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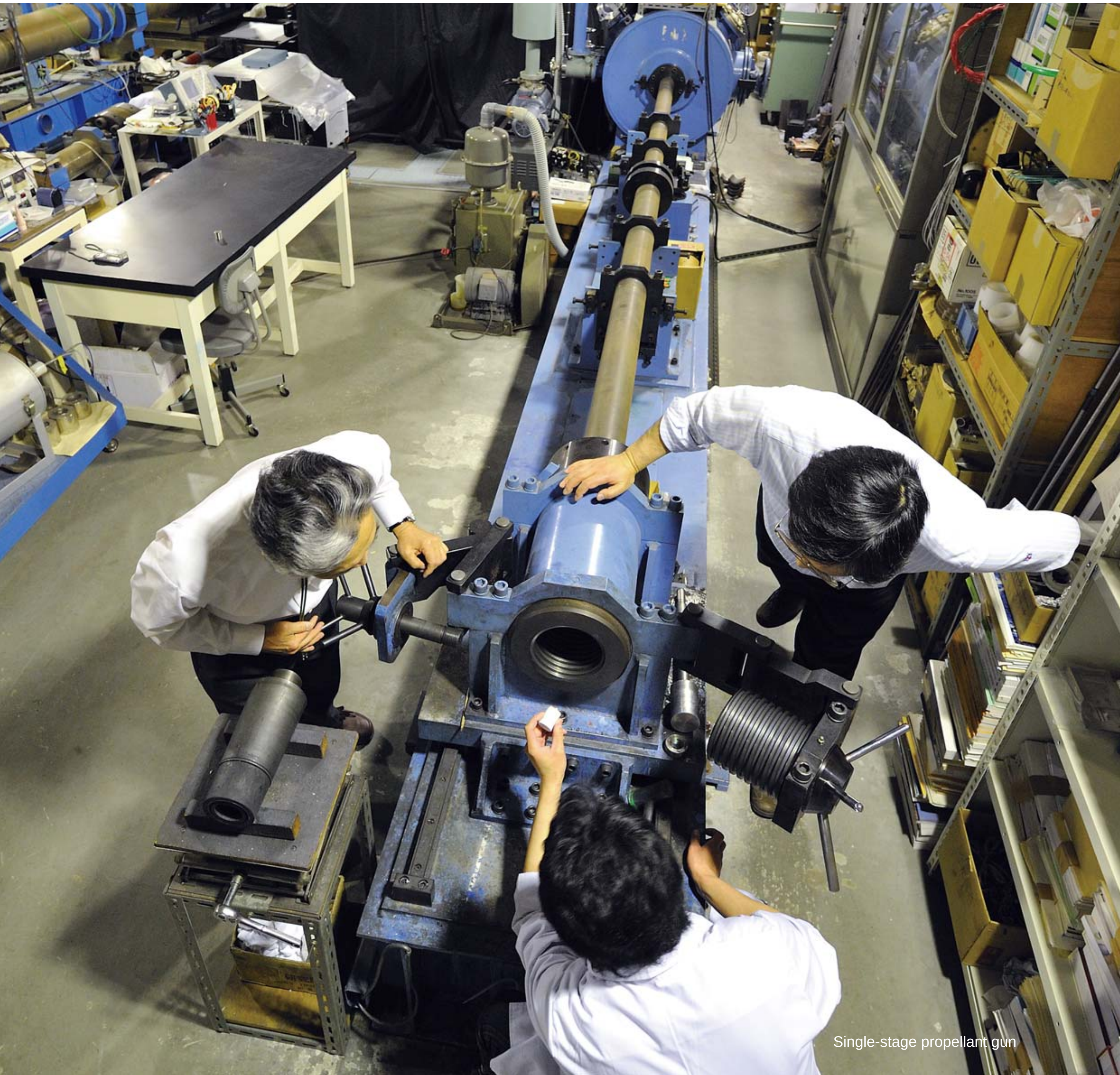
A New Scenario for the Origin of Life

Biomolecules were Formed by the Impact of Meteorites Striking on Early Ocean



Single-stage propellant gun

A New Scenario for the Origin of Life

Biomolecules were Formed by the Impact of Meteorites Striking on Early Ocean

One of the questions left unsolved by 20th century science is the mystery of the origin of life on Earth. Biologists have worked backward starting from the existing living organisms on the planet to make clear their origin. The question of how the complex organic molecules that make up life were generated from simple atoms and molecules was of concern primarily to organic chemists. However, integrated science on an even greater scale is required to investigate the origin of life. What phenomena were occurring on Earth at the time that life was born? The NIMS and Tohoku University research group conducts dynamic research that considers this question as well. The group conducted a series of shock experiments designed to simulate the violent hot chemical reactions that occurred as a result of the impact of a meteorite striking the ocean. Recently the researchers succeeded in confirming the generation of the organic molecules such as amino acids, carboxylic acids and other substances in the laboratory. We spoke with three of the researchers in the group.

The State of the Earth when Life was Born

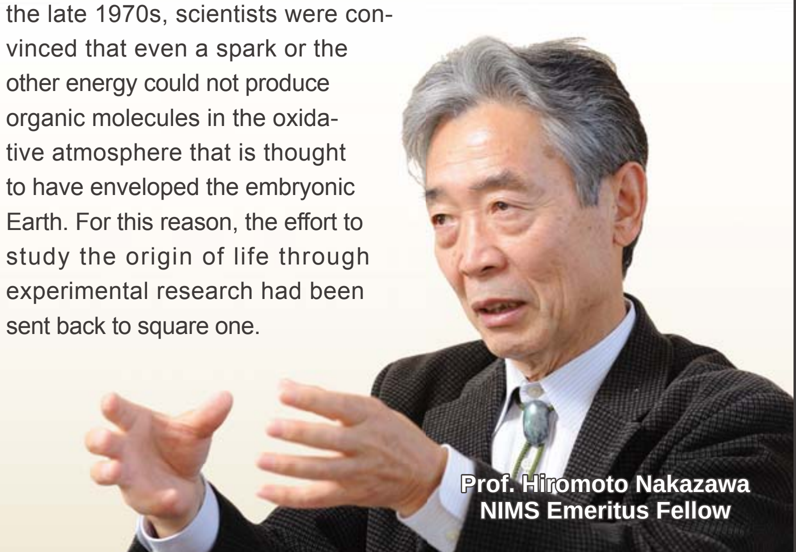
In an effort to study the origin of life, up to now researchers have first hypothesized and then created an artificial environment in the laboratory and studied the products of chemical reactions. The first and best-known example, one that is noted in textbooks, is the experiment by Stanley Miller in 1953. Miller, who at the time was a graduate student at the University of Chicago, recreated the composition of the primeval atmosphere postulated by his superviser, the famous chemist Harold Urey, inside a glass tube system. He then synthesized several types of amino acid by producing a spark discharge in the tube. Sealed inside were ammonia, methane, hydrogen, and water.

