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FEATURE

Full Research

From Philosophy to Practice

Research Hot Line

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In Brief

Full Research
From Philosophy to Practice

Practical Realization of Full Research

National Institute of Advanced Industrial Science and Technology (AIST)
President Hiroyuki Yoshikawa

Five years have passed since AIST was re-organized. Drastic changes in the organization and reforms in the administration methods at the time of re-organization resulted in large circumstance transformations on the individual researchers in AIST. These transformations were inconceivable in the existing frameworks of research institutes, thus considerable effort must have been required in accepting them, on the part not only of the individual researchers but those engaged in administration as well. Now, however, these efforts are beginning to yield results. AIST has become an organization that evolves toward a common goal with steady steps in producing results.

New methodologies for conducting actual research were created with the organizational and administrative changes at the time of re-organization. Among them, Full Research is deemed essential. The method enables AIST to serve as a place for open research to be conducted, being receptive to the expectations of society towards science and technology, understanding these expectations, and responding to them through research, while at the same time allowing the researchers to carry out studies in areas of basic science, guided by their own academic curiosity.

This diversity in research, from basic to application, combined with the diversity of fields — generated as a result of the fact that, in our effort to contribute to various industries, we have come to perform research in extensive disciplines — has become the major feature of AIST. Thus, AIST is characterized by the multiplicity of its researchers. Full Research, then, is a method of research which is realized upon this feature. Presently, each of our more than fifty research units of varying scale and area of specialty is involved in research that may be called Full Research. And now we are beginning to generate results. In view of this fact, we established the "AIST President's Award" in fiscal year 2004, which includes awards targeted specifically for Full Research.

The five researchers who appear in this feature are winners of the President's Award for Full Research within the past three years. They are the individuals who have taken the concept of Full Research and substantialized it into an actual form. The fundamentals of all five achievements constitute outstanding examples of academic research. In addition, in each case, the direction by which these results of basic research would link to industry was successfully and clearly shown. In other words, they covered all of Type 1 Basic Research, Type 2 Basic Research, and Product Realization Research. Meanwhile, reviewing their research efforts and speaking to the winners in the roundtable discussion featured in this issue, I was strongly impressed by a certain fact. It was not the fact that we were actually able to witness excellent research that could be called Full Research, by which of course I was amazed, made deeply happy and eager to offer a grand compliment.

The very fact that deeply impressed me was that these individuals, while working as the executors of Full Research, were, at the same time, "executives" of their own Full Research. Each project, according to performance, had different numbers of participating and cooperating researchers and managers, and likely differed in style of cooperation. These cases, however, are identical in that the award-winners all conceived their own goals, analyzed the problems, formulated research plans, and sought out the collaborators required to form a group, then conducted basic research and found contacts with industries to allow the industrial application of their outcomes. I was strongly moved by the fact that these winners set out with clear visions of Full Research and conducted their research according to these plans.

Although this feat was not entirely beyond expectation, I did believe it to be difficult. The Type 1 Basic Research which we conventionally refer to as basic research is currently conducted mainly at the science faculties of universities, while the application-oriented research is conducted at the engineering faculties, and Product Realization Research which encompasses corporate management is conducted at schools of business administration or at the companies. Full Research introduces further the style of Type 2 Basic Research, which includes complex aspects linking these various levels, and is structured to allow continuous and concurrent execution of the overall research process. Therefore, Full Research was intended to be built through a collaborative effort between the science, engineering, economics and corporately intuitive people, together with the individuals who perform Type 2 Basic Research which requires knowledge covering various fields that are not yet sufficiently recognized. If one individual could fulfill the diverse roles described above, we couldn't ask for more. However, I believed it not feasible for the present-day researchers who have received education in a segmented manner of science fields. Therefore, these diverse researchers were to be orchestrated into research units, and the unit directors were expected to enforce 'research management,' to execute research in a continuous and concurrent — not disconnected — manner. However, as mentioned earlier, these winners, even though they received the cooperation of many individuals, seem to have achieved results basically by single-handedly fulfilling the conditions required for Full Research.

This fact is significant in several aspects. The fact that these winners were able to think beyond the conventional research methodologies while actually doing research work in the laboratory, although allowing for the possibility that they may just happen to have been brilliant, constitutes an exemplification of their opening anew a virtually unprecedented horizon of research. Furthermore, we see that past winners of the President's Award for Full Research, including those who did not participate in this roundtable discussion, achieved results through accurate and selective application of knowledge in a nightmare-like research process which requires knowledge from diverse disciplines.

Collaboration between basic researchers and application researchers, or between researchers of differing fields, has been so far considered not easy by any means, much like cooperation between industry and academia often proves difficult. If so, the achievements of these winners go beyond their results being effective in reforming industry; the winners should be recognized for the experience by which they constructed within themselves a scheme of collaboration between diverse researchers which was conventionally deemed difficult. In this sense, it would be beneficial to future developments in Full Research that the experiences of these winners should go on to be expressed and disclosed so as to encourage other researchers.

Further, Full Research constitutes the most vital element in AIST's current goal of establishing an innovation hub. Full Research is anticipated to actually integrate various researchers, and further, to provide an effective research management methodology upon which we may build a Center of Excellence in Japan together with universities and corporations.

In this sense, AIST, while each research unit develops Full Research, needs to define its methodologies, upon which we may promote coordination between universities and other research institutions. Now, with my fresh knowledge that these methodologies are newly spawning in the research processes of individual researchers, I would like to offer my compliments to the award winners, as I renew my recognition of the deep originality of mankind.

Roundtable Discussion :

How are "Full Researches" Performed?

Hiroyuki Yoshikawa President

Shinji Yuasa Nanoelectronics Research Institute
Yuji Yoshimura Energy Technology Research Institute
Kenichi Fujii Metrology Institute of Japan
Hajime Ohgushi Research Institute for Cell Engineering
Kazuhiro Murata Nanotechnology Research Institute

Akira Ono Vice-President for Public Relations (Host of roundtable discussion)

Ono : I have asked researchers who implement "Full Research" at AIST to talk about how Full Research and Type 2 Basic Research were actually performed in each case. First, Dr. Yuasa, I understand you did work in the area of spintronics?

Yuasa : I conducted research on enhancing performance of the tunnel magnetoresistance (TMR) device and putting it to practical use for 5-6 years. What we first worked on at AIST was the development of a TMR device of a new, innovative material using an experimental deposition system. The system was an experimental setup built with little consideration for cost. We created a film, simply beautiful, like a fine work of art, on an extremely specialized, small substrate, thus achieving a performance several times better compared to the present devices.

Up to this point, we had been more oriented in Type 1 Basic Research, but we decided to somehow take a big step into the Valley of Death and attempted to make our way across it with Type 2 Basic Research. However, the Valley of Death was wider than we expected, and the electronic device makers were not willing to meet us halfway.

The device makers held their position that they preferred to simply buy manufacturing equipment from the equipment makers and introduce the necessary know-how together, and then perform product development in the production line. We were hoping the device makers would be willing to meet us halfway, but to our disappointment, such a situation could not be hoped for in present-day Japan.

What we thought of then was that we should be teaming up with the equipment makers instead. So we established ties with the top equipment maker in the field.

We advanced our materials and device technology to a level for the existing equipment installed in corporate production lines to be used as it is. In this way, once we had established a system where we could deliver to the device makers the materials and devices as well as the production know-how and equipment in the form of a comprehensive solution, the industry was finally set in motion. Now this equipment has been installed, and product development is finally under way for hard disks and magnetoresistance memories. From our experience so far, we have found that tying up with the equipment makers to build a close system of cooperation is an extremely effective scheme for implementing Type 2 Basic Research, and so we are currently using this scheme.

Yoshikawa : What really surprised me listening to Dr. Yuasa's story is that, normally, we would think that the device makers would participate in the Type 2 Basic Research and lead the way to development. However, this was not the case. In fact it was the equipment makers who did. While acknowledging this fact, I can't help but feel that perhaps this is a weakness on the part of Japanese device makers.

Yuasa : Our mistake with semiconductor devices was that we let a US giant maker dominate in the manufacturing equipment. Production is possible by any country that buys the equipment of that maker, which wiped out any competitive edge of the Japanese semiconductor industry. As manufacturing equipment is crucial, I would like to see Japan somehow dominate in the spin device area on which I am now working.

Yoshikawa : You're right. That was major finding. And you found it during the process of your research. Of course the device makers must have also become aware, but your finding is still an extremely important point. Your story clearly showed and reminded me that the significance of Full Research lies definitely not only in the laboratory, but really in how researchers and industries work together to take basic research to

How do we uncover the real needs and collect the seeds to resolve them, and how far can we develop them? Herein lies the significance of integration.

Shinji Yuasa

industrialization. I think it was extremely inspiring.

Yuasa : What's more, working together, we have found that our AIST-equipment maker partnership constitutes an extremely effective complementary relationship. We share a mutual interest, and I think we are conducting collaborative research that is highly substantive.

Yoshikawa : I see. This is new finding, or actually something so important and far-reaching that it may even affect the very nature of the industry.

Ono : Dr. Murata, you're working on the super-fine droplet?

Murata : I am researching a technology called super-fine inkjet, in which super-fine droplets, one thousandth in volume compared to those of inkjets on the market, are discharged. Looking back to the past, I think my research may have begun from a personal need of mine, as a means to build the equipment I wanted to use in my own research, rather as a Type 1 Basic Research endeavor.

In nanotechnology research, in order to use nano-materials in non-bulk form, we require equipment to place the required material in the required position. I started from this point, and just developed to as hyperfine as I could get. In the process, I didn't systematically try various engineering systems, but rather took a hit and miss approach.

As a result, for example, while drawing a line on a substrate surface with fluids is actually difficult, as it sometimes forms bulges or does not work as expected due to the effect of surface tension, we saw new phenomena when using the microscopic droplet. It is remarkably fast-drying and extremely limited locally in terms of the scope of fluid upon the substrate, which makes various feats possible, including stacking things three-dimensionally. We introduced it to the society, and it just happened to meet the needs of society, becoming a technology to fill the technological gaps, such as in energy- and resource-saving processes and production of many models in small quantities.

A comment I received from an individual at a manufacturer made me very happy. "There is a movement to use inkjets in industrial processes. Since you, Dr. Murata, have shown us the hyperfine realm, you serve the role as our beacon to guide us there, assuring us that the path we are taking in printable electronics is not dwindling."

Note, however, that as my research originally started out from personal needs, the results did not necessarily match well with social needs. So, I performed anew a reorientation of goals based upon social needs and tried to make my results practicable by taking advantage of the systems of the Venture Task Force and Venture Center.

Yoshikawa : What I found extremely interesting in Dr. Murata's story was that his objective was personal. This is an extremely important point. When you are trying to research a certain area and think, "I want to find out about this," or "I want to measure this," you look around and find a certain measuring instrument, so you use it to measure. But if so, you do not find what you really want — although there are a great many cases where we succeeded anyway.

In order to work on what you really want to know, I have always believed that the most creative technology is the approach of making various samples and measuring instruments of your own. Yours was a typical example. It really makes sense to me now, hearing that this topic had such a background.

Another interesting point was that, it seems, everything must return to Type 1 Basic Research. Although some challenges are born from intellectual curiosity alone like so, on the other hand, there are new challenges that are born as a result of our trying to solve a specific issue. I have a feeling that the time has come for major progress in science to begin being pulled in this direction.

In the past, it was not so. There were many unknown things in the world, and our curiosity to know about these things broke new ground, astronomy being an example.

Unlike that situation, our world is filled with artifacts, and in the process of figuring out how to make them better or create something new, there has been generated a systematic knowledge that we need to have, to know, which we use to create.

I think this means that not only are we implementing applications, but are bearing the leading role in fundamentally creating new areas of science. This is the fact that Dr. Murata expressed explicitly as "reorientation of the research goal." If such efforts would become more widespread, new and unprecedented fields may emerge. This is quite inspiring.

Ono : Dr. Yoshimura, you are studying hydrodesulfurization catalysts?

