHP sheets) and gave a monthly seminar that we called a "tree-viewgraph seminar", a presentation to introduce a single idea using only three slides. We didn't have to present the fully worked out details of our idea; it was more just to show people what we were working on, where we saw noteworthy things happening, and where we could perhaps receive input and information from others. This seminar was held throughout the physical sciences group at IBM in San Jose, which was a fairly large number of people, and it was taken very seriously. If it was done very formally, the presenters probably would've ended up announcing their final results. So from that perspective, it was also an excellent forum to present research results that weren't yet complete. Sometimes it's best to put ideas onto the table and get people discussing them.

- So first it's important to find topic to work on, and then look for an area of common interest.

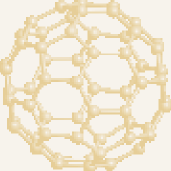
Professor Russell: Exactly. In order to work in with a researcher of an area that you are not very familiar with, the topic you will tackle has to be a challenge for both sides; and you have to rely on the expertise of this person to complement yours, and vice-versa. You also need to really discuss your respective fields with each other. You must be ready to step outside of your own field, your comfort zone, and into that of your research partner; this is what matters the most.

- In closing, could you please tell us your expectations of the AIMR initiatives?

Professor Russell: As I've already mentioned, I believe in the significance of the math-materials science collaboration. It really is a key element in our work to develop new materials that can change society. And I'm confident that Tohoku University, in particular the AIMR, has the right environment for such collaborations to work effectively.

Thomas P. Russell

Born on November 18, 1952. He received a Ph.D. from the University of Massachusetts Amherst in 1979. After working as a Research Fellow at the University of Mainz in Germany for two years and as a research staff member at the IBM Almaden Research Center for sixteen years, he took up a post as a professor at the University of Massachusetts in 1996. Since 2007, he has also been working as a principal investigator at the Advanced Institute for Materials Research (AMIR).



A short detour MATERIALS

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

Part 7

Tomography

Tomography is the generic term for using methods like sound waves or electromagnetic waves to explore the internal structures of objects that are not visible from the outside. One example of tomography is seismic tomography, which examines the internal structure of the Earth. This still might not give you a clear idea of what tomography entails. However, when we write "X-ray CT" (X-ray Computed Tomography), many people would probably remember what kind of equipment that is. Today, this equipment is installed in many medical institutions, and is used to diagnose diseases and injuries, as well as for health examinations. The representative form of radiography, utilizing X-rays, is roentgenography. This form of radiography takes its name from W.C. Röntgen, who discovered X-rays. In roentgenography (more commonly known as X-ray), X-rays are passed through one side of the body. The X-rays that emerge from the opposite side are captured by films or detectors and printed as photographs (images). Most of the X-rays are absorbed by parts made of elements with high atomic numbers, thereby reducing the intensity of the X-rays after they have passed through. As such, it is able to clearly distinguish bones in particular, which are mainly composed of calcium, as well as other parts of the body. However, passing the rays through the body in one direction means that, for example, if two bones are seen to be overlapping one another, it is difficult to tell just from the images which is in front and which is behind. To counter this problem, X-ray CT can acquire three-dimensional data. For cases like the aforementioned example, we can tell at a glance which bone is in front and which is behind.

The "C" in X-ray CT stands for "Computed." This means that enormous numerical calculations must be carried out with a computer. Mathematics contributes significantly to tomography technology. If we were to carry out computations based on mathematical theories for the multiple transmission images (projection images) obtained by passing X-rays from various directions through a certain object, we could observe the internal structure of the object (three-dimensional distribution of X-ray absorption coefficient). The mathematical concepts applied here are the Radon transform and inverse Radon transform. The paper of this theoretical foundation was published by Austrian mathematician J. Radon in 1917. The American physicist A. M. Cormack, who was unaware of Radon's achievements in the field, constructed his own theory equivalent to the Radon transform and inverse Radon transform, and published papers in 1963 and 1964 on calculating the three-dimensional structure of internal parts of objects (called "3D image reconstruction"). Although the papers did not draw much attention at first, the British electronic engineer G.N. Hounsfield developed a practical X-ray CT device in 1971 based on Cormack's theory. The following year, he announced the historical achievement of having successfully filmed images of the diseased parts of the human brain without carrying out a craniotomy procedure. With these achievements, Cormack and Hounsfield received the Nobel Prize in Physiology or Medicine in 1979. Although the MRI is a similar method used in the medical field, X-ray CT follows a largely different principle. Someday I will expound further upon it. MRI is also a form of tomography that makes use of computers, and therefore is considered to be a type of CT. However, CT is commonly used to refer to X-ray CT.

Such tomography technology is also becoming indispensable in material science. It is useful as a non-destructive method to examine cracks and other details in materials; and the ability to view the three-dimensional structure of objects is a significant plus. For example, electrical conductivity and the behavior of fluids are dependent upon the three-dimensional connection state (network) of substances. However, even when connections exist three-dimensionally, they often appear to be disconnected when observed in two-dimensional cross-sections. Hence, it is crucial to be able to observe network structures in their three-dimensional forms. The development of equipment is also rapidly advancing. The resolution of CT scanners used in the medical field, which have been specially developed for filming the human body, is about 1 mm. This is not precise enough for materials research. High-resolution X-ray CT scanners that have been developed for industrial use and for use in fundamental research have resolution ranging from 1 to 10 micrometers. On top of that, the cutting-edge X-ray CT device developed at the large-scale synchrotron radiation facility, SPring-8, now has a resolution of about 0.2 micrometers (200 nanometers), and is being utilized in various materials research activities.

Susumu Ikeda

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

Song Toan PHAM

"I wanted to find out more about the world I live in, and I believed science could give me the answers I was seeking." This is what motivated Dr. Pham to become a researcher.

Upon deciding to become a researcher, Dr. Pham felt that he wanted to make something new; so he started studying materials science. Among the various materials in this field, he was particularly drawn to organic material with its potentially high application in everyday life. "Apart from being flexible and extremely cost effective, with the use of spintronics, organic material is also able to transmit spin information over longer distances than inorganic material. As such, it is a fascinating material also for use in electronic devices."

Dr. Pham is currently researching organic spintronics devices at Prof. Mizukami's lab at AIMR. "Tohoku University is renowned in the spintronics field, and AIMR is well equipped with top level researchers and equipment. I greatly look forward to the opportunity to conduct research in such an excellent environment."

Before coming to Sendai, Dr. Pham lived in Vietnam and Osaka. When asked if the cold winters here are particularly tough for him, he replied with a smile, "I like snow and skiing, so I'm really enjoying my life in Sendai."

Song Toan PHAM

AIMR Research Associate

Born in 1986 in Hanoi, Vietnam. Graduated from Vietnam National University, Hanoi. After acquiring a Ph.D. at Osaka University, he started working at AIMR in 2015.

Text and photo: Yasufumi Nakamichi