More than half a century later, the research group of Prof. Hiromoto Nakazawa, NIMS Emeritus Fellow and the former Professor of Tohoku University, conducted experiments based on a dynamic hypothesis that encompassed the history of the Earth. Since his youth, Nakazawa had been keenly interested in the origin of life. "The origin of life is a scene in the history of the Earth," he says. "Naturally chemistry is also important, but we cannot possibly resolve the question through chemistry alone."

In the first half of the 20th century, many scientists such as Aleksandr Oparin, John Haldane and John Bernal considered the question of the origin of life. Miller's experiment was also part of this trend. And it was some time later that a new understanding was obtained with regard to the planets including the Earth and the universe in general. By analyzing the samples brought back from the moon by the Apollo spacecrafts and studying the craters on the moon and the oldest strata on Earth, scientists came to know a bit about the state of the Earth some 3.8 to 4 billion years ago, when the life was formed soon after. Nakazawa, a geoscientist, believed that surely there must be some connection between the birth of the Earth and the origin of life.

Miller's and subsequent experiments were based on the assumption that the Earth's primeval atmosphere was made up of groups of molecules coupled with hydrogen. However, the knowledge provided by earth and space science research at the end of the 20th century has convincingly overturned this assumption. Immediately after the Earth was formed, it was subjected to bombardment with numerous meteorites and violent collisions with planetesimals, and the entire planet is thought to have consisted of hot magma with a temperature exceeding 1200°C. Accordingly, the atmosphere must have been hot as well, and it is presumed to have consisted of nitrogen as well as carbon dioxide, carbon monoxide, water and other substances formed through coupling with oxygen. Prior to the formation of the continents, the earth was covered by ocean, and numerous meteorites continued to strike the ocean with tremendous energy.

The research group prepared an apparatus and substances with a composition that recreated these conditions. In the late 1970s, scientists were convinced that even a spark or the other energy could not produce organic molecules in the oxidative atmosphere that is thought to have enveloped the embryonic Earth. For this reason, the effort to study the origin of life through experimental research had been sent back to square one.



Prof. Hiromoto Nakazawa
NIMS Emeritus Fellow

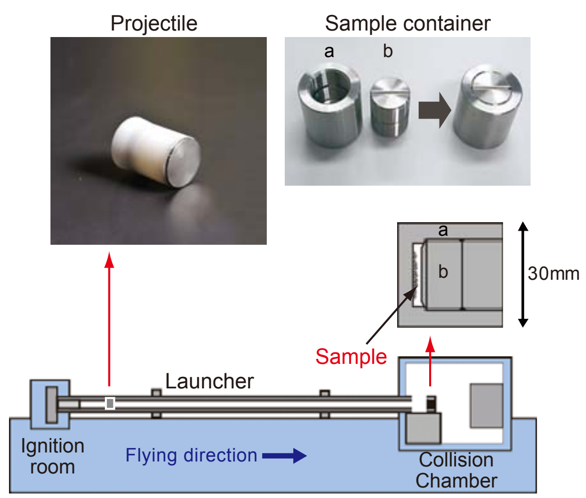
Simulating the Impact of Meteorites Using a Propellant Gun

Prof. Toshimori Sekine
Senior Researcher, NIMS

The research group thought that the impact of meteorites striking the ocean provided the organic molecules needed to form life. The most common components of meteorites are iron-nickel alloy, silicates and solid carbon. What reaction was produced through the impact of meteorites striking the surface of the ocean? Nakazawa thought that the high temperature and high pressure produced by the impact caused a violent reaction in which the water became supercritical and the metals in the water were vaporized to atomic state. Moreover, he thought that large quantities of hydrogen must have been released from the water that was reduced by the iron in the meteorite. "I theorized that the vapor flow that included various elements on Earth was blown up to the stratosphere, and the carbon in the flow reacted with hydrogen, nitrogen, oxygen and so on and produced various organic molecules," says Nakazawa. His book calls this the "'Big Bang' of organic molecules."

In a factory-like single-story building deep inside the NIMS Namiki Campus, the group performed a series of experiments. Inside the test building was a single-stage propellant gun with a 9 meter long launcher. A stainless steel container with the sample was placed at one end. From the other end, gunpowder was used to accelerate a projectile (Stainless steel disk supported by plastic sabot.) to cause a collision. The sample was composed of such materials as: 200 mg of iron, 20 mg of nickel and 30 mg of carbon to stimulate the components of meteorites, 130 mg of water, 15 μmol of nitrogen gas and 1.95 mol of ammonia to simulate the components of the ocean and the atmosphere of the Earth. The container was subjected to a high-speed impact of 1 km/second, producing high pressure and high temperature estimated at 6 billion Pa and 3000 - 5000 K in the interior of the container.

Shock experiment setup



Single-stage propellant gun

One member of the group, Prof. Toshimori Sekine, Senior Researcher of High Pressure Group, Advanced Nano Materials Laboratory, knew how to conduct experiments using a propellant gun. A skilled experimental geoscientist, Sekine had wanted to use this method to recreate the state of molten magma that existed before life was formed, in order to explore the origin of the Earth's stratified structure.

Although the impact lasted for only a fraction of a second, the subsequent recovery of the sample container and detailed investigation of what had been produced involved a great deal of time and effort. Dr. Yoshihiro Furukawa, a young Tohoku University researcher handled this phase. Furukawa studied under Nakazawa in his final year of university studies and developed a love for research in the process, and subsequently he joined the group. For extracting and analyzing minute quantities of a substance, "We used our ingenuity and devised one method after another until we produced results that anyone would acknowledge to be free from error," says Furukawa.