Yoshimura : Hydrodesulfurization catalysts are used to remove sulfur in petroleum oil. They are actually used in oil refineries, and due to the extreme tightening of environmental regulations, the needs for sulfur removal are increasing. Currently, due to needs to reduce sulfur content to less than 10 ppm, some amounts of sulfur-free diesel have been supplied to the market in advance. In view of the nationwide supply of sulfur-free diesel, there are needs on the oil refineries to reduce sulfur by exchanging the hydrodesulfurization catalyst only, without making diesel blendstock adjustments or process modifications.

In conducting our in-house work, we set out to achieve a breakthrough in the field of catalyst preparation, which holds the key to realizing an innovative industrial hydrodesulfurization catalyst.

To cite a few examples, first, we succeeded in complexation of metals using a new chelating agent. The primary feature is its low cost. Second, we were able to characterize, on an atomic level, the ionic structure of the impregnating solution used to prepare such catalysts, using a method of EXAFS, on the facility of the High Energy Accelerator Research Organization, KEK. Third, among others, we found a highly reproducible method for making a metal-containing impregnating solution for catalyst preparation based upon various data on molecular and atomic levels. In addition, we found new methods for catalyst activation. I was actually inwardly surprised that the hydrodesulfurization catalyst we finally achieved was able to successfully reduce the sulfur content in diesel to less than 10 ppm.

After applying for patents for these techniques, we proposed the top manufacturer of hydrodesulfurization catalysts in Japan with them, together with the relevant know-how information. Although our research tends to be weighted more in Product Realization Research rather than Type 2 Basic Research, of course these were still the results of beaker-level research and development efforts. I think the fact that the "catalyst preparation" developed at AIST was recognized by the hydrodesulfurization catalyst manufacturer is what allowed us to tie up in a joint development system, which, in turn, lead to commercialization.

Yoshikawa : I have a question. What is your definition of a breakthrough in in-house work?

Yoshimura : I use the term rather loosely, to refer the fact that we used the technologies uniquely owned and used by AIST — such fundamental technologies — to go as far as a new industrial hydrodesulfurization catalyst.

Yoshikawa : I see. Catalysts have an extremely long history here at AIST. In this sense, this is an extremely important treasure for AIST. So I understand that a breakthrough is not to simply use the basic knowledge you already possess but to develop it further. This is something I feel from meeting various people recently. For example, catalysts are found in various places, but the study of catalysis is not easily understood by the general public. So, if this in-house work exists, could you make a textbook of it?

Yoshimura : Catalysis research at AIST seems to be more or less oriented in an application approach. In areas such as environmental and energy-related studies which respond to social needs, research is more often oriented in Type 2 Basic Research approaching Product Realization Research, and, in some cases, we stretch our orientation as far as Type 1 Basic Research, such as using clean surfaces in order to understand the mechanism of the target catalyst reaction. Meanwhile, we also see, for example, some research oriented in Type 1 Basic Research, such as attempts to understand the activation mechanism of catalytic structures and reacting molecules, by taking advantage of the characteristics of various spectroscopic instruments, or by combining and upgrading them. The former sees catalysts as a 'tool' and is application research that seeks to resolve a problem, while the latter may be called basic research that places weight on "understanding" catalytic action.

The catalytic systems at which research is targeted are infinite in variety, and practical catalytic reaction conditions often differ greatly from the simplified reaction conditions used to understand structure and mechanism, thus I think that there exist some gaps between application research and basic research. Of course, in some cases, effective coordination from basic to application is made within a group. If there were more examples of such effective coordination to bridge this gap, catalysts, "the silent force behind the scenes," could be documented into a comprehensible form from an AIST approach, starting at the exit and working back to fundamentals.

Yoshikawa : As a personal and free interpretation, I see multiple individuals conducting Full Research without realizing it. In the cases of Dr. Yuasa and Dr. Murata, they worked alone throughout. In catalysis research, this is not the case. The issue is what kind of flow of knowledge is made between the individuals doing basic research and those doing application. I think that Full Research may essentially take such a shape. Even though no single person sees the total picture, they are linked on a large scale in the outcome.

In Full Research, essentially, first basic research is completed in a personal style of research, before progressing on to Full Research. Next, research is conducted through cooperation in the form of research units. Further, it expands and tie-ups between universities, AIST and industry are made to comprise a single large Full Research. It appears "fractal," as I would call it. Listening to your story just now, I felt that you were doing something like that with catalysts.

Ono : Dr. Fujii's research led to the determination of the Avogadro constant from a study of measurement standards.

Fujii : Speaking in relation to the Avogadro constant, the significant events in Type 1 Basic Research were the appearance of the X-ray interferometer in the 1960s, and the Josephson effect and the quantum hall effect in the 1970s and '80s. When the Josephson effect and the quantum hall effect were discovered, nobody imagined they could be used for mass standards. Nonetheless, these Type 1 Basic Researches have later come to be used in the mass standards.

What was done specifically in order to link them to the mass standards was the following — and I think this is Type 2

Basic Research. The X-ray crystal density method was first realized in the U.S.A. in the 1970s, and laboratory results followed. In the 1980s, the watt balance method was introduced, the Planck constant was measured using the mass standards, and from there, the laboratory technology to link it to mass was born.

We employed a method of determining the Avogadro constant using silicon crystal to measure density and then determine molar mass. When conducting Type 2 Basic Research, naturally, the theories obtained from Type 1 Basic Research are used, by which new laboratory technologies have been born in Type 2 Basic Research.

As a result, recently, we have become capable of definitely determining the fundamental physical constants. In particular, in the international adjustment of fundamental physical constants implemented in 2003, the Avogadro constant proposed by AIST made a contribution. It constitutes a database in the form of fundamental physical constants, and is considered a product.

If we view our newfound ability to do such things freshly by tracing back to the era of the French Revolution when modern measurement standards were first introduced, we see that in effect, for a long time, humankind has been defining standards for units by selecting universal elements in the natural world. At the time of the French Revolution, we were not aware of the existence of fundamental physical constants, thus, were not able to do this, but entering the 20th century, once we were able to confirm the existence of fundamental physical constants, we discovered that it is best to use the universality of the natural world as a standard, which was a crucial point. I think that to directly link this to units has been the trend for a long time.

Furthermore, once we are able to perform such measurements, we are able to measure the Planck constant using various other principles, which enabled us to confirm the validity of various laws in physics. Although we had been conducting Type 2 Basic Research based upon the theories of Type 1 Basic Research, once we are able to do such things, there arise cases where we inversely validate these theories, serving as feedback to Type 1 Basic Research. This fact, I believe, is also very significant.

We had a “win-win” goal with our joint research partner. I think the greatest factor in our success was that we were able to work together openly.

Yuji Yoshimura

Yoshikawa : Dr. Fujii’s research is moving, as this history represents the progress of grand human wisdom itself. Inversely, we can say that such basic knowledge leads to the future. People of the olden days probably did not think so, but it is central to science. Nonetheless, this, also, is something they don’t teach you in university.

Fujii : You’re right. Recently in universities, there are few people who can teach this, so AIST receives offers to give lectures. We give lectures at universities that request it, and receive surprisingly good reviews from the students.

Yoshikawa : I can imagine.

Fujii : Many students are interested in the significance and measurement methods of fundamental physical constants, since the lecture on measurement standards itself no longer exists.

Yoshikawa : I wonder how they can do physics without it, but nonetheless, they don’t teach it. It seems useless to me to do other research without it.

Ono : In the case of the quantum hall effect, Japan was not able to win the Nobel Prize due to a lack of fundamentals in this area. We couldn’t imagine that the quantum hall effect would link to resistance standards. We had an excellent Type 1 Basic Research here in Japan, but were not able to tie it into the Type 2.

Yoshikawa : So, in Japan, society didn’t recognize the fact. It was probably the same with the case of optical frequency, despite there being a very hot topic. The fact that it is not recognized by society must also be rooted in education issues.

Ono : Dr. Ohgushi is researching regenerative medicine.

Measurement standards constitute a fusion of various fields. Without integration of fields, we cannot make progress in Type 2 Basic Research. AIST offers the soil suitable to do so.

Kenichi Fujii

In order to advance research, we need participation by industry. I believe that working to create this framework is AIST's role.

Hajime Ohgushi

Ohgushi : I have been working as an orthopedic surgeon for many years. I work with bones. There are various technologies for treating bone diseases, of which an example is the utilization of cells. We tried to somehow create bone using an animal model, and thus developed a technology for making bone using cells. Our work up to this point completed the Type 1 Basic Research. Afterwards, we tried to develop some application, which is where we ran right up against a brick wall.

Just when I was about to develop an application for the basic research that I had spent about 20 years doing, I found I didn't have any facilities — or the know-how. This is exactly when AIST was founded. It was an extremely lucky break for me that the Tissue Engineering Research Center was established in AIST. In order to transfer my application research there, I requested the establishment of the Cell Processing Center.

AIST was founded in 2001, and by the end of the year, we had succeeded in bone regeneration. We performed a transplant on an actual patient using the technology that I developed. So, in my case, I made a fairly smooth transition from Type 1 to Type 2 Basic Research.

This probably applies to all of you, too, but even after going on to application research from Type 2 Basic Research, I am sure we all continue on with Type 1 Basic Research. In my case also, I did not end my Type 1 Basic Research but continued right on with it after joining AIST. What did I learn from Type 1 Basic Research? Cartilage, liver, nerves and blood vessels. Using the same cells, what wasn't even imaginable before 2001, we were discovering anew that we could also make liver, nerves, and blood vessels — besides bones.

I had been working on Type 1 Basic Research on bones for a quite a while before joining AIST and I continued this Type 1 Basic Research after joining. Using the knowledge I thus obtained, now, I am also working on regenerating the heart from the same cells. I think this is extremely important.

I worked with private businesses for establishing the Cell Processing Center, and I still do now. What I want to say is that I believe that establishing a social platform to cater to more companies and more patients in a wider sense is also a part of Full Research. For example, even if you can develop a car, to use it safely you need to build traffic lights and roads. I think it is important to consider such development of social infrastructure as a part of Full Research.

Building a social platform for the use of cells from regenerative medicine, in cooperation with the Ministry of Economy, Trade and Industry (METI), so that we can create more products in the future, is Full Research, or in a sense, may even be a typical example of AIST's Full Research. I think that establishing such a system which includes many companies, as well as building a platform in the sense of social infrastructure, is also important.

Yoshikawa : I found Dr. Ohgushi's story very interesting. It was a Type 2 Basic Research only feasible at AIST. By the way, in bio-research, the period to application seems quite short.

Ohgushi : Although the time required to application is short, there is not much industrial participation yet. This is what we need to work on from here. Unlike other fields, there are many issues, including regulations, in medicine. Nonetheless, luckily, METI is showing considerable interest. I think it is crucial that we work with the government. Building social platforms together with the government — this is important, and is exactly what AIST's Full Research is all about.

Yoshikawa : So, if we don't make roads, we have no place to drive the cars we make. This seems to be a common situation in biotechnology. Even if you have a good idea, there are regulations, or you can't conduct the clinical trials here in Japan. We hear so many such stories. I guess there should be a phase for building traffic lights before going ahead to build the freeway.

Ohgushi : I think that is what we should do first of all as a preliminary stage, instead of building the freeway off the bat. However, we can't do this part alone, so we really would like to work with the government on it.

Yoshikawa : An interesting summary of today's roundtable discussion is that Dr. Ohgushi's story and Dr. Yuasa's story are similar. If the relevant industry is not well organized, Full Research in the true sense cannot be realized. These things become apparent once we implement Full Research. Specifically, this means that we may need to change the system through policy proposals, start up new projects, or change the industry.

Ono : We have had the opportunity to hear examples of how new industries

From joint research, we receive various stimuli and obtain all kinds of knowledge. Our technology may develop in unexpected directions. Joint research is also beneficial to the researcher on a personal level.

Kazuhiro Murata

were born as a result of the technical platforms being established in society. I think it is wonderful that not only does AIST create new industries but works with METI to create the environment which will spawn such new industries.

