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Feature

## 100<sup>th</sup> Anniversary of Measurement Standards



National Institute of Advanced Industrial Science and Technology



# Full Research and

President

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## Social Contract

In recent years, public expectations for science and technology are rapidly growing. Since the enactment of the Basic Law on Science and Technology in 1994, the Japanese government has been injecting enormous amounts of funds into research on science and technology in the framework of the first and second Basic Programs for Science and Technology, regardless of the severe economic depression. The amount of the invested money indicates high degree of public expectations. It is evident that the nation is hoping for a recovery of the near-term economic conditions and also for Japan's cultural development in a longer term. In fact, research on science and technology in Japan seems to be developing steadily to fulfil such expectations by producing substantial results.

As the basic science and technology research is financed largely by public funds, it should be considered that those who are engaged in such research activities are obliged to meet these social expectations. Lubchenco<sup>1)</sup> defines this relationship between science and society as "Social Contract for Science". She points out that environmental issues are to assume the highest priority for mankind in the 21<sup>st</sup> century. She argues the necessity to confront these challenges by laying down a new contract, whereby the role taken by scientific knowledge is clearly recognized between the scientists and society. This is a prerequisite to conduct any research on science and technology.

In view of the subsequent changes in science communities originated by this view, it can be said that her "new contract" is more than a theory and is actually controlling.

The following facts will provide grounds for this assumption.

In 1987, the Brundtland report presented at the U.N. World Commission on Environment and Development, known as "Our Common Future<sup>2)</sup>" suggested that two contradicting needs, i.e. rapid improvement of living standards in the developing countries and preservation of the global environment can be met simultaneously in spite of considerable difficulties. The report confirms with conviction that the progress in science and technology will pave the way to achieve this aim. This is certainly a question posed by the world of politics to the scientists.

In the meantime, "Declaration on Science" was issued as a pronouncement of scientists at World Conference on Science in Budapest<sup>3)</sup> in 1999. In sum, the declaration states that the practice of scientific research should no longer be conducted for purely academic purposes but should aim at acquiring exploitable knowledge which benefits society in terms of progress, peace and development. In other words, science is a social function that serves society.

This is not a direct response to the question cast by Brundtland. However, reviewing the major achievements represented by the Earth Summit during the twelve years since the introduction of the concept of sustainable development, the declaration should be regarded as a response from the scientific communities. Thus, Lubchenco's idea has appeared in concrete form. The social contract on science has been closed by the scientists' affirmation of their commitment to conduct science and technology research that will promote the welfare of humankind

# Social Contract

and of the global environment.

## Type-II Basic Research Workshop ———•

Two years have passed since the inauguration of the National Institute of Advanced Industrial Science and Technology. Although there were some minor disruptions due to changes in the organization and management system, it can be said that duties are performed according to initial objectives. In terms of the research framework, full research centering on type-II basic research has surfaced. This concept proposed as an effective model for research on industrial technologies involves the question of the contract between scientists and society as described later in this article.

“Type-II Basic Research Workshop<sup>4)</sup>” has been held for eleven times since January 2003. The experiences during the workshop may provide a good example. Type-I basic research is an endeavor to elucidate the nature of an existing phenomenon by analyzing the subject from a certain perspective, yielding new knowledge. Principles and theories are constructed based on this knowledge. Whereas type-II basic research pursues universality of a process to create a new entity or product through applying those principles and theories in multiple fields. The latter is essential to achieve the AIST’s goal. The attempt to create the social benefits or wealth is composed of the following processes: 1) creation of scientific knowledge, 2) coordination of existing knowledge whereby a subject product is fabricated, and 3) establishment of the actual manufacturing process. These three processes correspond to type-I and type-II basic research, and product development, respectively.

Hence, type-II basic research involves the process of “synthesizing” multiple scientific fields that represents the difficulty inherent to this research. Although this point conclusively differentiates type-II research from type-I basic research, the process is not fully recognized. Type-II research often sinks into obscurity. In spite of the demand for greater efforts, it is not easy to accumulate experiences or deliver tangible results in this type of research. As a result, it is less likely to be granted sufficient research funds. This may be a period of “nightmare” for researchers caught in between the “dream” offered by type-I basic research and the “reality” of product development<sup>5)</sup>. However, in order to serve the purpose of industrial development, we must lose the sinister illusions and make a great leap forward to reality. There is a period of “nightmare” before any scientific discovery or innovative technological idea bears the fruit of social wealth. Hence, it should be considered that the commitment as a public research institute is to take the role and face these challenges.

The Type-II Basic Research Workshop was organized based on this proposition. Through the workshop, it was made clear that a number of type-II research projects were in progress at AIST. The following are some of the examples.

There had been high expectations on the completion of ceramics gas turbine (Ohji, AIST Chubu) for its overwhelming power. However, it was extremely difficult to assure the long-term reliability of the components and thus it did not come to fruition. It is foreseen that the creation of a new theory of compound materials will provide a breakthrough. However, steady efforts in theoretical research will be required to achieve this difficult goal.

Thermal conductivity hydrogen sensor (Murayama, AIST Chubu) is moving toward realization as the improvement of structural controls at the nano-level. In this project, the process of coordinating knowledge from different fields has been formulated. The effort should be considered as a typical example of type-II basic research.

Optical disk based on near-field optics (Tominaga, AIST Tsukuba) is finally approaching completion after four generations since the start of its theoretical research. Dr. Tominaga suggested that a keen “sense of smell” was required for the theory to evolve into the present state over generations. Interestingly, this remark shows an essential aspect of type-II basic research.

Voltage standard systems using Josephson junction arrays (Shoji, AIST Tsukuba) marked a notable achievement after the failure of the long-term research on applied computing systems. This project can also be categorized as type-II. The significant success demonstrates the essential elements for a successful type-II basic research.

The needs for nano bio-device (Baba, AIST Shikoku) is acknowledged commonly in the science communities and vigorous competitions have been observed for the fabrication of the device. This is also to be achieved by combination of the existing technologies and application of a vast range of knowledge that may involve the discovery of innovative scientific findings as in the other type-II basic research projects.

Nano length standards (Nakano, AIST Tsukuba) can be called a full research. The project progresses, producing required new knowledge through state-of-the-art research endeavors based on a prepared scenario.

In the research on fusion of nano and biotechnologies (Yumoto, AIST Kansai), the development of the world's smallest motor is an immediate goal. It is expected that the process would require the discovery of a great deal of innovative knowledge and may open a new sphere of research on biomolecular movement. This can be seen as a

model of type-II basic research.