Were any organic molecules produced inside the test container? And if so, what kinds were created? The substances extracted from the test container comprised four types of amine, an amino acid and six types of carboxylic acid. To confirm that no substances other than the sample were mixed in, isotope ^{13}C had been used for all of the carbon in the sample. As 99% of all of the carbon on Earth is ^{12}C, this made it possible to study whether the carbon had originated in the sample or was the result of contamination. "The idea of using ^{13}C came from NIMS diamond study group" says Nakazawa. "And that was the key to the success of the experiment."

Analysis by means of gas chromatography - mass spectrometry (GS-MS) and liquid chromatography - mass spectrometry (LC-MS) and so on revealed extremely minute quantities on the picomole level (one trillionth of a mol).

Shock Experiment at NIMS

The instant of impact of the projectile into the sample container at approximately 1km/sec (high speed camera photography courtesy of NHK).

0.0001sec before impact

0.00004sec before impact

Instant of impact

Destruction of the plastic part

Destruction and recoil of the projectile (plastic part) by impact

The Origin of Life: One Step in the History of the Earth

This experiment, which confirmed the generation of amino acids and carboxylic acids, provides one piece of evidence for the geoscientifically-based scenario for the birth of life postulated by Nakazawa. In addition to the amino acids and carboxylic acids that were detected in this experiment, Nakazawa thinks that sugars and nucleic acid bases were also produced when the meteorites struck the ocean. In this experiment, only limited kinds of molecules were extracted, therefore, it might have produced other organic molecules in addition to those that were detected. "This test was conducted with much lower levels of energy than that thought to have been produced by the meteorite impact. If an impact with higher energy levels could be reproduced, it might be possible to confirm a more diverse array of organic molecules," Furukawa says, displaying his enthusiasm for further research.

The research group has already made a guess as to the type of chemical reaction that occurred inside the test container. Confirming whether this assumption is correct is another issue that will require future study. Furukawa also wants to investigate the optical activity of the amino acids that were generated. The fact that only L-amino acids are produced by living organisms may also be related to the state of the Earth at the time life was formed. As yet, no clues that might resolve this mystery have been found.

Dr. Yoshihiro Furukawa

Graduate School of Science Tohoku University

Nakazawa's mantra is "It is integrated science that will solve the mystery of the origin of life." Chemistry will clear the chemical reactions that can produce amino acids and proteins. Physics will be needed to clear how structures such as cells were created. And geoscientific data will be indispensable for learning about the environment and events four billion years ago when this occurred. Unfortunately, we know that it is not possible to arrive at the origin of life by means of research that traces the history of life from the data written in genomes. Research for the origin of life on the background of geoscience is still a relatively new field -- one that Nakazawa says has recently begun to find acceptance at last.

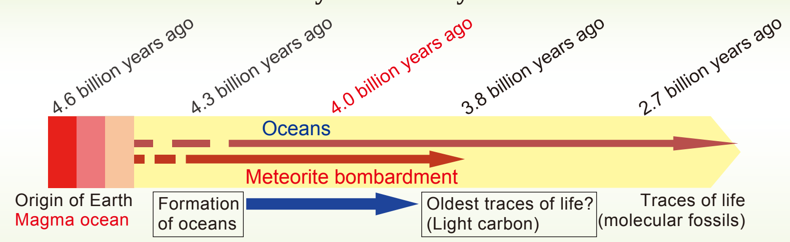
In January 2009, the paper by Nakazawa and colleagues was published in Nature Geoscience, and it had a major impact. In addition to scientists, scientific journals and the media showed intense interest, and the story was even featured in newspapers for children. The origin of life is a topic in which everyone is interested. At NIMS, budding hope that has been engendered is that this scenario may slowly but surely become clear in the 21st century.

* Biomolecule formation by oceanic impacts on early Earth
Y. Furukawa, T. Sekine, M. Oba, T. Kakegawa & H. Nakazawa
Nature Geoscience **2**, 62 - 66 (2009)

Experimental conditions and organic molecules produced.

Run No.		NH_3	N_2
Samples	Fe (mg)	200	200
	Ni (mg)	20	20
	^{13}C (mg)	30	30
	H_2O (mg)	130	130
	NH_3aq (mmol)	1.95	0
	N_2 (μmol)	15	15
Impact velocity (kms^{-1})		0.9	0.9
Products (pmol)	^{13}C-acetic acid	2,200	1,360
	^{13}C-propanoic acid	1,020	440
	^{13}C-butanoic acid	136	88
	^{13}C-pentanoic acid	22	24
	^{13}C-hexanoic acid	tr.	ND
	^{13}C-2-methyl proanoic acid	D	D
	^{13}C-methylamine	16,700	7,430
	^{13}C-ethylamine	945	280
	^{13}C-propylamine	89	12
	^{13}C-butylamine	tr.	ND
	^{13}C-glycine	24	ND

History of the Early Earth



Manabu Kato

Selene (kaguya) Science Manager,
Institute of Space and Astronautical Science/Lunar and Planetary Exploration Program Group,
JAXA*

During the period 4.0-3.8 billion years ago, the Earth experienced a heavy bombardment of meteorites. Virtually all evidence of that period was subsequently erased by volcanic activity, weathering, etc., but well-preserved traces remain on the Moon, which evolved simultaneously with the Earth, because activity on the far side of the Moon had ended almost completely by this time. If you recall the face of the Moon shown by Japan's Kaguya mission, which reached the Moon last year, in comparison with the extremely smooth near side, which is familiar to everyone and looks almost like a baby's face, the far side has the rough, pockmarked skin of a teenager. This shows that low viscosity magma had erupted until only recently on the near side, covering it with a smooth surface, while little magma erupted on the far side, and that side records the heavy meteorite bombardment of the past 4 billion years. The frequency of meteorite was 5 orders higher than it is today, and craters with diameters of 1km exist at a rate of about one crater per $10km^2$.