Yoshikawa : This means that we propose the needs.

Ohgushi : This is exactly the kind of thing AIST can do readily, unlike universities.

Yoshikawa : It is certainly different from the translational research conducted in university hospitals, which is done to actually treat patients.

Ohgushi : From our point of view, in order to have diverse and large numbers of patients utilize such technology, in the end, participation by industry is absolutely necessary. And in order for industry to enter, we need a framework that lets them. AIST is best fitted to create the seeds, as well as create such a framework and set it in place. This is an AIST's role. I would like to accomplish that much within the next few years.

Yoshikawa : This is a major issue for AIST as a whole.

Ono : An element common to all of your stories is that your work was markedly activated as a result of collaboration with external corporations and institutions. Without it, you would not have achieved what you did in the end. In this sense, it may be that companies and other institutions are essential as partners of Full Research.

Murata : A Center Director once said to me, "We implement cooperation between industry and academia for the purpose of doing research itself, not for the purpose of realizing practical applications."

From joint research, we receive various stimuli and obtain all kinds of knowledge. Our technology may develop in unexpected directions.

To a researcher, joint research in the form of cooperation between industry and academia is not only a service to others but something to be taken advantage of personally.

Yoshikawa : "Innovation hub" was intended to be a concept in which we would implement Full Research and then link it externally to others. But maybe that's not so. Full Research may not be effective if it is not linked internally with others to begin with. We may need to reconsider the nature of cooperation between business and academia. In order to activate Full Research, the researcher himself/herself must conceive the links, including external frameworks, and integrate them into the Full Research.

I think the significance of our conclusion today was extremely profound. The reason I was forced to insist upon Full Research was that I believed that the way human knowledge is produced has been incomplete, the reason being that the domain of academia has become isolated from society and that the way where knowledge is produced within a closed academic society has become an accepted social existence.

If that is science, then the field of engineering was created to counter this situation. However, I felt that it was wrong. I believed originally that in the true production of knowledge, the intent of the user of that knowledge should be taken into account. It cannot be isolated vertically. Knowledge flows, is born and is then used. My theory that proper growth of knowledge is only possible within a whole picture is what led to my proposal of Full Research.

However, it was extremely conceptual, and I didn't really speculate deeply about the relationship between the researches — such as we are talking about today, which are extremely precise in a sense — and their final uses.

The necessity that they must be related was clear, but as to what form they would take, I only found out as various researchers came together at AIST and began putting them to practice. I was encouraged. The five of you who joined us here today are already winners of the President's Award, but listening to your stories now, I was even tempted to award you all over again.

Ono : Thank you for your interesting stories.

Full Research in Spintronics Technology

Working to Actualize a Next-Generation Device

Third innovation in spintronics
—Development of MgO-TMR device—

Electrons, in addition to their negative charge, also possess a spin (properties of a small magnet) (Figure 1). Electronics is the field in which we have been creating beneficial functions using the electron charge in solids. Meanwhile, the field in which we only use the electron spin is magnetic engineering (such as in magnetic data storage). Both of these fields have long histories of research and development as well as extensive markets; they are responsible for the basic technology indispensable to our present-day IT-based society. Consequently, there is apprehension regarding maturation and saturation of these technologies.

Meanwhile recently, “spintronics,” a new field which has the potential of breaking through this stagnation, is blossoming. Spintronics is an area which exploits both the charge and spin of the electrons in a solid to realize electronic devices with new functions. The history of spintronics began with the discovery of the physical phenomenon called giant magnetoresistance (GMR) in 1988, and progressed through the realization of tunnel magnetoresistance (TMR) in 1995.

These device technologies are already in practical use as magnetic heads for hard disks and new nonvolatile memories (MRAM). However, the performances of GMR and TMR devices are approaching their limit, creating an anxious need, from the application end, for realization of a magnetoresistive device of even higher performance.

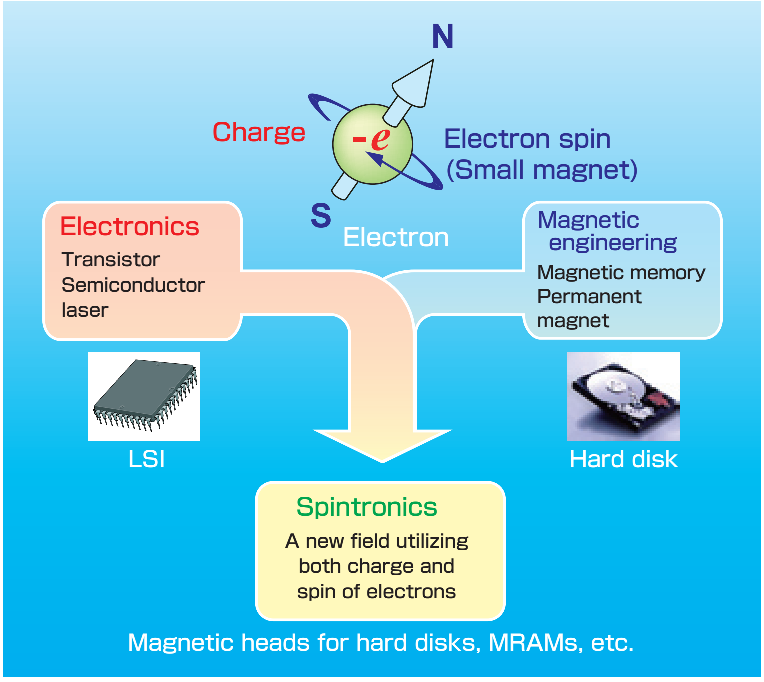

Figure 1 : What is spintronics?

In 2003, AIST succeeded in developing a new model TMR device using magnesium oxide (MgO) as the isolating tunnel barrier, achieving a revolutionary high performance of 5 times or higher compared to the conventional TMR device (Figure 2). I believe the key to our success was the fact that we effectively integrated the technological seeds that have been cultivated at AIST for years, such as the technology for forming thin, high-quality single crystal films and for processing devices, our knowledge regarding development of new materials, and our knowledge in fundamental physics to conduct technical development, which matched existing needs and was appropriate in timing.

This abundance of technological seeds is the strength of AIST. In order to maintain this edge, I believe that continued investment in Type 1 Basic Research is important.

Collaboration with a manufacturing equipment maker
—Developing a mass-production process—

Originally, when the revolutionary high performance of the MgO-TMR device was demonstrated on a laboratory level, feedback from industrial circles was unenthusiastic, the reasons for which included the fact that it used a deposition method which was not suitable for mass production (MBE method) and that the device was built on a specialized single-crystal substrate.

In order to make the MgO-TMR device marketable, there was a high technical wall to be overcome: the MgO-TMR device must be producible using a deposition method suitable for mass production called sputtering, on any arbitrary large-area substrate, at room temperature.

Graduate of doctoral program at Keio University. Was originally involved in research in fundamental physics, but, deciding that the value of solid state physics lies in how it benefits society, is now working on research and development of spintronics technology targeting industrial application. “Taking the step out from Type 1 Basic Research into Full Research, I often come under a lot of pressure from the outer world (industry), but I also see bright prospects. I am perceiving first-hand how ‘Full Research is a place for researchers to grow.’”

Shinji Yuasa
Spintronics Group
Nanoelectronics Research Institute

Originally, we were expecting the electronic device maker to take on this task of developing the production process. However, in the electronics industry today, division of roles is so far advanced that the device maker only installs virtually perfected technology into its manufacturing lines, so as to concentrate efforts on product development. Therefore, we were forced to advance the MgO-TMR device technology to mass-production level on our own through Type 2 Basic Research.

Consequently, we sought collaboration with the major manufacturing equipment maker, Canon Anelva Corporation. Although manufacturing equipment makers are often regarded as only making the equipment, actually, they bear the important role of developing the production technology for new materials and devices, thus make extremely effective partners in crossing the Valley of Death (Figure 2). We fused together the basic technology possessed by AIST on MgO-TMR devices with Canon Anelva's superior manufacturing technology and equipment, and implemented research and development in close coordination. As a result, in only one year, we succeeded in developing the mass production technology for the MgO-TMR device. We achieved a level which allows device makers, by implementing this technology, to immediately begin product development.

Product development efforts and future prospects

Now, we have started joint projects with industrial circles in order to conduct product development, the final stage in our Full Research. We are carrying out two NEDO projects as endeavors to bring our Full Research to a successful conclusion: "Spintronics Nonvolatile Technology Project," which aims to develop a high-capacity MRAM (spin RAM) using two new technologies, namely the MgO-TMR device and writing by spin injection, and "Research and Development of Nanodevices for Practical Utilization of Nanotechnology," which aims to develop future-generation hard disk magnetic heads using the MgO-TMR device.

These research and development efforts are anticipated to lead to landmark enhanced energy efficiency, performances and convenience of electronic equipment, as well as strengthening of the competitive edge of Japanese industry in several years' time.

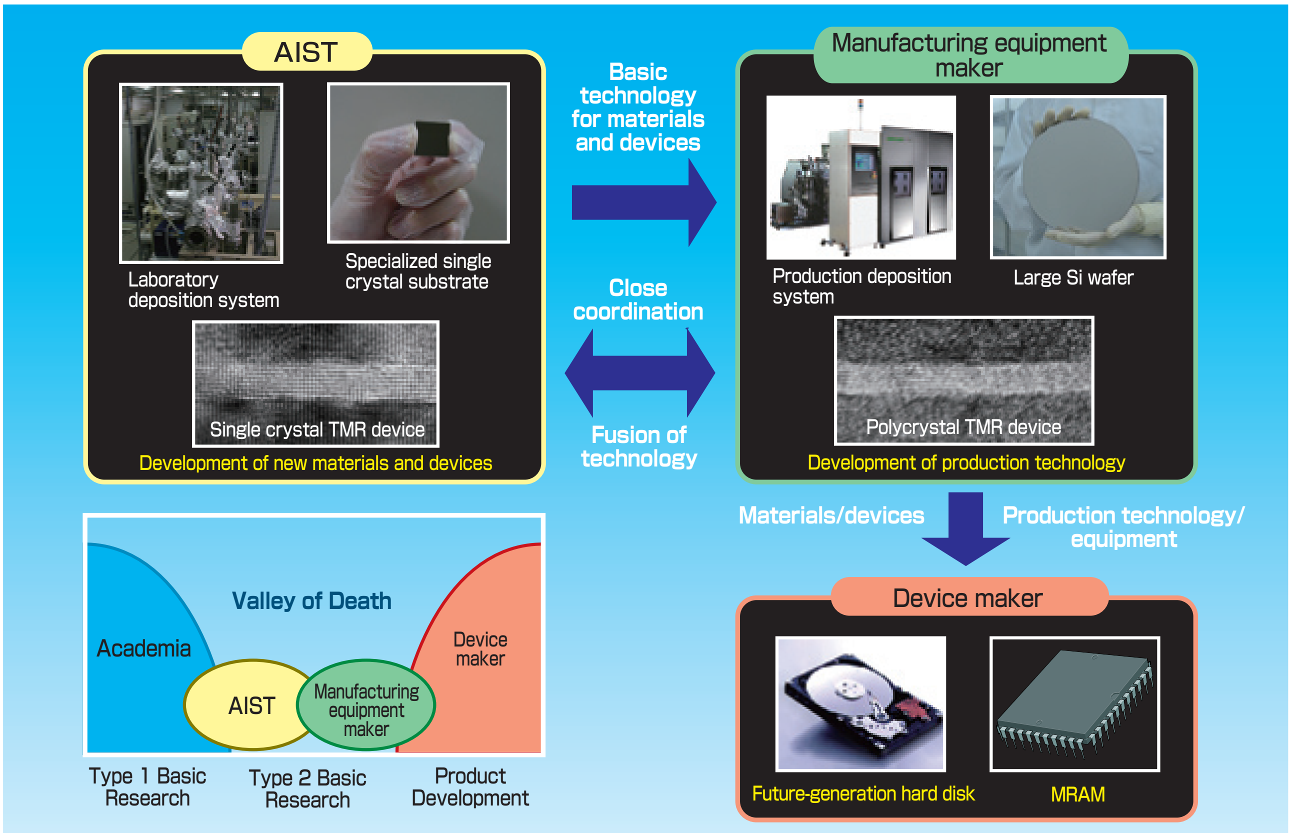

Figure 2 : Full Research and collaboration scheme of spintronics technology

Full Research on Development of a Catalyst for Producing of Clean Transportation Fuels

From Basic Research of Catalysts to Joint Research Aimed at Commercialization

Research that responds to social needs

Owing to reinforcements of the urban air environment regulations, expectations are ever-increasing for development of an innovative exhaust gas treatment technology which will lead to substantial reductions in automobile gas emissions (NO_x, PM, etc. from diesel-powered vehicles in particular). As the catalysts used in exhaust gas treatment are very sensitive to sulfur, nationwide use of ultra-low sulfur diesel (sulfur content, S<10 ppm) — referred to as sulfur-free diesel, the nationwide supply of which is planned starting in 2007 — was considered vital in order to enable rapid development and introduction to the market of a revolutionary catalysis technology.