## Inherent Difficulties

The presentations on the research given in a series of the symposium proposed a number of issues. Most of the research projects follow the definition of type-II basic research, and all of them involve the difficulties inherent to the research of this category. Such challenges can be typified as follows: (1) exploitation of a new scientific field to solve unknown problems, (2) inspiration that leads to innovative concepts, (3) selection of knowledge from vast amounts of accumulated experiences in multiple scientific fields, that requires endless “trial and error” or the establishment of a certain method of selecting, (4) a high risk that a research scenario is inadequate, which, nevertheless is indispensable to carry out the research.

Apparently, it is understandable that the aforementioned research projects have these problems. The researchers engaged in other projects are also striving to overcome similarly demanding tasks. However, as history has shown, the more challenging the problems are, the more there is to gain once these obstacles have been eliminated. The achievement here may include the creation of innovative products, drastic improvement of the product's performance, significant reduction of the environmental loads and considerable cost reduction. These are the merits to proceed with any research.

A type-II basic research is inevitably associated with the above mentioned difficulties. Another mission is to explicitly present the universally applicable solutions to such problems through research activities. This is why it is called “basic” research. It is not quite sufficient to surmount various obstacles and bring dreams into realization although this is certainly an admirable attainment. The process of overcoming problems must be “scientifically” recorded for use in future type-II basic research. It is expected that these records will eventually form the system of “knowledge for



application” in the type-II basic research framework, comparable to the system of “factual knowledge” in type-I basic research. The system will be created by the researchers in the type-II basic research field.

It may be difficult to provide a pertinent answer to the question whether knowledge for application can exist unrelated to factual knowledge. Furthermore, there is a doubt about the existence of knowledge that is liberated from the categorization of the subject matter. However, the possibility of the existence of such knowledge has been indicated by the author’s ongoing research, “Mathematical Theory of establishing academic disciplines”, that aims to verify the presence of knowledge for application. The details of the research will be published elsewhere.

### Next Leap

The workshop provided an opportunity to recognize that a number of type-II research projects are presently advancing at AIST. To make a further leap forward, it should be noted that some issues require improvement. Firstly, as mentioned before, more efforts should be made in the “basic” research to extract the methods to solve the problems for future reference. It is undeniable that type-II basic research involves difficulties entirely different from those in type-I basic research. Some are approaching the solution. Those who are working on such endeavors are by all means type-II basic researchers. However, they do not have records on the process of solving these problems. Considering the difficulty in keeping this kind of records, it is important to provide motives to encourage documentation. This indicates the fact that AIST currently lacks the system that rightfully evaluates such records. There is an urgent call to establish an evaluation system for type-II basic research.

Secondly, most of the type-II basic research projects presented at the workshop were no more than individual researchers’ activities. This type of research will have a

coherent plot : a researcher obtains new knowledge in his type-I basic research, creates a marketable product based on this knowledge and finally succeeds in manufacturing the product. Type-II basic research may be more understandable if explained along with the time course of one researcher’s project.

Having said that, as seen from the stated difficulties inherent to this kind of research, most of the projects require the combined efforts of a number of researchers in multiple fields. It is not common that a project is carried out “linearly” by an individual researcher. It is no doubt that more promising results are obtained from a type-II basic research project which is conducted under a common goal by a group of researchers who belong to different research categories: type-I, type-II and product development. In this sense, type-II basic research offers a pivot of research unit organization at the AIST. Researchers who engage in type-I, type-II or product development make up a research unit under a common research theme, achieving coherency of the activities. This relationship does not follow a time-shift, beginning with type-I, type-II and completing in product development. On the contrary, it has a nature of concurrency that can be demonstrated as an interaction of research of these three categories. This is the model of a full research. The important issue to be addressed is the reorganization of each research unit in accordance with this model.

Let us return to the original question of the social contract for science. Currently, the Second Basic Plan for Science and Technology is ongoing. The formulation of the next Basic Plan has started aiming at its launch after 3 years. The most important issue in the third Basic Plan will probably be the requirement of a system to evaluate profits returned to society from the 10-year investment in basic research. Tangible results should by all means be actively publicized. However, it is difficult to produce a recognizable result in basic research.

If venturing an evaluation of any basic research





project, the process to reach a result should be of focus. A full research centering on a type-II basic research offers a promising candidate for industrial application based on the newly discovered knowledge and simultaneously, creates the universal knowledge for its utilization. The Third “Basic Plan” will define such endeavors as the activity that is conducted observing consciously and proactively the social contract for science. Hence the research projects progressing at the AIST take an important role to fulfil the social commitments of science.

The contract is not limited to the arrangement between the investors and practitioners in Japan. Given that this contract has a global nature, as suggested by Lubchenco, it is important for each member of the AIST to realize a scenario to enable sustainable development in the world by achieving economic prosperity in Japan.

## Future Issues

During the past two years, the identity of the AIST as an organization has become commonly shared by all AIST researchers through the introduction of the concept of full research centering on type-II basic research. The next step is to clarify the AIST’s strategies.

The primary strategy involves the selection of a target field of research and an industry. This can be called “Field Strategy”. Although a number of research projects are currently in progress in such fields as system development, materials, biotechnology and information, admittedly, the vision may lack clarity in respect to industrial applications of such research outcomes and the effects on the sustainable development of humankind. As a matter of fact, there are difficulties deciding partner industries even within Japan. In a full research which requires autonomous operation of each research unit, it is essential to advance a research project effectively in accordance with a well-prepared scenario that may include a proposal for renovation of the existing industrial structure. This is essential to fulfil the social commitment.

The second strategy concerns the autonomy of AIST in employing the “field strategy” for the implementation of a full research. The autonomy or freedom of basic research should be reviewed from the standpoint of a national budget and a policy of the Ministry of Economics, Trade and Industry. As a pioneer of independent administrative agencies conducting research activities, this issue should be carefully considered.

Finally, the question of evaluation should be discussed. The autonomy of an independent administrative organization directly influences the system of evaluation. For the past two years, an enormous effort has been made to establish the AIST’s unique evaluation system. However, it is expected to set up a new evaluation procedure with a firm basis of a clearer vision which is applicable to type-II basic research. In principle, this system extracts the most significant research results to be evaluated so that the burden caused by the evaluation procedure can be minimized.