*JAXA: The Japan Aerospace Exploration Agency

Eiichi Tajika

Associate Professor
Department of Earth and Planetary Science
Graduate School of Science
University of Tokyo
Scientific Research Senior Specialist,
Research Promotion Bureau, MEXT*

In the earliest period of the Earth's history, its atmosphere is considered to have had a weak reducing composition consisting of N_2 and CO or CO_2, in which inorganic formation of organic molecules was difficult. Research by Dr. Hiromoto Nakazawa and Dr. Takeshi Kakegawa of Tohoku University provided an experimental demonstration of the idea that organic molecules may have been formed in local reducing environments caused by heavy bombardment of meteorites (especially, ordinary chondrites) on the oceans. Although this was an extremely revolutionary achievement, quantitative issues remain, as it is generally considered that the main extraterrestrial objects impacting on Earth at the time were not ordinary chondrites, and there is also a possibility that massive impacts which caused all oceans to evaporate occurred several times. Moreover, because the experimental conditions differed greatly from the conditions of impact by extraterrestrial objects on Earth, the results of actual impact are unknown. I very much hope that we will see progress in research on these questions in the future.

*MEXT: Ministry of Education, Culture, Sports, Science and Technology

The Voice of Academia

Issues for Nanotechnology in Japan

Prof. Tomoji Kawai
The Institute of Scientific and Industrial Research, Osaka University

With the resounding success of nano tech 2009, Japan maintained its position as the world's leader in nanotechnology. However, because China, Korea, and other countries are advancing rapidly, proactive policies and tough considerations will be necessary if Japan is to keep its lead in the future. Prof. Tomoji Kawai is an "evangelist" for nanotechnology and was also the Chairman of the Executive Committee for nano tech 2009. In this Special Interview, we asked Prof. Kawai to talk about his vision of the future of Japan and NIMS in the field of nanotechnology.

As Chairman of the Executive Committee for nano tech 2009, what did you particularly feel this year?

One thing which was extremely impressive was the fact that, Japan is strongly perceived as being at the center of global nanotechnology. Comparing the first event, which was a bit like a school fair, nano tech has well-grown into a major exhibition. This year, 50,000 people participate, and 40% of exhibition were occupied by people from overseas. Also, the exhibits now include a considerable number of actual items. In comparison with events in other countries, several nanotech exhibitions are also held in Switzerland, San Francisco, Germany, and elsewhere, but these have remained small affairs in all cases. Particularly as an event where researchers from around the world can meet and exchange views, Japan's nano tech exhibition has grown into the world's only major fair.

What are the current issues for nanotechnology in Japan?

If we compare the science and technology in the world's various countries on a radar chart, the United States is strong in biotech and information, but Japan is far ahead in nanotechnology. However, Japan's lead has decreased over the last 10 years as China and Korea have grown. Those two countries have gone a long way toward closing the gap in basic technology and industrial applications. A fundamental cause is the broad reduction in government support for initiatives like Nanonet. I am extremely concerned that this neglect in strengthening the infrastructure for nanotechnology in Japan may prove fatal in the future.

That is indeed disturbing. Can you suggest any good response?

It is important to show that nanotechnology is really contributing to Japan's national strength, industry, and our everyday life in every situation. This is public relations in the true sense. To the extent that nanotechnology is difficult to present, great efforts are necessary. For example, if we emphasize "green nanotech," meaning promotion of the practical application of solar cells and fuel cells in the current terrible economic crisis, it might be greatly useful in solving this problem.

Around the year 2000, nanotechnology was still a novelty, and topics tended to be too narrow. For example, attention was focused almost completely on nanotubes. Nanotechnology includes evolutionary technologies which progress little by little, as well as revolutionary technologies. Although revolutionary technologies like nanotubes is important, it is also higly necessary to speak out proper message about evolutionary technologies which has the power to drive industry. Japan is strong in this technology, and techniques such as hole processing which enable use in water treatment, and fiber nanocoating are representative examples.

That's an important point, isn't it?

To gain public understanding, it is important to work out winning moves that will lead to the next stage. For example, we still have doubts about electric vehicles. They aren't capable of long distance travel, charging takes as much as 8 hours, the lithium batteries are dangerous, and so on . . . . If technology that suppresses dendrite growth utilizing nanoparticles is applied to this problem, a safe, almost instantaneous charging technology is conceivable. Ensuring that the public properly understands this is public relations in the true sense.

What about the role of NIMS?

First, NIMS should be a center of nanotechnology. The importance of this fact goes without saying. However, I hope that NIMS will continue to be a center of scientific culture in Japan by constantly producing fundamental "seeds." Second, I hope that NIMS will take charge of the translational function. This demands the organizational capabilities which ensure that seeds take a form that will reach practical application and be useful in industry as quickly as possible. In this role, NIMS should focus on various discoveries, create scenarios, and work to effectively realize those scenarios. Third, I hope that NIMS will conduct publicity activities that are easy for the public to understand. Publicity should make the ordinary person look forward to seeing what new discoveries and products nanotechnology will create tomorrow.

Finally, how should we nurture young people?

The best way of nurturing people is to have them do something that they think is interesting and feel passionately about. To achieve this, leaders must show an attitude that they themselves are doing it in earnest. When we talk about nanotechnology, I think that a "new meister" may perhaps be necessary. People who have mastered the secrets of technology and science attract young people. When this happens, young people will be inspired, and will be absorbed in their work and put their hearts into it.

The Voice of Industry

NIMS, Be a Robust Leader in Technical Innovation!

Dr. Michiharu Nakamura
Director, Hitachi, Ltd.

Progress in nanotechnology is one extremely important mission for Japan, which professes to be a science and technology-oriented nation. For this, close cooperation between industry and research institutes is demanded. NIMS has produced numerous results in basic and infrastructural research in nanotechnology, but how does the industrial world view NIMS? What expectations does industry have? We put these questions to Dr. Michiharu Nakamura of Hitachi, who has been a driving force for nanotechnology in Japanese industry and also serves as Chairman of the Executive Committee of the Council on Competitiveness-Nippon.

How do you see the current status of nanotechnology in Japan?

Of course, roadmap-type research is very important for industry. Exponential increases in memory capacity, improved precision in micro-fabrication techniques, and higher performance in magnetic disks are all absolutely necessary. However, taking on the challenge of so-called "destructive innovation" is also important as well, for responding to the expectations of society, creating new currents in technology, and ensuring that Japan is a world leader in nanotechnology. This includes a large number of topics such as photocatalysts, MEMS, micro-reactors, carbon electronics, spintronics, and others. In thinking about the role of nanotechnology, it is essential to look at both sides and consider the balance.