Therefore, there is a strong demand for development of a high-performance hydrodesulfurization catalyst that can produce sulfur-free diesel (S<10 ppm) via a simple exchange of the catalyst, without modifications to the diesel producing operation conditions (S<50 ppm, partially S<10 ppm) that are currently used within the oil refinery. Over the hydrodesulfurization catalyst, the organic sulfur compound (S = approx. 0.5-1.5 wt%) contained in the fuel oil reacts with hydrogen, by which the sulfur is converted to hydrogen sulfide and is thus removed from the light gas oil (hydrodesulfurization process).

In response to such social needs, we have advanced the research on petroleum refining catalysis which has been ongoing for years at AIST, to propose a prototype catalyst and achieve commercialization of a new hydrodesulfurization catalyst through joint research with a company.

Catalysis research oriented in Type 2 Basic Research

Catalysis research can be classified broadly into two types. The first includes working to elucidate the catalytically active phase from a surface chemical approach, reveal the mechanism of activation of chemical bonding and reaction mechanisms, and understand the catalytically active phase using the theories and computing methods of molecular dynamics, etc., in addition to researching to propose the potentials of new active phases (Type 1 Basic Research). The second is the research for fusing knowledges from inorganic chemistry, organic chemistry, analytical chemistry, surface chemistry, chemical engineering, thermodynamics, etc. with actual experience to design and prepare catalysts, then perfect the catalysts by equipping them with the performance and life, etc. required in the target reaction (Type 2 Basic Research).

In the case of this hydrodesulfurization catalyst for sulfur-free diesel production (sulfide nanoparticles of cobalt, nickel, molybdenum, etc. are supported on a porous Al_2O_3), our research was oriented in the latter Type 2 Basic Research targeting commercialization of the catalyst while perhaps even bordering on modification research, owing to the implementing date of the sulfur regulations of diesel (Figure 1).

Regarding hydrodesulfurization catalysts, there exist needs from both a functional (user's) perspective and a manufacturing (maker's) perspective (Figure 2). Catalysts, in order to become industrial, are required to fulfill both sides of these needs. We considered these needs, and limited focus to working from our strength in catalyst preparation, to target development of a catalyst which possesses a hydrodesulfurization activity of about 2 times or higher than that of conventional hydrodesulfurization catalysts (S<50 ppm). We did not take the approach of increasing the number of hydrodesulfurization active sites, but rather conceived a method for catalyst preparation which changed the quality of the active sites, by supporting molybdenum disulfide (MoS_2) particles — in nanoparticles (diameter 4-6 nm), highly crystallized, and with few stacking layers (mono to double) — on porous Al_2O_3, and positioned nickel and cobalt effectively coordinated around the MoS_2 edge, to successfully boost hydrodesulfurization activity. During this time, structural analysis of the impregnating solutions used for catalyst preparation, which contained metal polyanions including Mo and metal ions such as Ni and Co, using extended X-ray absorption fine structure (EXAFS) and other methods, was effective. We found that efforts, at times, tracing back to Type 1 Basic Research were also necessary.

Has been involved in research and development of energy- and environment-related catalysts. Specifically, works on catalysis technology for producing and cleaning of coal liquid, petroleum transportation fuels, vegetable oil transportation fuels, and synthetic transportation fuels, etc. With his joint award-winning partner, Makoto Toba, he debates on a nano level regarding catalysis, and on levels ranging from several hundred cc/d to several tens of thousand bbl/d on transportation fuels, as well as on an global environment level concerning alternative fuels for petroleum.

Yuji Yoshimura
Hydrotreating Catalysis Group
Energy Technology Research Institute

Joint development with a company for Product Realization Research

In the case of trying to develop a prototype catalyst obtained as an outcome of Type 2 Basic Research into a commercial product, joint research with a company is indispensable. We implemented joint research with Catalysts & Chemicals Ind. Co., Ltd., the leading manufacturer of petroleum refining catalysts in Japan, through AIST's joint research system for practical application of patents, and succeeded in commercializing the new hydrodesulfurization catalyst LX-NC1. In our effort to develop technologies in response to various needs (Figure 2), we were able to discover, albeit on a laboratory scale, a method for preparation that allowed control of the various dominating factors within the catalyst preparation process, through nanostructural analysis of the catalysts and the impregnating solutions, etc. used in catalyst preparation. This fact, we believe, was one of the reasons that allowed the technology to be incorporated anew into the already established commercial production technology for hydrodesulfurization catalysts within the company.

The fact that, we were able to build a relationship of trust (a win-win relationship) with our joint research partner and were able to clearly define each roles based upon this trust, was probably the greatest contributing factor leading to this synergy effect.

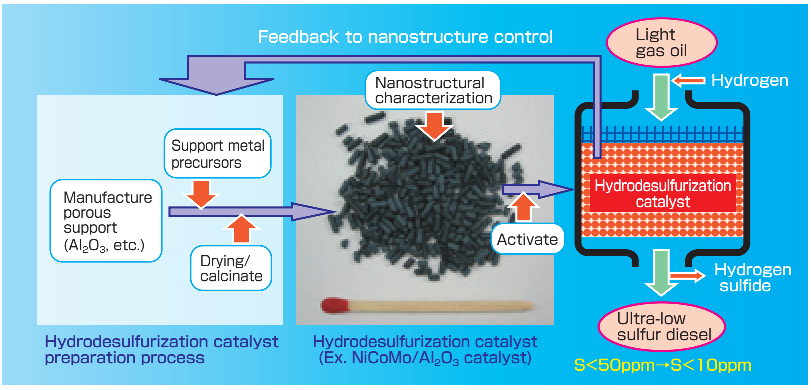

Figure 1 : Design/preparation, structural analysis, and catalyst performance evaluation constitute the trinity technologies in hydrotreating catalysis

Returning the achievements of research to society

If oil refining companies domestic and abroad employ this hydrodesulfurization catalyst for producing sulfur-free diesel, the widespread use of sulfur-free diesel will be accelerated. As a result, it is expected to prompt rapid introduction to the market of automobile technologies such as new exhaust gas treatment technologies with sulfur poisoning issues alleviated or resolved, thereby leading to the spread of environmentally-friendly diesel-powered vehicles.

Meanwhile, there is also a rapidly increasing anticipation for bio-diesel fuels of plant origin, arising from the needs for a diversified and stable supply of transportation fuel resources due to the rise in oil prices, as well as needs in response to the Kyoto Protocol. As petroleum refining catalysis technology is fully applicable to the producing and in securing the quality (non-sulfur properties) of these fuels, its development is anticipated. In the future, we plan to continue on with our research responding in advance to potential needs, while simultaneously tracing back at times to basic research.

Function/utilization of hydrodesulfurization catalyst (S<10 ppm) :

- ◆ Activity of about 2 times or higher compared to conventional catalyst (S < 50 ppm) (life span of 2 years or longer, equivalent to conventional catalyst), as well as low hydrogen consumption
- ◆ Applicability to existing refining facilities by a simple exchange of catalyst
- ◆ Similarity in handling and safety, etc. to conventional catalysts, and others

Manufacture of hydrodesulfurization catalyst (S<10 ppm) :

- ◆ Availability of cheap catalyst raw materials, and a preparation technology that can be scaled up (from beaker to ton level)
- ◆ A preparation technology which allows control of dominating factors in the catalyst preparation process
- ◆ A catalyst preparation technology which enables utilization of the commercial production line of the hydrodesulfurization catalyst currently in use, and others

Figure 2 : Demands from functional and manufacturing perspectives (typical examples)

Our joint research experience in Type 2 Basic Research

I have given an account of our endeavors up to present aimed at commercializing petroleum refining catalysts. In Type 2 Basic Research, apparently, the somewhat cloudy but important factors, such as grasping the needs accurately, brushing up your "specialty" technology and obtaining external assessment, as well as encountering a partner with whom you are eventually likely to implement joint research, have a large impact on the direction (scenario) and sustainability of your research. I hope I serve as a useful reference, in particular, to young researchers. Finally, research on hydrodesulfurization catalysts had been ongoing for over 40 years at the former Government Chemical Industrial Research Institute, Tokyo, former National Chemical Laboratory for Industry, and former National Institute of Materials and Chemical Research. The success of our research is largely attributable to the achievements of many, including our predecessors and the members of the former Nishijima Laboratory (Professor Akio Nishijima, presently teaching at Waseda University), thus I would like to express my sincere appreciation.

Full Research Aimed at Redefining the Kilogram

The Role of Fundamental Physical Constants in Metrology

Metrology and Full Research

Full Research, which consists of Type 1 Basic Research, Type 2 Basic Research and Product Realization Research, may be viewed as being created through a “fusion” of differing fields of technology. And metrology, which intrinsically consists of an aggregation of differing fields such as electromagnetics, dynamics, thermophysics, and chemistry, possesses high potential for spawning new Full Research.

AIST, in our efforts to support the diverse measurement technologies required in every aspect of society, boasts a long history of developing highly-reliable measurement technologies (since the time of our forerunner, the National Research Laboratory of Metrology) and supplying the measurement standards to society.

Redefining units

Now we are seeing increased activity to redefine the base units in the International System of Units (SI) using universal fundamental physical constants. I would like to discuss the true nature of Full Research, using such activities to review the fundamentals of units. History of the meter and kilogram are shown in Table 1 as typical examples. Originally, efforts to scientifically determine the units of physical values trace back to the period of the French Revolution. At the time, they were looking for a universal unit that was independent of, say, a length of a king’s arm. Later, owing to progress in science and technology, the meter prototype was deemed unnecessary, and presently, by defining *c*, the velocity of light in a vacuum, the unit of length is realized by measurement of optical frequency. However, of the SI units, the kilogram remained as the only SI base unit to depend upon an artificial prototype. The mass of the world’s only international prototype of the kilogram stored at the International Bureau of Weights and Measures (BIPM) in Paris is believed to have changed by roughly 5×10^{-8} within the past 100 years due to effects of surface contamination. Even using today’s state-of-the-art technology, there has not yet been established another method for realizing mass with such high repeatability. Recently, however, two different methods are finally being proposed. The first is the X-ray crystal density method which determines mass from the Avogadro constant N_A, based upon the mass of atoms such as carbon ^{12}C. The other is the watt balance method, which determines mass from measurements using electrical standards upon definition of the Planck constant, *h*.