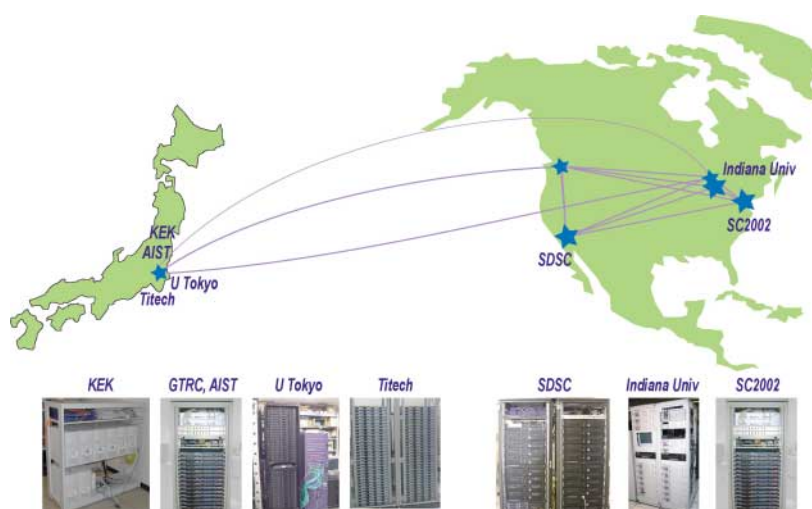
There are a number of urgent tasks. Most importantly, an effective system and method should be introduced to enhance the fruits of the efforts of the past two years. Any obstacles against development must be eliminated. Under the common goal to establish a framework of full research, it is expected to nurture a shared recognition of the fundamental needs for research activities.

- 1) J. Lubchenco ; Entering the Century of the Environment : A New Social Contract for Science, Science, 23 Jan. 1998, Vol.279, P.491
- 2) G. Brundtland ; Our Common Future, Oxford Univ. Press, 1987.
- 3) World Conference on Science (ICSU/UNESCO, 1999, Budapest), UNESCO 2000
- 4) K.Naito; A New Research Methodology on Industrial Technology, Technology Information Department, AIST (to be published)
- 5) H. Yoshikawa; Robots and Humans, 475, NHK Books, NHK Publishing Company, 1995, P.146

# Grid Datafarm: Record Speed Data Processing between Japan and U.S.

**Record Volume Data Travelled 10,000 km at 741 Mbps**

The Grid Technology Research Center of AIST succeeded for the first time ever to demonstrate the effectiveness of large-scale data analysis by the use of "Grid Datafarm" architecture. A large amount of simulation data of high-energy physics was generated for the experiment and processed by the network linked by seven computer clusters located in Japan and the U.S., a total of 190 computers. The data transfer rate during the data copying process reached a speed of 2.286 Gbps in the U.S. and the data transfer reached 741 Mbps between Japan and the U.S., at a distance of more than 10,000 km, which had never been achieved before. This success led to a breakthrough in the attempts to establish a global center for super large-scale data processing as well as international projects on data processing involving large volumes.



● Fig. 1 Network map of each site and PC cluster

## ● Grid Datafarm

The Grid Technology Research Center advances the research and development of "Grid Datafarm" architecture that enables the process of large amounts of data at multiple regional computer clusters. The aim of this project is to establish a large-scale parallel file system by exploiting local storage of computers spread in the extensive area, a platform system needed to support a Petabyte scale data intensive computing (Petabyte: 1 PB is equivalent to 1,000 trillion letters, 1.7 million CD-ROMs). Grid Datafarm architecture enables high-speed access to a large amount of data by utilizing the file access locality, and realizes fault tolerance of hard disk drives and networks by data replication.

Grid Datafarm can be applied to theoretical or experimental science that calls upon large-scale data analysis and simulation such as particle physics. It enables to process several PBs of experimental data every year and can

also be useful for analysis of observational data of all-sky multiple wavelength bands in astronomy, gene analysis in bio-informatics and so on. Furthermore, the system can be utilized to handle large volumes of data processing in business fields, e.g., e-governance and e-commerce. It also provides data redundancy and load sharing by high-speed data replication between the computer clusters geometrically separated. This technology offers a platform for efficient and secure global sharing of a large amount of data and is expected to be applied to various industrial needs.

## ● Grid Computing System Field Test in Japan and the U.S.

During the international conference SC2002, held in Baltimore from November 16<sup>th</sup> to November 22<sup>nd</sup> of 2002, the field test of large volume data analysis by Grid Datafarm technology proved successful for the first time in the world. The field test was implemented linking seven computer

clusters in both Japan and the U.S.

Seven systems of computer clusters, including the one at the SC2002 booth (a total of 190 PCs) were located in the research centers of both Japan and the U.S. (AIST, High Energy Accelerator Research Organization, Tokyo Institute of Technology, the University of Tokyo, Indiana University and San Diego Supercomputer Center {SDSC}). They were integrated into the Grid Datafarm architecture (Fig.1). Tsukuba WAN, APAN/TransPAC and MAFFIN supported in establishing the network.

The system demonstrated the maximum computing rate of 962 Gflops, about twice as fast as the super computer SR8000 installed in the Tsukuba Advanced Computing Center of AIST. It was equipped with a large capacity file system of 18 TB (Terabyte) at 6,600 MB/s access rate which means that the data of a CD-ROM can be read/written in 0.1 second.

For the field test, a large amount of scientific data taken from particle physics was generated mainly in the large-scale PC cluster of Tokyo Institutes of Technology and created back-up copies of several hundreds of GB (gigabyte) at each of the other clusters.

## ● Record-Speed File Transfer

In the field test, multiple high-speed wide-area networks were used, that is, Tsukuba WAN and SuperSINET in Japan, APAN/TransPAC and NII-ESnet HEP PVC between Japan and the U.S., Abilene and ESnet in the U.S. and SCinet at the SC2002 booth. The bandwidth from SC2002 to both Indiana University and SDSC was 622 Mbps. In the transpacific network, it was 893 Mbps. Total theoretical maximum bandwidth of the network linking seven clusters was 2.173 Gbps one way (See Fig.2).

Data transfer speed achieved during the test was 1.691 Gbps for outgoing traffic and 0.595 Gbps for incoming traffic, 2.286 Gbps in total (290 million letters per second, equivalent to the speed to transfer data of a CD-ROM in 2.3 seconds). Twelve computers were used at the SC2002 booth. Furthermore, the actual data transferring speed reached

741 Mbps (90 million letters per second, equivalent to the speed to send data of a CD-ROM in 7 seconds), 83% of theoretical bandwidth of the network between Japan and the U.S., over a distance of more than 10,000 km, by using four computers installed at the Grid Technology Research Center of AIST in Tsukuba and four at the SC2002 booth (Photo 1).

The achievement of high performance during the field test attributed largely to the effective utilization of two APAN/TransPAC networks. Using a single application to send large volumes of data at 741 Mbps across the Pacific Ocean has never been done before.