Concretely, what kind of efforts does this mean?

Where nanotechnology is concerned, Japan is making progress in basic research and materials research. One challenge is to make sure that the results of this research are reflected in industry as quickly as possible. Today, we can't wait 30 years or 50 years for basic research to reach applications. I'm talking about an acceleration of the process by which basic research contributes to business as quickly as possible, thereby generating new employment and activating local economies . . .

What measures are necessary for that?

Under difficult economic conditions like we face today, development of innovative technologies is difficult in private companies where research activities are limited to focused themes. Given these conditions, the national government must inevitably compensate for the reduction by private companies. Whether we have the margin to do this or not is a question. For example, the United States has considerable margin because it has a pool of human resources in military research. In Japan, we don't have that kind of margin, but there should be some margin in our national research institutes. In other words, this margin exists in the Independent Administrative Institutions (IAIs). Because it seems that the IAIs still haven't exhausted their human resources, positive efforts centering on improving Japan's vitality by shifting priorities to social innovation and development of innovative technologies are required.

I imagine that what you've just said is directly related to your expectations for NIMS . . .

That's right. NIMS is now in the 2nd period of its Mid-Term Program. From our viewpoint, I think that NIMS has firmly established its position as a top level research institute in nanotechnology. Since you've accumulated this level of real capabilities, as you go forward, I hope that you will consciously make efforts to cultivate new seeds with the aim of realizing revolutionary technical innovation. Even if it takes time, I hope that NIMS will complete truly innovative technologies. In creating innovative technologies, discontinuous research is also necessary, but that is one role of national research institutes.

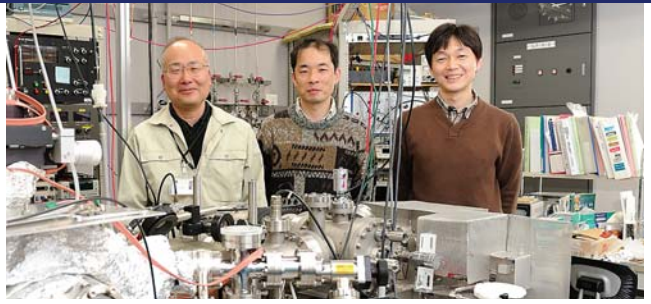
I hope that NIMS will become a robust leader in technical innovation, which can fully satisfy people in the general society.

For this, cooperation with private companies and others will be important.

In the case of cooperation with companies, one-to-one cooperation with individual companies is important, but I would also like to see cooperation with a number of companies in different industries, centering on NIMS. For this kind of one-to-many cooperation, NIMS must provide powerful leadership, and must have research results and technologies which are far superior to those of other companies. If you work as a part of secretariat that simply acts as a mediator among the parties, you won't be able to lead the whole. There are many issues in which NIMS can take a leadership position in promoting national policy, for example, in connection with the problem of rare metals, among others. In any case, I hope that NIMS will make a series of recommendations that give direction to science and technology policy in Japan.

Observing Spin Polarization of Organic Molecules with Atomic Beam

Atomic Beam Group, Quantum Beam Center

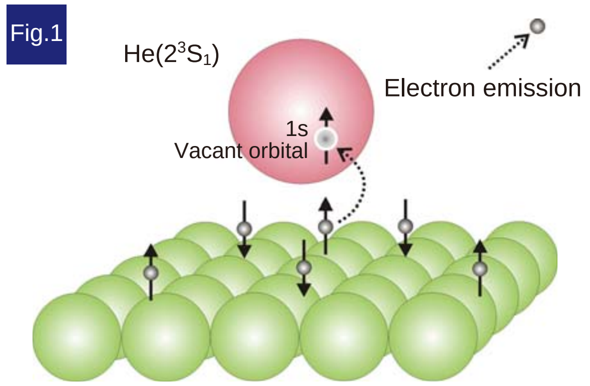


Group Leader
Yasushi Yamauchi, Mitsunori Kurahashi, Taku Suzuki

When you operate a computer or other IT gear, the electron charge carries information in the electronic devices inside. Replacing this carrier charge with spin, which is an attribute of electrons as extremely tiny magnets, has been suggested as a potential means of achieving substantial improvement in power saving, high density, and high speed. This would be a paradigm shift to so-called spin devices. In order to realize this, we are attempting to solve the problems peculiar to spin device materials by clarifying the upward and downward polarization of spin (up-spin and down-spin) at the interface between magnetic materials in which spin direction is aligned, such as half-metals, and the substrate material. Thus we have developed techniques for forming and utilizing spin-aligned atomic, ionic, and molecular beams.

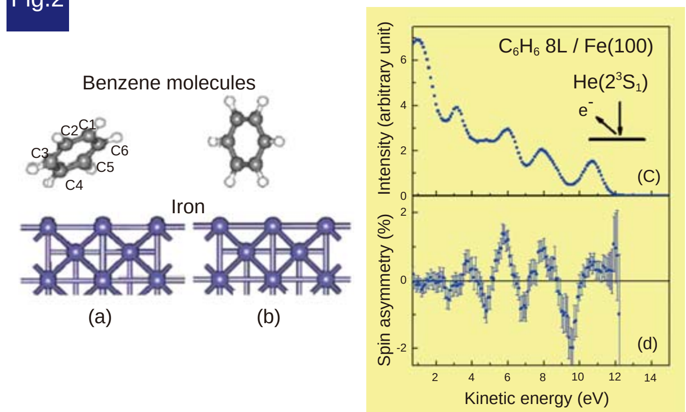
As you know recent progress of the organic displays for cell phones and other organic devices has been quite remarkable. There have of course also been attempts involving organic spin devices, which draw attention to the question of whether organic molecules exhibit spin polarization at the interface of a magnetic substrate. We discovered that the pentacene molecule ($C_{22}H_{14}$) exhibits spin polarization on the surface of iron, but also clarified the spin polarization of the benzene molecule (C_6H_6), which is a constituent unit of pentacene, using an atomic beam (**Fig. 1**). As a distinctive and unprecedented feature of this beam, spin-aligned helium atoms so softly touch the surface that the spin polarization of only the electrons at the outermost surface can be detected. The peaks of the obtained spectrum (**Fig. 2(c)**) correspond respectively to the response from the electrons which occupy molecular orbitals with different energy in benzene molecule. Spin asymmetry (**Fig. 2(d)**), which shows differences in intensity depending on the direction of spin, changes to positive or negative together with the peak, and enables us to investigate the degree of spin polarization of respective molecular orbitals. A detailed analysis of the results revealed that spin polarization is not limited to the neighboring atoms (C3, C4 in **Fig. 2**) which interact directly with the magnetic substrate, but extends to molecular orbitals distributed in carbon atoms (C1, C6 in **Fig. 2**) separated by 3 atoms from the magnetic substrate. If molecular orbitals extending over relatively long distances exhibit spin polarization due to local interaction with a spin-aligned magnetic substrate, organic materials such as C_{60}, graphene (single-layer graphite sheet), etc. which have similar molecular orbitals are not simply charge device materials, but can also be considered promising spin device materials.