Table 1 : History of metrology and SI units

	Meter	Kilogram
1789	French Revolution (Need for a universal unit)	
1889	International prototype	International prototype ↓ Present
1960	Krypton wavelength	
1983	Definition of velocity of light *c* (Optical frequency measurement)	

Table 2 : Type 1 Basic Research that contributed to redefinition of the kilogram

1960s	Development of X-ray interferometer
1970s	Josephson effect
1980s	Quantum hall effect
1990s	Laser cooling
2000s	Optical frequency comb

Although these two principles of measurement are completely different, the Type 1 Basic Research which made these measurements possible originated from the development of X-ray interferometry technology in the 1960s (Table 2). Owing to this development, high-accuracy measurement of the lattice constant of crystals with reference to the wavelength of light was made possible, making way for measurement of the Avogadro constant by the X-ray crystal density method. Later, the discoveries of the Josephson effect and the quantum hall effect were extremely significant in terms of measurement standards, as they brought about the dramatic improvement in repeatability of voltage and electrical resistance. In recent years, progress is being made in research and development to extend the frequencies of the microwave range made by the cesium atomic clock to the optical frequency range, to enable measurements in the terahertz range. Thus, the accuracy of length measurement has been improved dramatically. Each of these research outcomes represents a major discovery in physics, thus we can say that the foundation of measurement standards lies in Type 1 Basic Research.

Entered the National Research Laboratory of Metrology in 1984, and developed the scanning laser interferometer, etc. used to measure the Avogadro constant. For two years since 1994, he was involved in measurement of the Planck constant by the watt balance method, as a guest scientist at the National Institute of Standards and Technology (NIST) in the U.S.A. In 2003, he succeeded in measuring the Avogadro constant with the highest accuracy, thereby contributing to the revision of the fundamental physical constants by the Committee on Data for Science and Technology (CODATA).

Kenichi Fujii

Fluid Properties Section
Material Properties and Metrological Statistics Division
Metrology Institute of Japan

Table 3 : Type 2 Basic Research that contributed to redefinition of the kilogram

1970s	Measurement of N_A by X-ray crystal density method
1980s	Measurement of h by watt balance method Silicon sphere polishing technology
1990s	Measurement of gas constant R by acoustic method Boltzmann constant $k = R / N_A$

Table 4 : Products of Full Research

Database of fundamental physical constants		
	Approx. 300, including N_A, h, e, R, k, m_e, m_p, G, and α	
Confirmation of validity of theory		
	Feedback to Type 1 Basic Research	
Simultaneous revision of SI base units (around 2011)		
	Kilogram	N_A or h
	Ampere	e
	Kelvin	k
	Mole	N_A

Type 2 Basic Research aimed at redefining the standard for mass

Next, let us consider the Type 2 Basic Research that directly contributed to redefinition of the kilogram (Table 3). In the 1970s, National Institute of Standards and Technology (NIST, or NBS at the time) in the U.S.A. became the first to succeed in measuring the Avogadro constant using the X-ray crystal density method. This measurement technology was passed on to AIST's National Metrology Institute of Japan (NMIJ, or National Research Laboratory of Metrology at the time) and Physikalisch-Technische Bundesanstalt (PTB) of Germany, where precision was improved further. The polishing technology for silicon spheres developed in the 1980s was also an important element in Type 2 Basic Research, as it enabled the dramatic improvement in measurement accuracy of crystal density (see Photo). Mass analyses of silicon isotopes are also important elementary technologies in this area. Recently, an international project undertaken by eight research organizations including AIST is in progress to further increase accuracy of the Avogadro constant, by isotopically enriching ^{28}Si to up to 99.99%. The accurate measurement of the Avogadro constant is achieved upon a fusion of many research fields and measurement technologies, such as X-ray engineering, crystal engineering, optics, mass standards, nanometer/picometer measurements, density standards, chemical analysis, temperature standards and surface measurement. Without any one of these fields, such accuracy enhancements cannot be achieved.

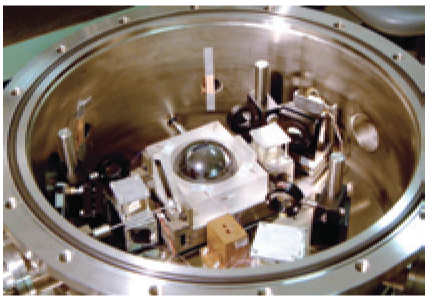

Photo :
Laser interferometer which measures the volume of a crystal from nanometer measurement of the diameter of a silicon sphere of 1 kg mass. The number of silicon atoms existing within the sphere can be determined by combining this information with the data of the lattice constant measured by X-ray interferometry.

The measurement of the Planck constant by the watt balance method is also made possible by a fusion of dynamics, electrical standards, optics, electromagnetics, etc. The electrical power (product of voltage and current) is determined from measurements of dynamic values (force and velocity), and, using the Josephson effect and quantum hall effect, h is determined. The research outcome which set the stage for this technology was obtained at National Physical Laboratory (NPL) in the U.K. in the 1980s, while recently, high-accuracy measurements of the Planck constant are being performed at NIST.

In this way, this Type 2 Basic Research is characteristic in that it is achieved only upon the fusion of theories and technologies of differing fields, and thus requires a relatively long time span from conception and development to reaching final outcome. Meanwhile, it is similar to other Full Researches in that it must also take on the Valley of Death, although research has successfully been continued with the cooperation of international metrology institutes.

The product obtained in these researches is information in the form of a "database" — covering roughly 300 fundamental physical constants obtained experimentally and theoretically, including the Avogadro constant N_A, the Planck constant h, and elementary charge e — possessing an extremely high propagational effect. In addition, by investigating whether or not the fundamental physical constants obtained from differing principles such as the X-ray crystal density method and the watt balance method are consistent within the range of the uncertainty of the experiment, we are able to verify the exactness of the Josephson effect and the quantum hall effect. In other words, we are able to confirm the degree of accuracy of our current physics system (outcomes of Type 1 Basic Research) through Type 2 Basic Research.

Measurement standard products generated by Full Research

Now, the current new international trend is to define the standards of base units using these fundamental physical constants (see Table 4). By using fundamental physical constants as benchmarks, we can build "units directly linked to universality of the natural world." It will be possible to realize the kilogram, not only at the International Bureau of Weights and Measures (BIPM) but at any research institute in the world, and our ideal from the time of the French Revolution will finally bear fruit. Then, the new definition will likely foster new measurement and experimental technologies. The development of a measurement standard across such a long time period is also an example of Full Research that is particularly and highly characteristic in that a fusion of differing fields becomes the soil to spawn new outcomes of research.

Full Research in Technical Developments of Regenerative Medicine

Establishment and Clinical Application of a Human Cell Processing Process

Success and a new viewpoint gained from misery

The Full Research that we conduct is not "research for the sake of research," but rather research to create 'products' that may be returned to society, thus it is "research that will contribute to technologies for resolving actual problems."

Regenerative medicine is the medicine for regenerating tissue/organs which have lost their function, or have become dysfunctional. Although it is made possible through various means, the first step is to construct the target tissue/organ. For example, in bone diseases, construction of the bone tissue is vital. In order to ensure construction, the bone tissue should be induced in a location where there is no existing bone tissue. Proteins such as bone-inducing factors (BMP: bone morphogenetic protein) induce the new formation of bone tissue in muscular or subcutaneous regions, thus, the research of these may be regarded as the research model for bone tissue regeneration itself. In the latter half of the 1980s, I took up a post at the laboratory of Dr. Arnold I. Caplan at the Case Western Reserve University, U.S.A., to work on purification of this protein (BMP). At the time, BMP had not been purified, and many researchers even doubted its existence. Nonetheless, I spent day and night trying to purify this protein. This task proved extremely difficult, however, and a year flew by without any data. Eventually, I gave up on this research, and conceived the idea of using cells instead of protein to induce bone formation. I considered the use of various cells, but as it was already known that the precursor cell of the osteoblast, which is responsible for bone formation, exists within bone marrow, I decided to use marrow cells. Only, I did not succeed using the cells alone, but found that using ceramic as a substrate for the cells allowed new bone formation to be induced extremely efficiently*1.

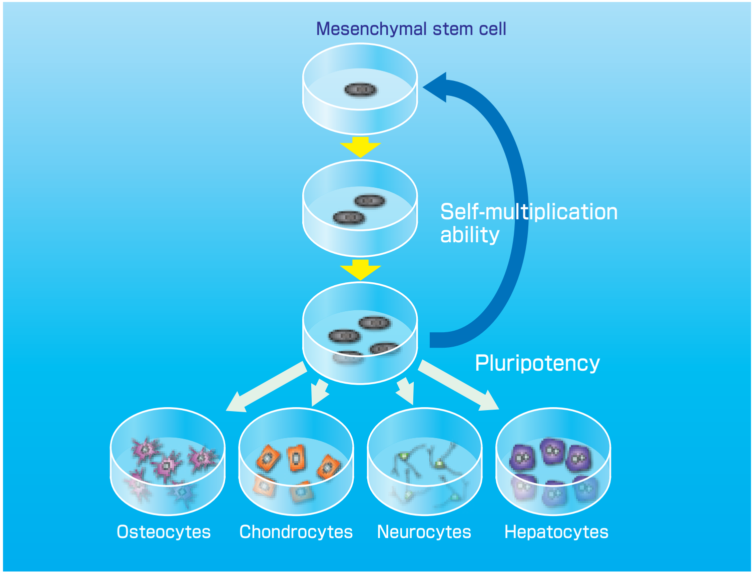

Figure 1. Type 1 Basic Research: Research on proliferation/differentiation of human bone marrow mesenchymal stem cells

I learned from experience that research, at times, requires a change in methodology. In fact, I changed my strategy from research on BMP to that using cells, but now feel proud that this shift is what allowed me to build the platform for the bone/joint regenerative technology that is implemented today*2.

This experience bestowed upon me a new attitude towards research. Sometimes, no matter how hard you try, you may not achieve the results you hoped for. However, such is an opportunity that has the potential to perhaps spawn a new methodology. I would like young researchers to be aware of this fact. Any result (even a negative one) should be accepted proactively, and at times, it is necessary to modify your original strategy (don't always obey boss's orders!) and keep your mind open to ideas from a different viewpoint.

A necessary but low-key research

In this way, I developed a technique for constructing (regenerating) bone using cells and ceramic. However, this was a study using animals, and to put it to practical use (clinical application)

Graduated from Nara Medical University in 1976, moved on to graduate school of the same, and worked as an orthopedic surgeon at several hospitals, later serving for two years as a Research Associate at the Case Western Reserve University in the U.S.A. Although his original research (protein purification) was unfruitful, he changed his direction of research to cell differentiation, and after returning to Japan, has been working on developing treatment technologies using cells. He joined AIST in 2001.

Hajime Ohgushi
Tissue Engineering Research Group
Research Institute for Cell Engineering

it needed to be confirmed through proliferation of human cells. A method called culture is required for this proliferation. Culture aimed at clinical application requires an ultra-clean environment. This means the cells are processed (cultured) in an environment of cleanliness equivalent to, or higher than, that of a semiconductor plant. In order to achieve such an environment, we require a special facility called a cell processing center (CPC).

About a year prior to the foundation of AIST as an independent administrative institution, the Millennium Project was kicked off by Prime Minister Obuchi at the time. The Tissue Engineering Center (headed by Tetsuya Tateishi) was launched in the AIST Kansai Center as part of this Project. The CPC was to be constructed in this research center, thus I, together with my staff, implemented all, from the design to installation of the equipment and facilities, of the CPC. Although today CPCs are built in various places, at the time, there were no operating ones in Japan, and the facilities overseas, although used for skin regeneration and such, did not match our circumstances. Therefore, we spent great effort in groping our way around to starting up the CPC, so as to establish a culture process for human cells that would guarantee safety and effectiveness. Quite simply, this was a Type 2 Basic Research, with the objective of creating a bone regeneration product (tissue-engineered bone) based upon the bone regenerative technology (Type 1 Basic Research) that I achieved. Unlike Type 1 Basic Research, such a process is not published in the form of an article and constitutes very low-key research. Nonetheless, tissue-engineered bone can be made only through this culture process. And luckily, thanks to the efforts of many staff members, the CPC was completed, and the cultured bone prepared here is used in transplantation treatment in university hospitals, etc.