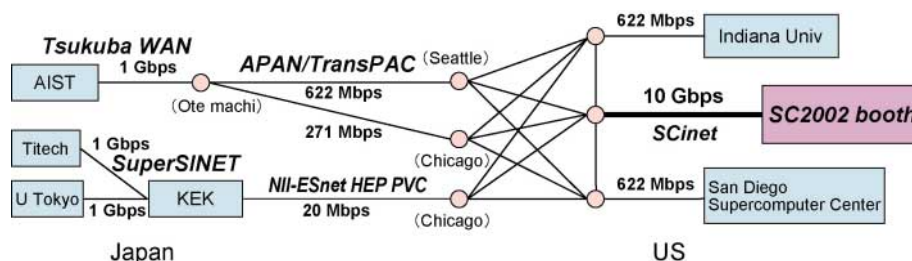
## ● Key to Success

Grid Datafarm improved network data transfer performance as well as I/O performance and, in addition, accelerated long distance data transfer speed by simultaneously conducting parallel transmissions between the clustered PCs.

A signal was transmitted on fiber-optic cables that was used for long distance communication with a delay of 5 nanoseconds per meter. The distance between a PC cluster at the SC2002 booth in the U.S. and a PC cluster at the Grid Technology Research Center in Japan is about 10,800 km in total. However, as the actual length of the fiber-optic cable was longer than this distance, there was approximately a 0.2 second lag over both incoming and outgoing traffic. Network delay caused by network routers was also a factor.

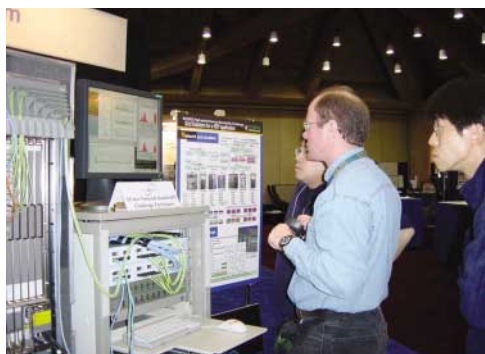
The delay of 0.2 seconds causes the drop of data transfer speed to 2 Mbps regardless of network performance in mid-stream when TCP/IP communication is used. This is because TCP is not originally designed for the long distance high-speed data transfer. For this experiment, it was attempted to improve the data transfer performance by use of High Speed TCP, whose protocol specification is currently being designed. Furthermore, for improved performance that depends on the network conditions and cannot be solved by High Speed TCP, detailed settings of the communication parameter were made including flow control of communication streams, number of parallel streams and so on.

In the meantime, four hard disk drives were simulta-



● Fig. 2 Network logic diagram of grid network established in the field test





● Photo.1  
Ongoing large volume data transmission



● Photo.2  
Grid Datafarm PC cluster



● Photo.3  
AIST and KEK members of Grid Datafarm Bandwidth Challenge Team succeeded in super large-scale data processing between Japan and the U.S. Research Center.

neously used with each PC in order to increase the I/O bandwidth. Consequently, disk access performance was improved to the level of that was nearly equal to the network performance (1 Gbps). These were all high-density packages that can be mounted in a PC of 1U (rack-mount type server of about 4.5 cm high). This occupies little space but provides high performance (Photo 2).

## ● Bottlenecks of Long Distance File Transmission

The wide area network is not for exclusive use but open to the public. Therefore, even though network performance is supposed to be improved by a different communication parameter, the change in performance cannot be measured when the network is busy. This makes it difficult to determine the effect of the applied parameter. Furthermore, stabilization of the communication performance may take some time in long distance data transfer, resulting in more time to decide on the communication parameter that offers high performance. This time, the PC cluster at the SC2002 booth and SCinet set up only during the conference term were mainly used for the field test and therefore had only two days to determine the communication parameter.

Meanwhile, in order to achieve the bandwidth at the level of theoretical peak performance, the network condition must be well maintained. This requires a good deal of study and coordination with the operators of the network to be used for the field test. The use of multiple extensive networks in Japan, the U.S. and across the Pacific Ocean complicated the identifying process of network malfunction. In fact, a symptom seemingly caused by network malfunction was observed during the experiment and there was a trouble identifying the source network and the cause. Finally, it was revealed that a bug found in a network system in the U.S. caused the trouble. Although the bandwidth recorded before modification was only 35 Mbps,

it exceeded 500 Mbps after error correction. Such problems can only be found when there is a need to fully utilize network bandwidth. As a result, the field test unexpectedly made a contribution to debugging the network in the U.S.

## ● Fruits of International Research Cooperation

For the field test, AIST developed software for Grid Datafarm and arranged for environments for the test while KEK developed a program to simulate the experiment of particle physics. Tokyo Institute of Technology generated the data of the simulated experiment to be distributed to the PC clusters for processing. Indiana University and SDSC participated in the project as a collaboration research in the framework of PRAGMA (Pacific Rim Applications and Grid Middleware Assembly, a collaboration for Grid application in the Pacific Rim), and cooperated in providing computing, network and storage resources, establishing the test environment and assessing the network performance (Photo 3).

## ● Future Prospects

Grid Datafarm aims at global secure sharing of Terabyte/Petabyte scale data processing. By utilizing higher speed networks and by employing larger scale equipment, a ten fold, even a hundred fold higher speed data transfer/processing can be achieved. A field test of greater magnitude is to be implemented in the future by using the global Grid network including Europe.

### ● Further Information

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# AIST Announces World's Thinnest Vertical-Type Double-Gate MOSFET Using Newly Discovered Process

## Significant Step toward Practical Application of the Double-Gate MOSFET, Namely-Ultimate MOSFET

The AIST Electronics Research Institute has succeeded in developing a vertical-type, double-gate MOSFET that is ultra-small and extremely power saving by adding the newly-discovered ion-bombardment-retarded etching process to the conventional CMOS production process. Simultaneously, they experimentally proved the superior device characteristics. The double-gate MOSFET is also called IMOSFET named after its resemblance to the letter "I".

This achievement is expected to lead the way to the practical application of the double-gate MOSFET, which is called "Ultimate MOSFET", to the ultra-large-scale integrated circuit, i.e. ULSI. The double-gate MOSFET was originally proposed by the former Electrotechnical Laboratory that was reorganised into AIST.