Fig.1



When a helium atom He(2^3S_1) with a vacancy at the low-energy orbital is brought into proximity with the surface of a substance, a surface electron migrates to the helium atom and fills the vacant orbital. If the vacant orbitals can be controlled to only up-spin (spin-aligned beam), the migrating surface electrons can be restricted to up-spin electrons. In actuality, a second electron is emitted simultaneously with this migration. The difference in up- and down-spin surface electrons and their energy distribution can be obtained by detecting this emitted electron.

Fig.2



Model in which benzene molecules are adsorbed on an iron surface (a) obliquely and (b) vertically; (c) shows the kinetic energy distribution of electrons emitted from the surface of iron exposed to benzene vapor of 8L (Langmuir: 10^{-6} Torr・sec) at low temperature (85K) when irradiated with an atomic beam, and (d) shows their spin asymmetry (difference in intensity of up-spin and down-spin, normalized by the sum).

The Material and Manufacturing Technology of the World's Highest Heat Resistant Cast and Wrought Alloys for Aircraft Engines have been Developed Successfully.

High Strength Materials Group,
High Temperature Materials Center

Group Leader
Yuefeng Gu, Yutaka Koizumi, Tadaharu Yokokawa, Chuanyong Cui

The high temperature and high pressure turbines in aircraft jet engines are operating in the severest environment; therefore, the highest performance materials should be used for the key turbine components, blade and disk. The NIMS High Temperature Materials Center is leading the world in developing a 5th generation nickel (Ni) base single crystal alloy with a temperature capability of 1100°C (stress: 137MPa) as a blade material for use in high temperature, high pressure parts of turbines. Since 2006, the center has been engaged in practical research with Rolls-Royce.

On the other hand, highly reliable wrought materials have been used for the turbine disk on which the turbine blades are mounted. Catastrophic damage could be caused to the aircraft if disks fail, (**Fig. 1**). We have started independently research on cast and wrought (C&W) alloys for turbine disks at the laboratory scale (i.e., up to 20kg) since 2003, and succeeded in developing a nickel-cobalt base C&W alloy (TMW alloy) with the World's highest heat resistance of 725°C (stress: 630MPa), exceeding that of the existing high strength cast and wrought Ni base alloy U-720Li by 50°C. For practical research and application, the conditions of forging processes from large-scale ingots up to approximately 2 tons have been established, which makes a great step for TMW alloys to product manufacture of the actual applications.

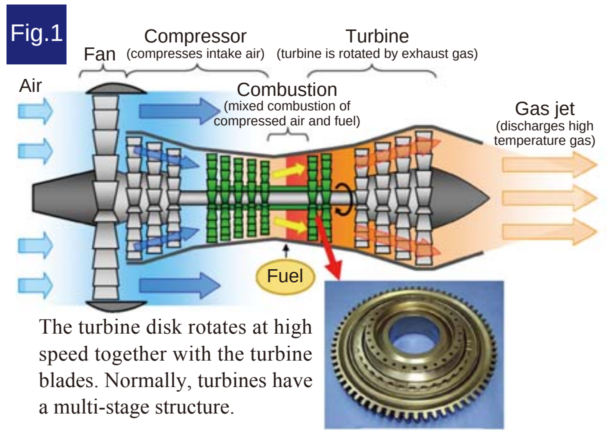
In this work, we developed an application technology of real-scale manufacturing for the above-mentioned TMW alloy in joint research with Mitsubishi Materials Corporation under a commission from Japan's New Energy and Industrial Technology Development Organization (NEDO) over a 2-year period from 2007 to 2008. Furthermore, we succeeded in producing turbine disk pancakes for use in aircraft engines. The high temperature properties of this turbine disk pancakes were evaluated by creep tests, and the results confirmed that it possesses the World's highest temperature capability for forgeable products, which is more than 50°C higher than that of the currently existing U-720Li alloy (**Fig. 2**).

In order to increase the temperature capability of high temperature alloys used for turbine disks, normally it is needed to add various refractory elements, which results in the problems of deviations in chemical composition and susceptibility to cracking in the manufacturing (i.e., forging) process. To overcome these problems, we designed TMW alloys basing on our innovative concept and determined melting, cast and forging conditions suited to TMW alloys for making large-scale ingots, and thereby successfully manufactured large-scale ingots and prototype turbine disk pancakes (**Fig. 3**) with a homogeneous fine-grained microstructure of a 10μm grain size in practical-scale pancakes (diameter: 440mm).

With the establishment of a practical manufacturing process of turbine disk pancake at the actual application scale and demonstration of the high temperature properties of the material, TMW alloys are expected to be made into various wrought parts, including turbine disks, compressor blades etc, and to enter into the domestic and foreign markets for aircraft engines and industrial gas turbines in the near future.

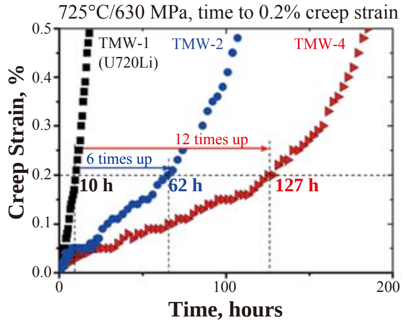
* The temperature capability of turbine disk alloys is defined as the temperature at which 0.2% creep strain is reached after 100 hours at stress of 630MPa.