Starting a new basic research

In this way, Type 2 Basic Research is an essential research which leads to commercialization. However, we are also conducting Type 1 Basic Research alongside our Type 2 Basic Research. For example, we have discovered that cells of nerves and liver can be obtained from human bone marrow cells (Figure 1). We have also found that new blood vessels are formed within the body upon transplant of bone marrow cells. Given these facts, I have advanced the outcomes of such Type 1 Basic Research to develop a technology for treating heart failure patients using human cells, jointly with Noritoshi Nagatani, Department Head of the National Cardiovascular Center. In eight cases already, cells have been proliferated from the bone marrow cells of the patient, after which they were transported back to the National Cardiovascular Center for administration into the heart. In this way, the existence of a platform of Type 2 Basic Research has made it possible for a new Type 1 Basic Research to be put promptly to practical use (Figure 2).

As I have described above, research that is continuous from Type 1 through Type 2 is necessary in order to create products that are returnable to society. Owing to such a background, a basic research using cells that was conducted for ten-odd years was successfully put to practical application in a relatively short period, of only a few years of research (Type 2 Basic Research). However, this practical application has only just begun. In the future, we need a system which allows such medical treatments to be received widely and readily in society. As establishing a new social system by researchers alone would be difficult, we need to work in cooperation with government officials. I believe these efforts, such as building social platforms, should also be included in the realm of Type 2 Basic Research. The technical developments in regenerative medicine on which we are working still stand right in the middle of Type 2 Basic Research.

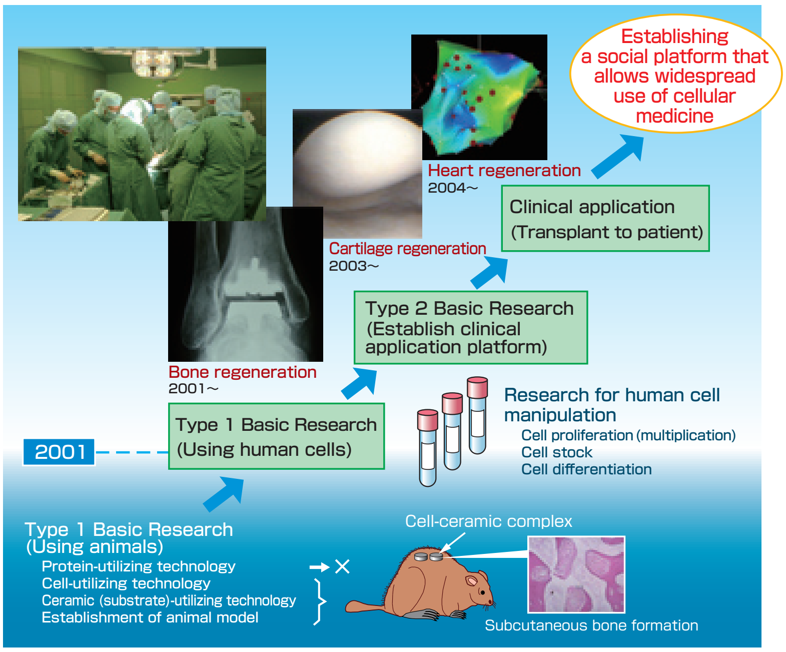

Figure 2 : Example of Full Research: Technical development of regenerative medicine for bone/joint and heart diseases
The facilities of the Cell Processing Center are indispensable to these researches.

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Full Research of the Super-fine Inkjet

A Nanoscale Function-Adding Tool Aimed at Industrialization

Triggered by a personal need

What is nanotechnology? Although responses may vary per individual, my bottom line is that it is the technology for the ultimate utilization of materials. New nanomaterials are being developed every day. In order to extract the functionality of these to the utmost and allow them to demonstrate their individual characteristics 100%, we need a technology to place the required quantity of nanomaterial in the required position. This was my conclusion.

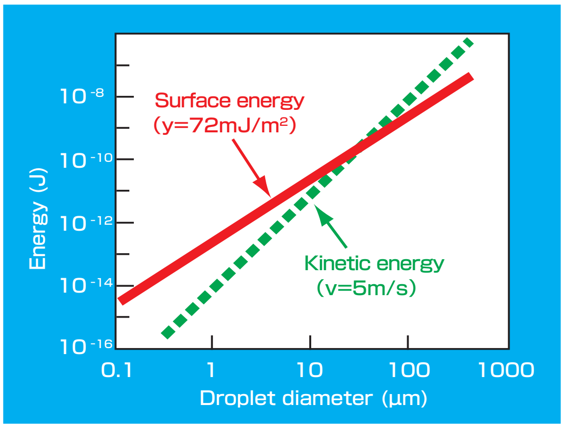

Figure 1 : Relationship between kinetic energy and surface energy of droplet

The silicon technology which sustains present-day electronics is a technical system of high versatility, with exposure and etching technologies at its core. Meanwhile, for the patterning of nanomaterials, these conventional technologies are not necessarily the best answer. The positioning of nanomaterials is synonymous with the positioning of functionality. Functionality is imparted not through conventional processing such as cutting, carving or shaving, but through new methods such as painting, adding on, or application of materials.

To do this, a technology that could arrange microscopic quantities with precision was required. Since little or no such technology existed at the time, I was forced to make it myself. This was my start. In other words, it was a completely personal need-oriented research.

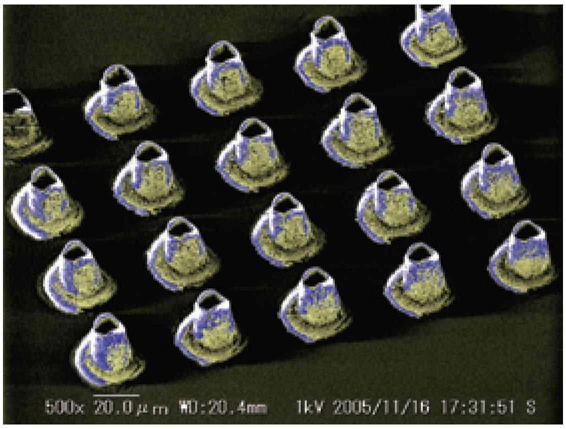

Figure 2 : Three-dimensional structure created by super-fine inkjet

A Type 1 Basic Research-like element

Difficulties with the super-fine droplet

At first, I had the simple notion that if we used a small nozzle and applied a large pressure, the fluid would shoot out. However, it was actually not that simple. Figure 1 shows the relationship between kinetic energy of a water droplet and surface energy. The common velocity of 5 m/s for an inkjet droplet is used for the kinetic energy. In order for the droplet to shoot out, it must overcome surface tension. Surface energy is proportional to the square of the droplet diameter and kinetic energy is proportional to the cube of the diameter. With microscopic droplets, the surface energy becomes larger than kinetic energy. Thus it becomes difficult to impart sufficient kinetic energy to the discharge fluid or the droplets shooting out. As a result of various efforts of trial and error, I was able to achieve the prototype of the current super-fine inkjet. My research during this time was rather closer to Type 1 Basic Research than application research.

Joined Electrotechnical Laboratory in 1994, and Nanotechnology Research Institute of AIST in 2001. Has specialized in magnetic properties of materials, conductive polymers and organic films, and now works in development of direct patterning technology of various nanomaterials. His super-fine inkjet technology has been made a venture business at AIST. Presently he is involved in the topic of reforming production technologies through nanotechnology.

Kazuhiro Murata
Molecular Nanophysics Group
Nanotechnology Research Institute

Figure 3 : Super-fine inkjet equipment

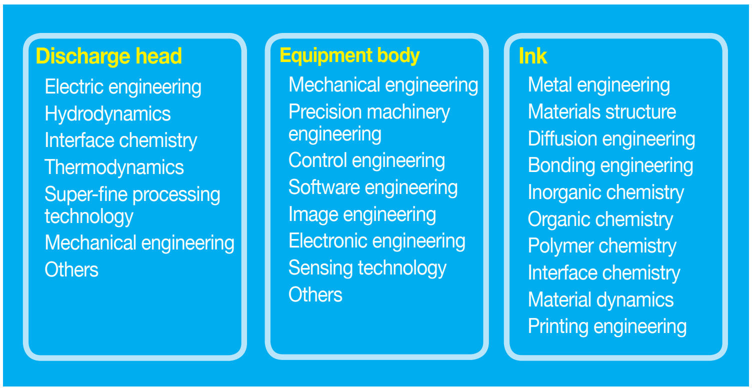

Figure 4 : Fields required for inkjet technology

Moving on to Type 2 Basic Research Efforts aimed at practical application

I presented the achievements of my basic research described above at the International Nanotechnology Exhibition & Conference (nanotech 2002). I received a significant response at the time, including many requests to make the device commercially available. However, the actual device itself was something a researcher developed as his own research tool and did not necessarily match general needs. Therefore, I redefined my goals to incorporate the needs of society. Regarding this endeavor, we are still in the middle of technical development, thus we may not yet be considered completely clear of the Valley of Death.

Research during this period consisted of the task of redefining my research goals by incorporating the needs of society — rather than the needs and seeds of myself, the researcher, accumulating the usable technology, and also adding or developing any missing areas. Although the work was fragmentary, I made progress by combining various technical elements. I received the help of countless individuals inside and outside of AIST as I encountered many aspects which I could not resolve on my own.

During the process of research

There were many unexpected surprises during the course of my research. One was the high drying characteristics of the microscopic droplet. Normally, fluid that lands on a substrate changes shape so as to minimize surface energy. The effect of surface tension becomes more prominent as the droplet becomes more minute, thus patterning exactly as planned is not easy. Conventionally, the problem of how to prevent the occurrence knobby distortions called bulges was important in the development of inkjet technology, and constituted the know-how owned by manufacturers. In case of my inkjet, the droplet size is so small that it dries immediately upon landing. The volume of fluid is limited, and thus bulges do not easily form. Further, actively exploiting this drying characteristic, the three-dimensional forms such as shown in Figure 2 can be built by the inkjet. Formerly, in order to create such microscopic three-dimensional forms, a vacuum process or expensive equipment was necessary, but by using the super-fine inkjet, a three-dimensional structure can even be added on afterwards, in the atmosphere at room temperature, on a target spot on the substrate. The super-inkjet equipment is so compact that it can be placed on a desk, as shown in Figure 3. This is a unique characteristic not seen in other technologies.

The other surprise for me was that such a hand-made piece of equipment could perform with fair precision. Today's cutting edge equipments for manufacturing industrial products are all large and expensive. The reason is that they need to guarantee accuracy for combining things built using various machines. However, if incorporation of the necessary functions were possible on one processing table, it would be possible to make the equipment simpler.

Presently, based upon this new viewpoint obtained during the course of research, I am considering starting an endeavor going back once again to Type 1 Basic Research. By adding the essentials I learned from Type 2 Basic Research, I hope to make my second round of Type 1 Basic Research something different.

Effects upon future society

The inkjet technology is a technology for placing the required quantity of material in the required position. Not limited to inkjets, I believe that the method of making things will be reassessed in the future, from cutting, carving and shaving, to painting, adding on and applying. This applies to printable electronics, rapid prototypes, and may even include the technology referred to as near net shape. Instead of using materials loosely as bulk, we can draw out their functionality to the maximum. Expensive equipment and clean rooms may thus become unnecessary, as we conduct resource- and energy-saving production low in environmental load using equipment of a size only several times that of the product.

In the far future, we may see an SF-like world, in which an industrial plant is able to produce various objects based upon data, so hardware design data fly about the Internet and software and hardware are evolved simultaneously.

Research Hot Line

UPDATE FROM THE CUTTING EDGE

Jul.-Sep. 2006

The abstracts of the recent research information appearing in the Vol.6 No.7–No.9 of "AIST TODAY" are introduced and classified by research area. For inquiry about the full article, please contact the author directly.

Life Science & Technology

Primary Process in the Growth of Quantum Dot Nano-crystals

We have experimentally analyzed a crystal nucleation process and a subsequent crystal growth process in the colloidal synthesis of CdSe quantum dots. Furthermore, theoretical analysis clarifies relationships among crystal size, crystal structure, and optical absorption spectra in the primary process of the crystal growth. The techniques will contribute to the design and creation of nano-scale electronic materials including quantum dots.