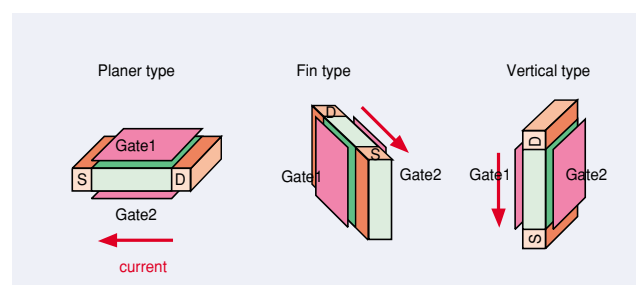


● Dr. Meishoku Masahara (left) and Dr. Eiichi Suzuki (right) of the Nanoelectronics Research Institute, who succeeded in the development of the world's thinnest vertical double-gate MOSFET

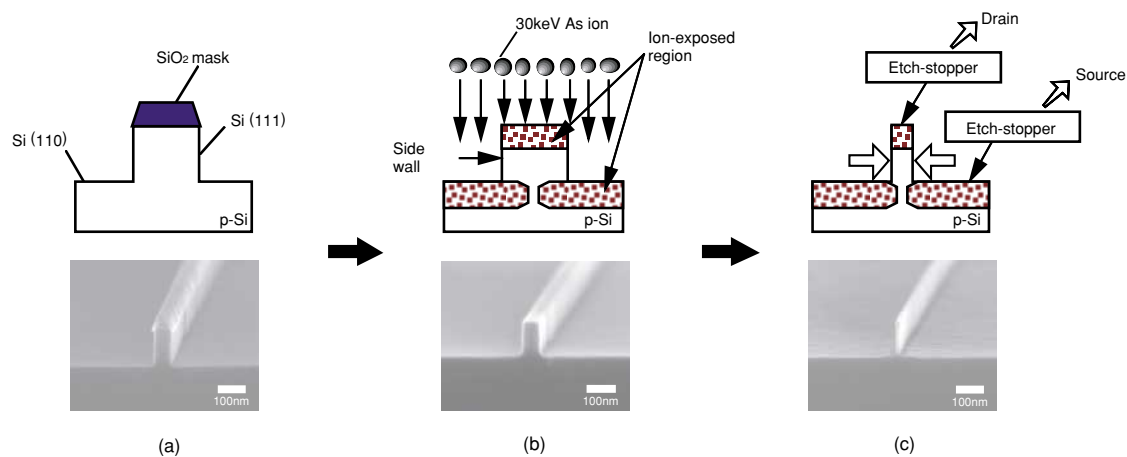
## Significant Step toward Practical Application of the Ultimate MOSFET

The miraculous development of the performance and integration density of silicon ULSIs composing the latest information and communication devices has achieved as a result of the minituarization of MOSFETs. However, major obstacles are expected to stand in a direct challenge to further miniaturization for further integration. The biggest hurdle to the further miniaturization is the short-channel effect, i.e., the mutual interference between the source and drain as the distance between them is reduced. This results in a degradation of the device performance, thus determining the limits of minituarization. Although the double-gate MOSFET, wherein a thin channel is layered between two gates, has been recognized as the ultimate device structure in order to eliminate this problem (See International Technology Roadmap for Semiconductors 2001). XMOSFET, the double-gate MOSFET, proposed by the former

Electrotechnical Laboratory for the first time in the world has not yet been put into practical application due to the difficulty of fabrication of the double-gate structure. However, the double-gate MOSFET has rapidly received much attention in the U.S. as a future device since 2000. The development of a Fin-type double-gate MOSFET (the double-gate MOSFET where the drain current horizontally flows through the Si Fin channel, see Fig.1, center) has been



● Fig.1  
Possible orientations of the double-gate MOSFETs.  
We have succeeded in developing a vertical-type, double-gate MOSFET among the possible three types.



● Fig.2

Flow chart of fabrication of an ultra-thin silicon wall using the ion-bombardment-retarded-etching process, and SEM photos of the Si wall channel at each step: (a) thicker Si wall formation by SiO<sub>2</sub> mask; (b) As-ion implantation after stripping the SiO<sub>2</sub> mask; (c) ultrathin Si wall channel formation by using IBRE (wall thickness: 15nm).

started at IBM, AMD, Intel and UCLA. The device's two-gate structure permits optimal control of threshold voltage, which makes it possible to minimize the power consumption. In this sense, the double-gate MOSFET is very promising as a solution to another problem inherent to ULSI, that is, desperate increase in power requirement.

The new vertical double-gate MOSFET developed by AIST utilizes a commercially available bulk Si substrate. Fabrication of the world's thinnest channel was achieved by using the conventional CMOS fabrication technology and the newly discovered process where an etching rate by an alkaline solution is greatly retarded at the surface exposed to ion bombardment. With this new process, the group has succeeded both in fabricating a prototype of the world's thinnest vertical double-gate MOSFET featuring a channel thickness of 15 nm and in providing the experimental proof of its double-gate performance. Actual measurements confirmed the superior electrical characteristics predicted by the theoretical evaluation. It can be said that this technology paves the way to the practical application of the double-gate MOSFET, or what is referred to as the ultimate MOSFET. These results were presented at the 2002 IEEE International Electron Devices Meeting (2002 IEDM) in December 2002 and generated great interest.

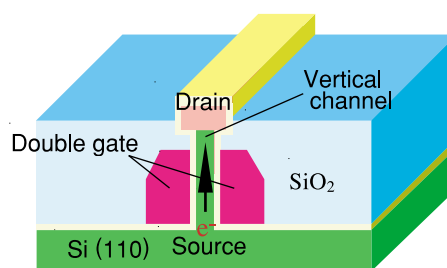
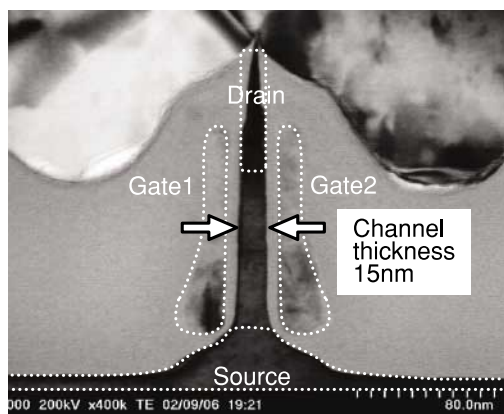
## ● Newly Developed Ion-Bombardment-Retarded-Etching Process

The technological breakthrough in forming the extremely thin Si wall that acts as a vertically oriented channel is the newly discovered ion-bombardment-retarded-etching phenomenon (patent pending). The commercially

available alkaline developing fluid (2.38% tetramethylammonium hydroxide) causes a significant retard in the etching rate for the Si substrate portions exposed to ion bombardment. Using these surfaces as etching masks, the group successfully formed a nanoscale wall on a bulk silicon substrate that serves as a vertically-oriented channel. Firstly, a somewhat thicker wall with SiO<sub>2</sub> mask was fabricated on a (110)-oriented Si substrate (Fig. 2 (a)). Secondly, 30keV As ions were implanted, where the top and the bottoms of the Si wall were exposed to the keV ions, while the sidewalls remained unexposed (Fig.2 (b)). When the Si wall is dipped in a TMAH solution, the ion-exposed region worked as an etch-stopper and the Si wall was horizontally etched, ensuring a high level of control of the Si wall thinning. This method is excellent in both repeatability and practicability, enabling it to easily fabricate a Si wall channel thinner than that achieved using lithography without any RIE damage. In fact, this method has been applied to the development of the fabrication process of a vertical double-gate MOSFET (IMOSFET) with an ultrathin Si wall channel.