Fig.1



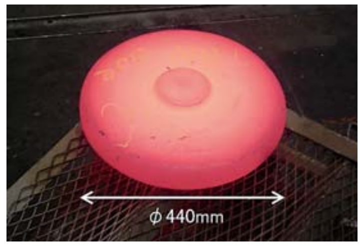
The turbine disk rotates at high speed together with the turbine blades. Normally, turbines have a multi-stage structure.

Fig.2



Creep strain curve in a creep test under conditions of 725°C and 630MPa. The service temperature of the developed alloy is improved by more than 50°C in comparison with that of the high strength cast and wrought alloy (U-720Li) currently in practical use.

Fig.3

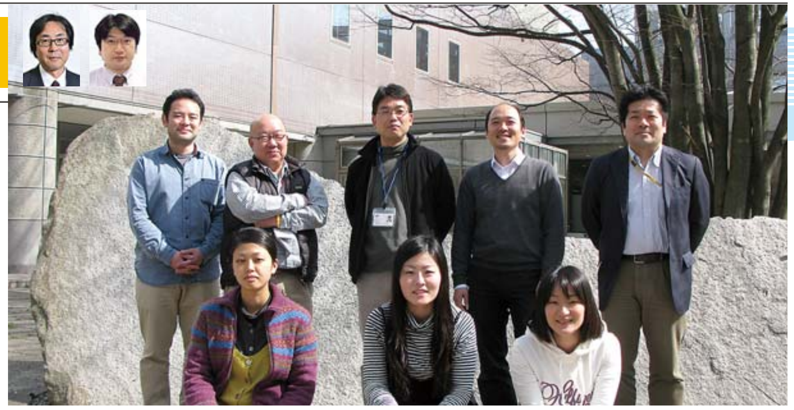


A prototype turbine disk with a size that can be practically used in real applications (diameter: 440mm). The material has a homogenous fine-grained microstructure with a 10μm grain size. This photo shows the external appearance of the disk material during the high temperature forging process.

New Project

Nanotech-driven Materials Research for Biotechnology

Tissue Regeneration Materials Project



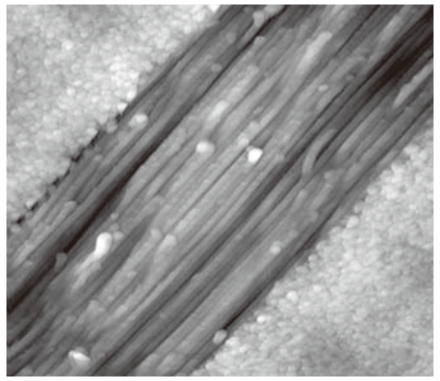
Living tissue contains many oriented structures consisting of protein fibers, such as collagen fibrils. These structures are the optimum environment for cells and display diverse functions of cells in such niche. For example, the ligaments, in which collagen fibrils are oriented in one direction, join bone and enable smooth motion; the structure shows a strong and tough tissue. The corneal stroma of the eye, which transmits light, has a layered structure in which the successive layers of unidirectional collagen fibrils are alternately rotated 90 degree in each layer. This Project began its activities in FY2008 with the aim of artificially creating biomaterials which closely resemble these living tissues.

The objectives of the Tissue Regeneration Materials Project are (1) to create fibrous oriented materials utilizing magnetic fields in order to mimic the structures and functions observed in living tissue, and (2) to clarify the biological mechanisms of oriented structures. Because a magnetic field acts by permeating a substance, it is possible to create new structures by applying the effect of the field uniformly from the material surface to the interior. To clarify the structures of fabricated materials and their affinity with the living body, this project is engaged in interdisciplinary research using technologies such as electron microscopy and cell culture, among others. Researchers from the NIMS Biomaterials Center, Nano Ceramics Center, and Advanced Nano Characterization Center are participating in this research.

Figure 1 shows the oriented structure of collagen fibrils produced by a living organism. In the central part, the collagen fibrils are aligned from the lower left to the upper right and the cross-sections of collagen fibrils can be observed in the upper left and lower right parts. It can be understood that the collagen fibrils produced by living organisms form an order, high density structure. One objective of this project is to create this type of structure using materials science techniques.

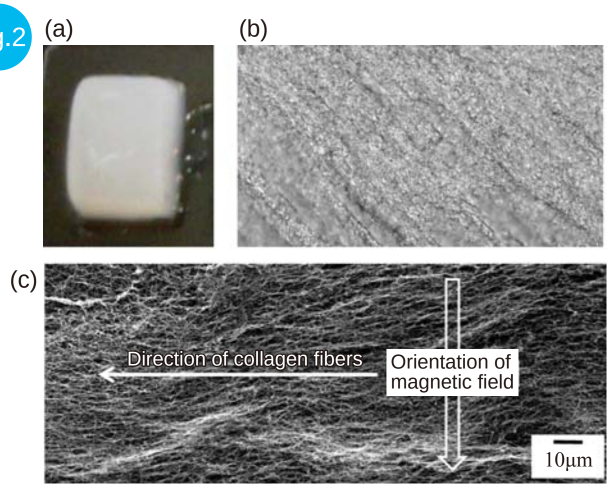
A concrete example of research is shown in **Fig. 2**. The scanning electron microscope image shows an oriented fibrils structure which was fabricated by fibrogenesis of collagen molecules in a high magnetic field (12 Tesla). The collagen fibrils have aligned perpendicular to the direction of the magnetic field. The peptide bond which connects amino acids in collagen has different magnetic susceptibility depending on the direction. For this reason, collagen fibrils are affected by torque and align in one direction in a magnetic field. At present, we are conducting research on the properties relating material strength of oriented structures fabricated by varying the intensity of the magnetic field, and on their reactivity with cells. In this Project, as mentioned above, we are conducting materials development with the aim of establishing synthesis techniques for new biomaterials consisting of aligned fibers and inducing regeneration of tissues such as ligaments (tendons), the corneal stroma, nerves and others.

Fig.1



Cross-sectional structure of fish scale as observed with an atomic force microscope. The collagen fibrils are aligned with high density.

Fig.2



Oriented structure of collagen fibrils treated in a magnetic field, showing (a) the external appearance of the fabricated gel, (b) a confocal microscope image, and (c) the oriented fibrils structure as observed with a scanning electron microscope, in which the collagen fibrils had aligned perpendicular to the orientation of the magnetic field.