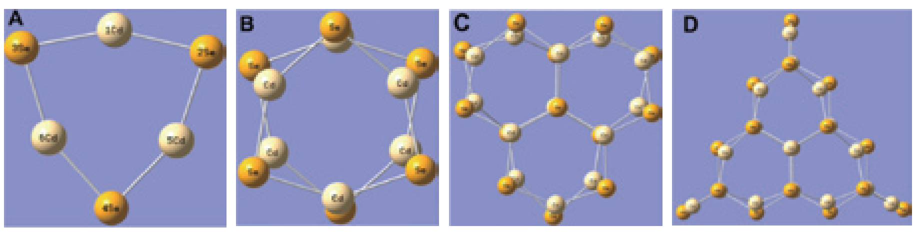

Figure : Crystal structures of CdSe predicted by theoretical calculations and found to be physically reasonable. (A) $(CdSe)_3$, (B) $(CdSe)_6$, (C) $(CdSe)_{13}$, and (D) $(CdSe)_{16}$.

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AIST TODAY Vol.6, No.8 (2006) p.20-21

Development of Global Earth Observation Grid (GEO Grid) System

In accordance with "Earth Observation Summit/GEOSS 10-Year Implementation Plan", we are developing “GEO Grid” system. The system archives a large scale of earth observing satellite data, unifys disparate earth observation databases and Geographic Information Systems and provides secure service to users using the Grid technology.

Figure : A geological map and a satellite image

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AIST TODAY Vol.6, No.7 (2006) p.20-21

Creation of a New Type of Highly Luminescent Glass Phosphors Dispersing Cd-Free Nanoparticles

Light-emitting semiconductor nanoparticles without harmful cadmium have been prepared by an aqueous solution method. They are composed of Te-added ZnSe covered with ZnS, and show high emission efficiency in a blue-color region. These nanoparticles were successfully incorporated in a glass matrix by a sol-gel method and exhibit stable emission. A novel method based on self-organization effect was also developed for dispersing nanoparticles at high concentrations in glass thin films. The brightness of the glass thin films was estimated to be approximately 30 times higher than that of the conventional phosphor having the same sample thickness.

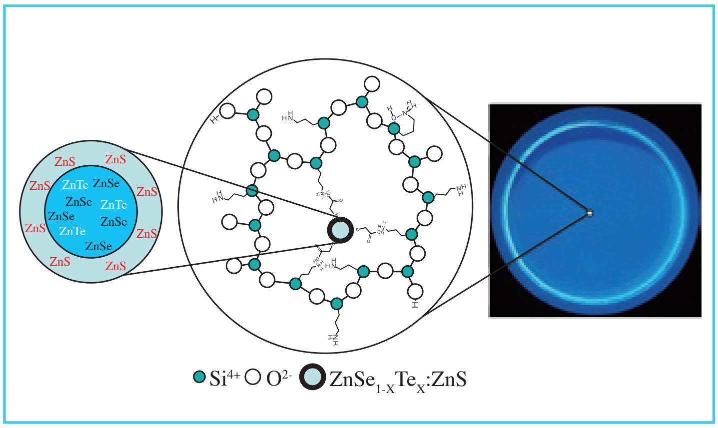

Figure : Left: Illustration of nanoparticles prepared by the addition of Te (inside) and S (outside) elements. Center: Illustration of nanoparticles dispersed in glass matrix. Right: Blue luminescent image of the prepared glass irradiated with ultraviolet light.

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AIST TODAY Vol.6, No.8 (2006) p.22-23

Real-Time Observation of Nano-Scale Cutting Process

Acceleration of technical development for practical use such as fabrication and repair of nano-molds

Nano-mechanical fabrication technology using atomic force microscopes (AFM) has been developed for practical applications, however, the fabrication process has not been understood clearly yet, and thus optimal conditions for fabrication have been determined by trial and error. We have developed a nano-mechanical fabrication system using AFM which works in a scanning electron microscope (SEM), and thereby succeeded in the real-time observation of the nano-scale cutting process. This technique is expected to be a powerful tool for clarifying the removal mechanism of materials in cutting process, and for optimizing fabrication conditions, and to accelerate technological development for practical applications such as the fabrication and repair of nano-molds.

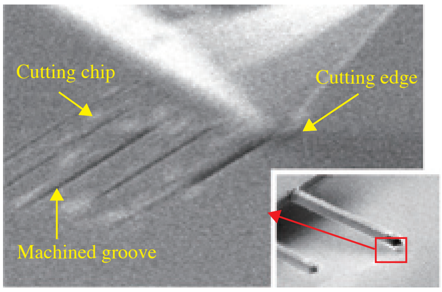

Figure 1: The SEM image of nano-cutting process (captured from movie)

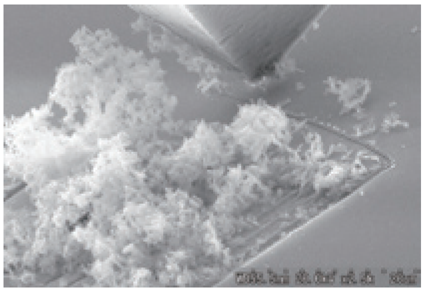

Figure 2: Cutting edge and chips after nano-cutting

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AIST TODAY Vol.6, No.7 (2006) p.12-15

Field-Effect Transistor (FET) of High-speed Operation Using a Liquid Crystal Semiconductor (LCS)

Development of a self-assembling organic semiconductor and a device fabrication

A novel liquid crystal semiconductor (LCS) has been developed under the collaboration with Kanto Chemicals Co. Ltd. The LCS was applied to “top-contact/bottom-gate” type field-effect transistor (FET) to investigate operation and on/off ratio of the FET with Osaka University. The LCS, a long-chain substituted dithienylnaphthalene, shows the fast hole mobility of 0.1 cm^2 V^{-1}s^{-1} in the plastic mesophase. Our FET shows the hole mobility of 0.14 cm^{2}V^{-1}s^{-1} at room temperature, which is in the top class mobility of FETs made of LCS. The LCS characterized both by good solubility into various organic solvents and by “defect-free” property for electronic charge transport. The LCS is expected to become a novel organic semiconductor for high-performance devices.

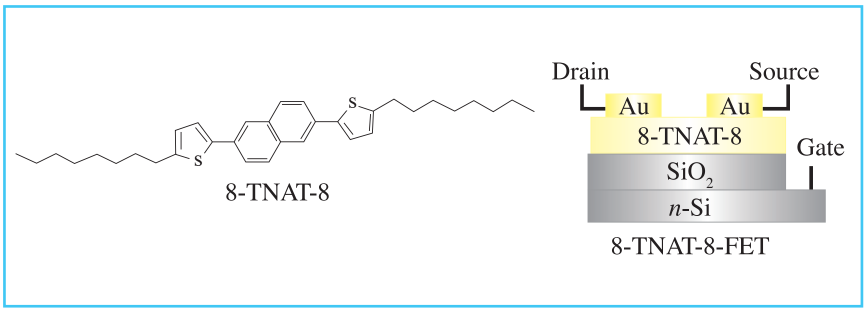

Figure : Chemical structure of the novel mesophase semiconductor 8-TNAT-8 and the FET device geometry

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AIST TODAY Vol.6, No.8 (2006) p.24-25

Control of Light by Magnetic Field

Optical magnetoelectric effect in a patterned polar ferrimagnet

A simple method to dramatically enhance the optical magnetoelectric (ME) effect is proposed and demonstrated for a polar ferrimagnet $GaFeO_3$. We patterned a simple grating with a period of 4 µm on a surface of $GaFeO_3$ crystal and used the diffracted light as a probe. The optical ME modulation signal for the Bragg spot of the order n=1 reaches 1–2% of the bare diffracted light intensity in a magnetic field of 500 Oe, which is amplified by more than 3 orders of magnitude compared to that for the reflection of bulk $GaFeO_3$.

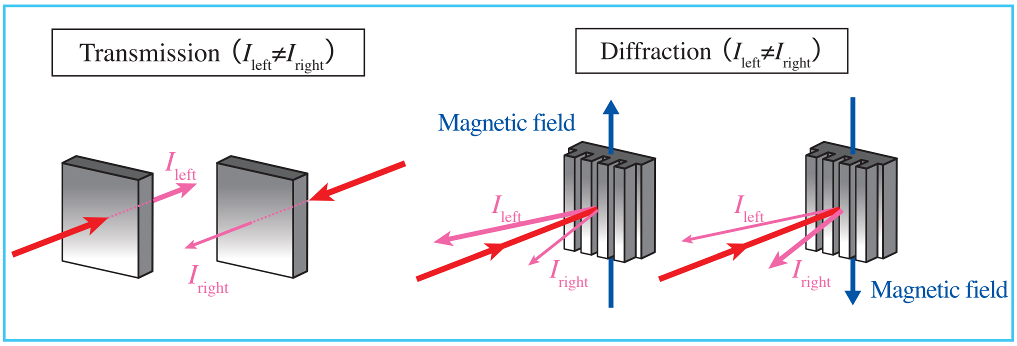

Figure : Optical ME effect in transmission (left) and diffraction (right) geometries.

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AIST TODAY Vol.6, No.8 (2006) p.26-27

Spinning of High-Strength Fiber Using Single-Walled Carbon Nanotubes

Establishing a technology to produce high-quality single-walled carbon nanotubes for industrial applications without aftertreatments

We have developed a novel synthesis method for single-walled carbon nanotubes(SWNTs) which are expected to be the core material for nanotechnologies. This method modified from the direct injection pyrolytic synthesis method has dramatically achieved high purity and a high degree of graphitization by controlling the reaction conditions accurately. The purity of the nanotubes increased from 50% to 97.5% and the structural defects in the nanotubes were reduced to one tenth of the previous level. Without purification processes, surface treatments or binders, these high quality SWNTs can be used to make high-strength threads (SWNT wire) and SWNT mesh sheets.

Figure : An origami crane made from a non-purified high-quality SWNT sheet (sheet thickness: approximately 9 micrometers)

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AIST TODAY Vol.6, No.9 (2006) p.26-27

Continuous Synthesis of Diesel Fuel from Wood

We have succeeded in a continuous synthesis of diesel fuel from woody biomass in laboratory scale. The new process consists of pressurized gasification, gas cleaning with activated carbon at high temperature, and Fischer-Tropsch synthesis. As this process does not have gas compression and reheating process, compact and portable plants are expected. The portable plants are economical since the cost for wood collection can be reduced.

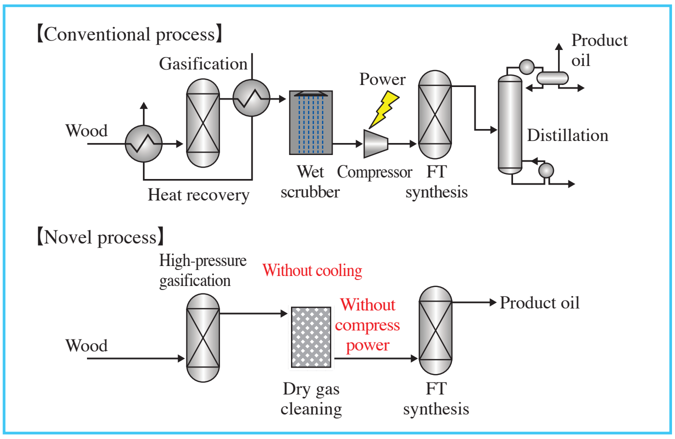

Figure : Conventional process and novel process

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AIST TODAY Vol.6, No.7 (2006) p.18-19

Chemical Recycling of PET to Monomers in High Temperature Water

We have developed a new technique of chemical recycling for polyethylene terephthalate (PET), which can depolymerize PET to terephthatic acid(TPA) and ethylene glycol(EG) using water at high temperature. This method uses no any hazardous material, and is a promising environmentally-friendly chemical recycling process. The process is expected to be an economical compact process in combination with the present collection system for used PET bottles in Japan.