## ● Verifying Excellent Device Characteristics

A cross-sectional TEM image of the world's thinnest IMOSFET is shown in Fig. 3. The Si wall thickness is measured to be 15 nm. The operation of the fabricated IMOSFET was verified and the experimental characteristics were precisely measured. Fig.4 shows the dependence of the gate threshold voltage ( $V_{th}$ ) and subthreshold slope (S-slope) on the Si channel thickness, both of which are the important indicators of the performance of the MOSFET. S-slope is



● Fig.3

Cross-sectional TEM image of the fabricated world's thinnest vertical double-gate MOSFET (IMOSFET) with a wall channel thickness of 15nm

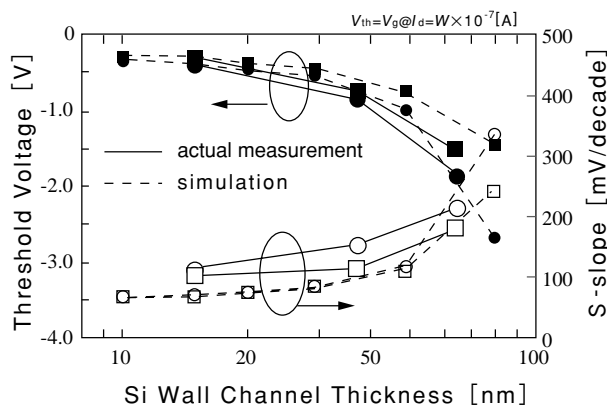
the necessary gate voltage when a drain current increases by one decade in the subthreshold region. The theoretical S-slope at room temperature is 60mV/decade. The prominent short-channel effects are the increase in the S-slope which means degrading drain current stand-up against a gate voltage and the threshold roll-off to the negative direction in case of n-channel. These effects can be effectively diminished by thinning of the Si channel, thus proving the superior characteristics of the double-gate MOSFET. It can be concluded, therefore, that the short-channel effects are sufficiently suppressed by making the Si-channel thickness less than 20nm as shown in Fig.4. This means that the characteristics of the device do not degrade but is rather improved by further scaling-down of the circuit elements. The finding is certainly a major advance in the realization of ultra-high density ULSIs in the future. The experimental results of the fabricated IMOSFET indicate that the S-slope degradation can be effectively inhibited even in the device with a ultra-short channel, meaning that less drain current is

required to turn on the device. Hence, the device contributes to less power consumption while the system is in operation. Furthermore, each of the two gates can be utilized to control the gate threshold voltage of one another. This function to optimally control the threshold voltage is an advantage for the power reduction.

## ● Future Prospects

These results have led to the establishment of a basic fabrication technology for scaled vertical MOSFETs(IMOSFETs) using a bulk silicon substrate. The newly developed IMOSFET fabrication technology has the following strong points and is expected to be applied to practical use: (1) utilization of ion-bombardment-retarded etching process to fabricate the thinnest Si wall without any process damage; (2) fabrication of a thinner wall than using lithography; (3) easy scaling to the level of nm by controlling the height of the Si wall; (4) a vertically shaped channel capable of carrying a high electric current; (5) allowing the introduction of a High-K gate dielectric material.

Future plans include improving device characteristics through optimization of the processes, establishing ULSI technology for ultra-low power, and multiple applications of the device, making the most of the features of the double-gate MOSFET as a 4-terminal device.



● Fig.4

Gate threshold voltage ( $V_{th}$ ) of the fabricated IMOSFET, and S-slope as a function of the Si wall channel thickness. Circles and squares indicate the values under the saturation mode and linear mode, respectively. Smaller S-slope and  $V_{th}$  mean that the short-channel behavior is suppressed.

## ● Further Information

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# 100<sup>th</sup> Anniversary of Measurement Standards

## New Technology and Frontiers in Measurement Standards

In 1903, the Central Inspection Institute of Weights and Measures was founded in Japan, and started on dissemination of the modern measurement standards. The year 2003 marked the 100<sup>th</sup> anniversary of the official introduction of the modern measurement standards in the country. Since the establishment of the core organization of measurement standard technologies, a national infrastructure for measurement in industry and science has largely contributed to the development of the country. Now, the AIST established a framework centering on the National Metrology Institute of Japan (NMIJ) that systematically addresses the issues related to measurement standards in physics, electricity and chemistry.

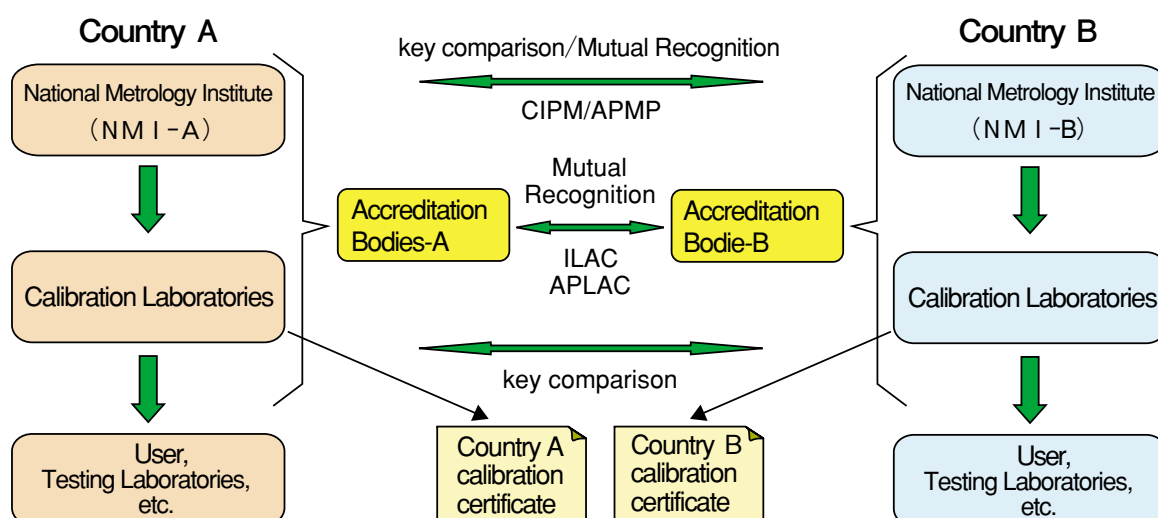


● Central Inspection Institute of Weights and Measures

## The Need of International Trade and Commerce

Goods arriving from foreign countries often create concerns regarding the accuracy of the quantity, the reliability of the permissible level of toxic substances and so on. It is indispensable to provide factual data based on both measurement and testing in order to eliminate such suspicions. However, if the data presented by the country

of origin disagrees with that shown by the importing country, the anxieties will continue. To solve this problem, the Traceability System and the Mutual Recognition Agreement have been introduced in the metrology world, to provide uniform and accurate metrology system for domestic and international measurement, respectively (Fig.1). By the traceability system, the calibration basis of any given measurement tool can be traced to the national standards. The Mutual Recognition Agreement acknowl-



● Fig.1 Traceability system and mutual recognition agreement



edges that the measurement standards of the participating countries have been certified as exact equivalents among any national research institution or authorized calibration organization of the member countries. The certifications of calibration issued by these organizations are to be mutually approved. These two systems will offer the foundation for mutual trust on the measurement data of respective countries.