F/A/C/E フェイス interview

Steel, which possesses a combination of high strength and toughness, plays a large role as a basic material supporting our infrastructure. Last year, the NIMS Structural Metals Center succeeded in developing a steel which displays room-temperature yield strength of 1840MPa and approximately 6 times greater impact absorbed energy than high alloys steels, even thought the developed material is a steel alloy with very low addition of alloying elements. In this interview, the Center's Managing Director, Dr. Kaneaki Tsuzaki, discusses research on iron and steels.

Kaneaki Tsuzaki

Managing Director, Structural Metals Center

Have the Spirit to Challenge Research that Investigates the True Essence of Things

First, please tell us about your research on iron and steels.

I joined NIMS in 1997, but at the time, there was a downward tendency in the presence of steel research. The "Super Steel Project," which spanned a period of 9 years, was begun as a way to break out of that condition. The dream of the Super Steel Project was to create high quality steels unlike any which had existed in the past. The concrete objectives included doubling strength and doubling life. Furthermore, although addition of scarce alloying elements had long been used to improve strength and corrosion resistance, one aim of the project was to achieve these results without using scarce alloying elements. Looking back on this project, I think this was extremely challenging research, with goals that actually anticipated the current era, when many resources are approaching depletion.

What kind of research did you do in the Super Steel Project?

During the first 5 years, my mission was to develop iron and steel materials with resistance to hydrogen embrittlement. However, it is extremely difficult to discover where hydrogen exists and how it behaves. Creating strong materials while simply knowing that hydrogen causes embrittlement, but not understanding the true nature of this phenomenon, is no different from treating the symptoms of a disease and not the cause. Up to that time, various elements had been added to steel in order to improve its performance, but in many cases this was empirically-based, and the actual functions of those elements were not adequately understood.

What results did you achieve in this work?

It is possible to double the strength of steel materials by refining their grain size, but conversely, it also became clear that grain refinement has significant demerits, as it reduces uniform elongation performance and lowers impact absorbed energy. In metals, the microstructure has merits and demerits of this kind. There are also merits and demerits in the functions of the alloying elements, and this must be fully recognized. I also found that it is extremely important to aim at research with a view fixed on the future. For example, in order to construct a natural gas line from Alaska, steel materials which are capable of withstanding arctic weather conditions are necessary. Addition of nickel as an alloying element is one way of preventing embrittlement in extremely low temperature environments, but if we can no longer use this element in the future due to limited resources, an entirely different approach will be required. In other words, change is not limited to the environments in which materials are used; the environment controlling the resources used in materials will also change. We must carry out research in preparation for this, anticipating environmental changes of this type.

Finally, what do you hope for in attitudes toward research and in young researchers?

Research for practical applications must be supported by basic research. The first and foremost motivation for a researcher is to discover, themselves, the "why" of things, and to try to respond to that in some way. For example, even today, where hydrogen exists and how it behaves are not well understood. My dream, and my mission, is to elucidate these questions and create materials with excellent resistance to hydrogen. I strongly feel that researchers should do this kind of research, which investigates the true essence of things. There are fascinating subjects in every field. If you think you can't find them, then you need to raise your antenna and become more sensitive. Curiosity is necessary in human beings, but without a doubt, the things that attract our curiosity exist all around us. Therefore, I hope that young researchers won't worry about anything, but will take on the challenge of this "why."

The 2nd MANA International Symposium

(Feb. 25-27, 2009) The 2nd MANA International Symposium was held jointly with the International Center for Young Scientists (ICYS) at the Epochal Tsukuba International Congress Center. The purpose of the Symposium is to bring together researchers from Japan and other countries and promote research/disseminate information related to the MANA project.

Over the three days, presentations were given by a total of 30 Principal Investigators, Scientists, and Independent Scientists from MANA and its satellites and ICYS researchers, focusing on the four research fields in MANA, nanomaterilas, nanosystems, nanobiotechnology, and nanogreen technology, as well as research at ICYS.

MANA Symposium at Epocal

The lectures in various fields by eight invited researchers from Japan and other countries, who are distinguished scientists in the field of nanotechnology, beginning with Prof. Anthony Cheetham from the University of Cambridge in the U.K. and Prof. Roland Wiesendanger of the University of Hamburg in Germany. More than 300 persons participated in this year's Symposium, exceeding the number at the 1st MANA Symposium last year.

The 2nd NIMS-KIER Joint International Workshop

(Mar. 4, 2009). The Energy Efficiency and Materials Convergence Research Division of the Korea Institute of Energy Research (KIER), which is located in Taejeon City, Korea and the NIMS Nano Ceramics Center held a joint international workshop at the NIMS Sengen Site. This workshop was planned in order to strengthen substantial research exchanges between the two institutes, which signed an MOU in December 2007, and was the second following the 1st round workshop held at KIER in Korea. For 2nd Workshop, a mission of six KIER researchers, led by Dr. Kim Hong Soo, Director of the Energy Efficiency and Materials Convergence Research Division, visited Japan for a period of 2 nights and 3 days. Approximately 50 researchers participated in the workshop, which included a total of 14 presentations from Japanese and Korean researchers. The two sides engaged in spirited debate on their counterparts' recent research in the nano, ceramics, and energy materials field, as well as in discussions toward closer research cooperation in the future.

NIMS-KIER Workshop at NIMS

WMRIF 世界材料研究所フォーラム
World Materials Research Institutes Forum

Announcement : The 3rd WMRIF in Washington, DC on June 21-25, 2009

The 3rd World Materials Research Institute Forum (WMRIF), General Assembly and Symposium on Materials Challenges for Clean Energy will be held on June 21-25, 2009 at the National Institute of Standards & Technology (NIST) in Gaithersburg, Maryland (USA), near Washington, DC.

The WMRIF is organized by the world's leading materials science research institutes.

The 3rd Forum is sponsored by NIST, ORNL* and NIMS with the aim of enhancing international collaboration in materials science, focusing on energy, nanomaterials, sustainability, and synchrotron research.

For more details:
http://www.e-materials.net/network/WMRIF/modules/wordpress/
On-line registration will be closed on June 15.

* ORNL: Oak Ridge National Laboratory

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