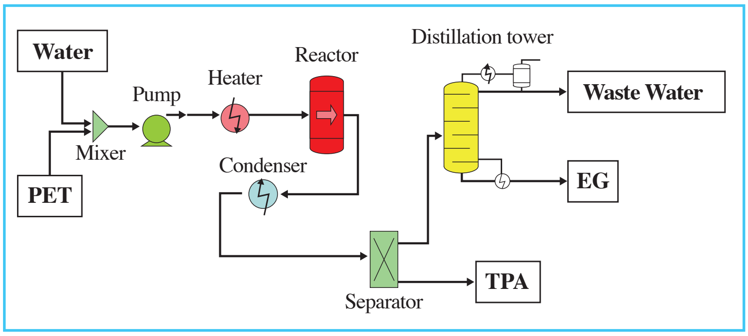

Figure : Flow scheme of chemical recycling for PET in water

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AIST TODAY Vol.6, No.9 (2006) p.28-29

Development of Frequency Transfer and Dissemination Methods Using Optical Fibers

An economical remote calibration technique is being developed using existing synchronous optical fiber communication networks. The measured frequency stability (the Allan deviation) is 1×10^{-12} for an averaging time of one day. The result shows the method is promising for the simple frequency calibration service. An ultra precise two-way optical fiber frequency transfer method is also under development for ultra-stable future atomic clock comparison.

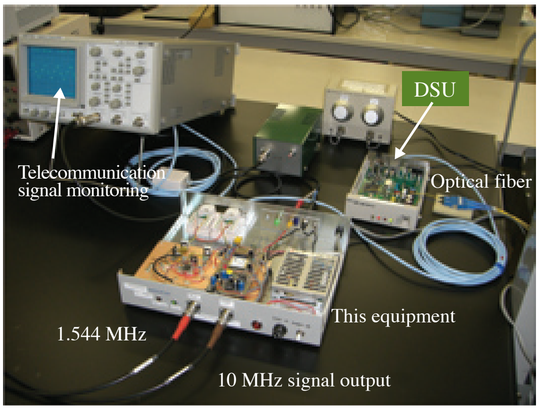

Figure : Prototype of the network lock oscillator for the simple remote calibration service.

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AIST TODAY Vol.6, No.7 (2006)
p.16-17

Time-of-Flight Mass Spectrometry with an Ion Attachment Ionization Technique

We have developed a new mass spectrometry based on a time-of-flight mass spectrometer combined with an ion attachment ionization technique (IA-TOF). An alkali ion attachment scheme can ionize organic molecules without producing fragment ions. The adduct ions distributing over a wide mass range can be investigated with a high mass resolution by time-of-flight mass spectrometers. A tabletop IA-TOF system was developed and applied to typical specimens in a gas-phase as well as in a solid-phase as a performance test. We have succeeded in a fragment-free ionization and a mass analysis with a high mass resolution over a wide mass range. The IA-TOF realizes an accurate and versatile real-time analysis.

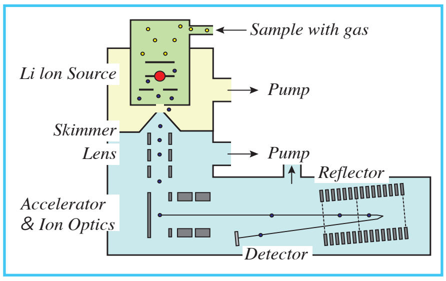

Figure 1: A schematic view of the IA-TOF system.

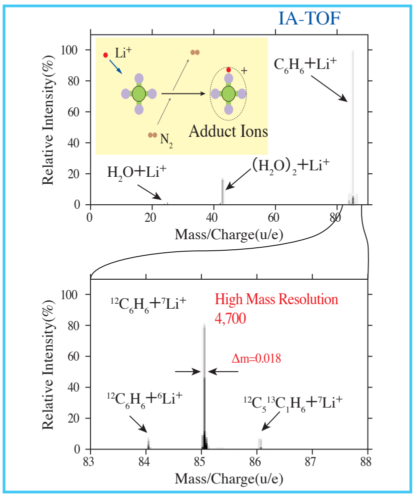

Figure 2: Typical mass spectra of benzene (C_6H_6) diluted by N_2 gas. We have succeeded in a fragment-free ionization and a mass measurement with a high mass resolution.

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AIST TODAY Vol.6, No.8 (2006)
p.28-29

Subsecond Multi-Property Measurement for Thermal Design

We have developed a method for simultaneously measuring four kinds of thermophysical properties of electrically conductive materials at high temperatures. In this method, a plate-shaped sample is rapidly heated up to a high temperature by passing an electrical current pulse through it. After that, a surface of the sample is irradiated by a laser pulse. Thermal conductivity, specific heat, total emissivity, and electrical resistivity are derived from the temperature response of the sample due to the electrical-optical hybrid pulse heating. The major advantage of this method is the minimum exposure of the sample to high temperature, which can minimize the contamination of the sample.

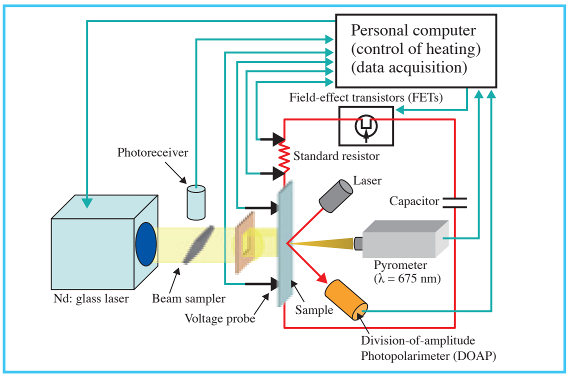

Figure : Schematic diagram of electrical-optical hybrid pulse-heating system for a subsecond multi-property measurement.

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p.30-31

Calibration Facility for Feed Water Flowmeters in Nuclear Power Plants

We are developing ultra-large water flow rate standard up to Reynolds Number of 16 million. The facility can achieve real traceability for feed water flowmeters used at nuclear power plants, and the plants will be able to get uprated by reducing uncertainty of the flowmeters. This technology will contribute to the reduction of CO_2 emission from hydrocarbon-fired power plants.

Figure 1: Overhead flow tank and test channels at ambient temperature.

Figure 2: Hot water circulating channels and working standard flowmeters.

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p.32-33

Director of the Korea Institute of Industrial Technology (KITECH) Visits AIST

On June 2, Key Hyup Kim, director of the Korea Institute of Industrial Technology (KITECH), paid a visit to AIST Tsukuba Center along with two senior researchers of KITECH. After exchanging greetings with Kodama, Director of Tsukuba Center, Igarashi, Research Coordinator and others, Director Kim and his party were given a basic explanation of the facilities by Kodama.

Kim showed great interest in Kodama's explanation, actively asking questions and making comments. Finally Kim also gave a general explanation of KITECH. He explained that KITECH is a national research institute under the administration of the Ministry of Commerce, Industry and Energy of Korea, that its mission is to develop industrial technology for small and medium sized businesses, and that it is about one-fourth the size of AIST, with centers all over South Korea. Kim mentioned that KITECH was considering how to overcome the "nightmare" scenarios that can come up in working. He expressed his desire for cooperation between AIST and KITECH to find solutions to such problems, finally inviting Kodama and Igarashi to visit KITECH.

Kim and his party were then given a tour of the Micro-Electro-Mechanical Systems (MEMS) related research facilities of the Networked MEMS Technology Group and the Nanoimprint Manufacturing Technology Group of the Advanced Manufacturing Research Institute, with which KITEC is going to carry out joint research.

British Journalists Visit AIST Tsukuba Center

Anatole Kaletsky, general editorial writer of *The Times* and five other British journalists visited the Tsukuba Center on June 7.

After receiving explanations of AIST's role in Japan's technology policies and its organization and activities in general by Ono and Yamazaki, Vice presidents of AIST, the journalists were treated to views of the Intelligent Systems Research Institute's humanoid robot as one firsthand example of AIST research. They seemed very interested in Japanese robotics technology and showered questions on Hirukawa, Deputy Director of the Institute, who was explaining the technology.

Notice of Apology and Correction

AIST TODAY wishes to deeply apologize for having failed to prevent errors that occurred in the article FEATURE (The 4th AIST Advisory Board Meeting) in the Spring Issue (No. 20) of AIST TODAY. The amended version is presented below.

Dr. Geoff Garrett

It is necessary to clearly position AIST in the national innovation system and define its respective advantages in regard to other research organizations in order to differentiate AIST, for example its focus on 'full research'. It is important to clarify and state AIST's uniqueness in particular areas and how it can make a special contribution.

Second, I would like to emphasize the importance of networking in the innovation process, and mobility in facilitating effective technology transfer. This personal networking, and good communication skills, is often more important than scientific papers in transmitting our science outcomes: the roles that individuals play through this networking is very important in ensuring effective application of quality research.

Third, and relatedly, it is important to nurture leaders who can stimulate 'porosity', and move across fields of science and technology, for example those of the nano and the bio. As technologies increasingly converge, it is important to nurture a generation of individuals who can readily transcend traditional disciplinary boundaries, collaborate effectively and move beyond the framework of usual organization hierarchy.

Fourth, it is very important that we clearly understand what the measures of success are, that we communicate these and that we cascade these measures throughout the organization. It is also important to reflect on possible unintended consequences: for example, if externally generated funding is a particular measure, this might drive some shorter-term focus than we might have intended. Therefore, we have to be very careful about how we measure performance in the context of the behaviours and outcomes we seek to achieve.

Finally, there are two meanings of the words "look out". The first is "danger, or beware". As this implies, we need to be vigilant around the increasingly competitive environment in which a publicly-funded research organization is operating, locally and internationally. Another meaning implies that our existence is only really justified by others, ie those outside our organization who are the effective recipients of our work and the difference our science makes in helping society advance. We have to watch an over-emphasis on matters internal, with our priority on our external contributions, commercially and socially.

International Organization for Standardization's Technical Committee on Nanotechnology (ISO/TC229) Holds 2nd General Meeting

Nanotechnology is expected to be a fundamental technology playing a major role in the next generation of industry. It has been one year since the International Organization for Standardization's Technical Committee on Nanotechnology was formed with the goal of more smoothly and effectively promoting research and development as well as industrialization of nanotechnology through their standardization. AIST was approved as a body for deliberations on TC229 within Japan by the Japanese Industrial Standards Committee (JISC), the representative member organization for ISO in Japan, and has led the secretariat, administering domestic deliberations with the cooperation of industry. This 2nd General Meeting was held from June 21 to the 23 at AIST Tokyo Waterfront.

With a representative group of 67 members from 16 countries including the U.S.A., U.K., France, Germany, Canada, China, and South Korea, five individuals from three liaison organizations, and more than 30 observers in attendance, Committee Chair Peter Hatto (BSI) called the meeting into session. The opening presentation continued with a welcome address by Satsuki Katayama from Parliamentary Secretary of Economy, Trade and Industry and a report on the status of industry and academia by Michiharu Nakamura, executive vice president of Hitachi, Ltd. Michiharu Nakamura and Seizo Morita, Professor Osaka University, driving home to each of the other countries the expectations on Japan's nanotechnology sector and its great potential. The workgroups formed by the technical committee (WG1: Nomenclature System, WG2: Measurement and Characterization, WG3: Health, Environment and Safety) then engaged in debate over strategy. In particular, in WG2, in which Shingo Ichimura, Director of Research Institute of Instrumentation Frontier (RIIF) acts as International Convener, there was a presentation on the subject of standardization of measurement methods regulating carbon nanotubes and other nanomaterials by Akira Ono Vice President of AIST who is head of the Japanese delegation as well as other representatives of industry, resulting in the acceptance of basic policies and other notable results. While it was also brought up that there have been demands from regulatory authorities for emergency work concerning nanotechnology safety, strategic roadmaps will first need to be worked out among the workgroups. Concrete proposals for international standards will then begin at the 3rd General Meeting held in South Korea at the end of this year.

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