In order to respond to expanding globalization in this field, the NMIJ is advancing the establishment of the quality system based on the international standards, and carrying out the comparison of national measurement standards of various countries. The introduction of this system will facilitate international trading and assure the consumers of the reliability of the quality indications of the product.

## Development of Measurement Standards in Next Generation

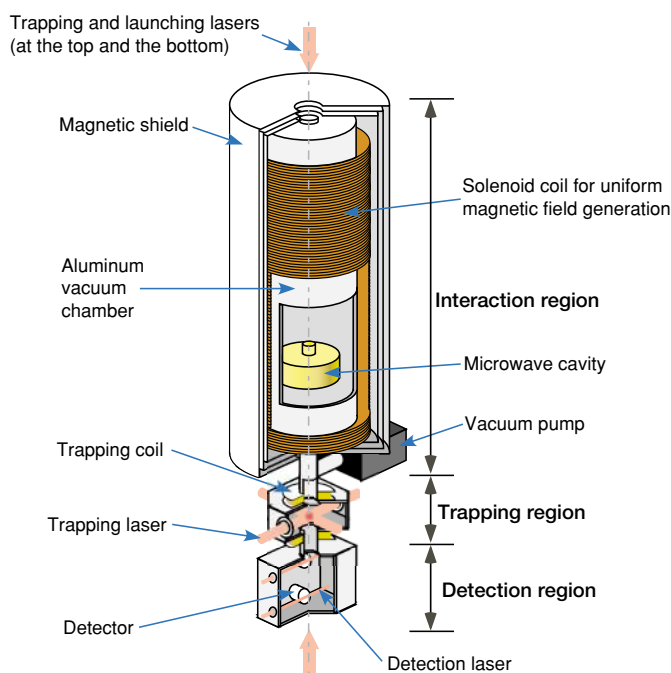
The rapid advancement of science and technology requires measurement standards which feature a new concept and has higher accuracy and stability. The AIST is taking a role to promote the development of the next

generation measurement standards that contribute to the advancement of science and technology.

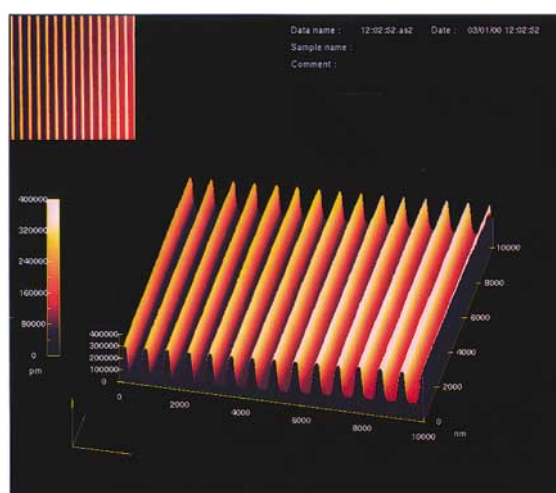
Taking a standard of time for instance, the NMIJ has developed an optically pumped Cs frequency standard. The uncertainty of the standard frequency is  $2.9 \times 10^{-14}$  and it serves as a reference for Coordinated Universal Time as one of the primary frequency standards. For further improvement of the accuracy of the frequency standard, the NMIJ is conducting the development of Cesium atomic fountain frequency standard (Fig. 2). The principle of this frequency standard is to grasp Cesium atoms using radiation pressure of laser light, launching them upwards and letting them fall down freely. It is expected to attain at least a single-digit decrease in the uncertainty compared to the conventional standards.

## Measurement Standards in High-Tech Industry

There is the rapid progress in the micro-fabrication technology in the field of semi-conductors and micro machines. It has long been suggested that the development of a high precision scale measurable of nanometer digits is essential to support these fabrication technologies



● Fig.2 Cesium atomic fountain frequency standard



● Photo.1 AFM image of a one-dimensional diffraction grating

(nanometrology). Currently, the NMIJ is developing the technology that enables accurate measurement of minute surface features. The scope of research includes the development of a nanoscale "yardstick" that is applicable to the measurement in depth direction.

The newly developed atomic force microscopy (AFM) combined with a homodyne laser interferometer is utilized for the calibration of dimension and shape in minute scales. This apparatus serves for the calibration of grid spacing of one-dimensional diffraction grating for a nanoscale "yardstick"(Photo.1). Additional research on measurement standards will further the advancement of high technologies and contribute to industrial developments.

## Measurement Standards in Biotechnology

Although there has been remarkable progress in the field of biotechnology, it is only recently that the question was posed regarding the reliability of analysis methods and analytical instruments. The Consultative Committee for Amount of Substance (CCQM) of International Bureau of Weights and Measures (BIPM) ensures the traceability of analytical data to the International System of Units (SI) and

international consistency of measurement standards in the biotechnology field. Furthermore, Joint Committee on Traceability in Laboratory Medicine (JCTLM) was set up with the purpose of establishing traceability in the field of pharmaceutical products. Thus, the metrological concept that involves evaluation of uncertainty has been rapidly adopted in the fields of biotechnology and clinical analysis. The NMIJ is proactive in promoting measurement standards for the biotechnological field in close cooperation with the related research units in response to the rapid advancements in this area.

## Measurement Standards in Environment, Safety and Health

In recent years, there has been a growing interest in environmental, safety and health issues. Even an extremely small amount of environmental pollutants such as sick house gas, PCB and environment hormone may cause seriously harmful effects to not only humans but also to ecological systems. As the volume of the substance to test is extremely minute, it is likely that the test results may vary depending on the test methodology and the testing organization even though an identical sample is used. Therefore, the NMIJ is supplying reference materials for precision calibration of the testing equipment. For example, the NMIJ has developed two types of sea bottom reference materials for analyzing butyltins and poisonous metals. These materials enable the analysis of trace amounts of harmful substances contained in sea-bottom soil (Photo.2). In addition, their reference materials for environmental hormone disruptors have become available. The NMIJ will proceed with the development of reference materials in order to cope with various environmental issues.



● Photo.2 Sea bottom reference materials for analyzing butyltins and poisonous metals

## Expanding Role of NMIJ

Starting from weights and measures, the application of measurement standards has been gradually broadened. At the start of the 21<sup>st</sup> century, the importance of measurement standards will be enhanced for the advancement of high-tech industries, and will contribute to solve environmental, health and safety issues.

# AIST RESEARCH HOT LINE

# UPDATES FROM THE CUTTING EDGE

(Jan. - Mar. 2003)

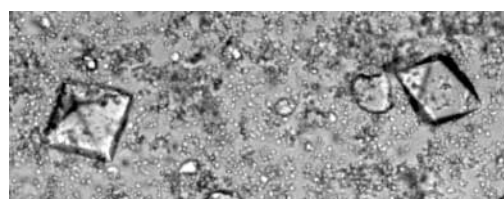
The abstracts of the recent research information appeared on the Vol.3 No.1-No.3 of "AIST Today" are introduced and classified by research area.  
For inquiry about the full article, please contact the author directly.

## Life Science & Technology

### Action of a Water-Soluble Polymer on Protein Crystal Growth

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(2003) 17

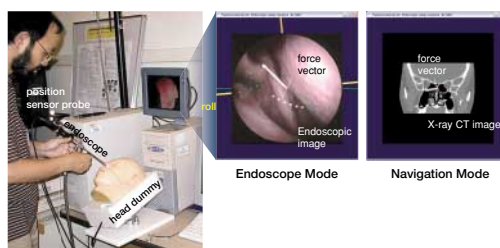
Addition of polyethylene glycol (PEG) has been empirically known to promote crystallization of a number of proteins. We have recently shown that the "depletion model" can be used to reproduce the attractive interaction between apoferritin molecules induced by addition of PEG [S. Tanaka and M. Ataka: *J. Chem. Phys.* 117, 3504 (2002)]. The depletion model, originally proposed in 1953 by Asakura and Oosawa, is used recently to explain the behavior of a variety of protein and colloid solutions. Combination of the model with a recent theory of protein crystallization is capable of predicting the most efficient molecular weight of PEG.



A microscopic photograph of apoferritin crystals obtained by the addition of polyethylene glycol.

# Endoscopic Sinus Surgery Training System

Recent surgical technology provides less invasiveness for patients, but requires surgeon's higher surgical skills and experience than conventional means. We are developing an endoscopic sinus surgery training system for surgical skill evaluation. It consists of a realistic head dummy, force sensor, position sensor and computer. While a trainee doctor performs surgical procedures inside the dummy, the force vector is overlaid on an endoscopic image, to alert to excessive collision between the surgical tools and the dummy. The orientation of the endoscope is also shown to avoid its unnecessary rolling. The position of the surgical tools is displayed as a sliced X-ray CT image at the tip of the tool.



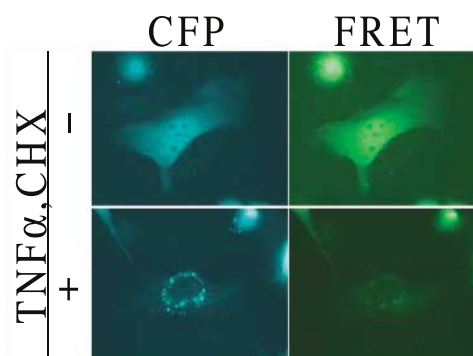
Endoscopic sinus surgery training system with force and position sensors.

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AIST Today Vol. 3, No. 2  
(2003) 19

# Apoptotic Pathways in Alzheimer's Disease

Alzheimer's disease, a progressive neurodegenerative disorder, is characterized by deposition of A $\beta$ , accumulation of intercellular neurofibrillary tangles, and neuronal cell loss. Recently, it was reported that the activation of caspase 8 was observed in A $\beta$ -induced neuronal apoptosis. In general, when cells are exposed to death-inducing molecules such as TNF- $\alpha$  or Fas, caspase 8 is activated and cleaves an apoptotic facilitator Bid that is a member of the Bcl-2 family. After additional modification, the carboxy-terminal moiety of Bid is translocated to the mitochondria and induces the release of cytochrome c into the cytoplasm. In an attempt to directly observe the cleavage of Bid and the following events in living cells, we constructed a vector that encoded Bid fused with YFP and CFP (YFP-Bid-CFP). Upon expression of YFP-Bid-CFP in mammalian cells, we were able to observe the efficient transfer of energy from excited CFP to YFP within the YFP-Bid-CFP molecule, and, importantly, the fusion protein YFP-Bid-CFP was fully functional in cells. When YFP-Bid-CFP was cleaved by caspase 8, upon activation by anti-Fas antibodies

but not by A $\beta$  or tunicamycin, no such transfer of energy was detected. This data suggests that other apoptotic pathways are more important in A $\beta$ -induced apoptosis.



Activation of caspase 8 was detected in single cells by disappearance of Fluorescence energy resonance transfer (FRET). CFP-Bid-YFP-expressed COS 7 cells were incubated with TNF $\alpha$  and cycloheximide (CHX) to induce cell death. In general, caspase 8 is activated by TNF- $\alpha$  and CHX.

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AIST Today Vol. 3, No. 3  
(2003) 11

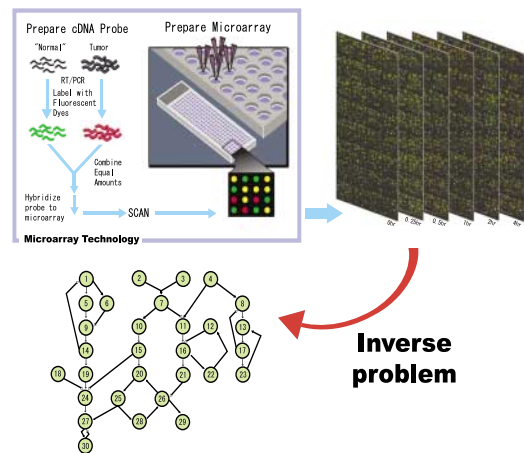
# Inference Structures of Gene Regulatory Networks

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AIST Today Vol. 3, No. 3  
(2003) 12

We have developed an efficient algorithm base on the genetic algorithm (GA) for optimization of a nonlinear system where the details of gene regulatory networks.

Estimation of the interaction mechanisms among system components by using experimentally observed dynamic responses (time-courses) of some of the system components is generally referred to as "inverse problem". The S-system, which belongs to power-law formalism, is one of the best representations to solve such an inverse problem; the S-system is rich enough in structure to capture all relevant dynamics. In our research, for the purpose of solving the inverse problem, we introduce the genetic algorithm and propose an efficient

procedure for the estimation of large number of parameters in the S-system formalism.



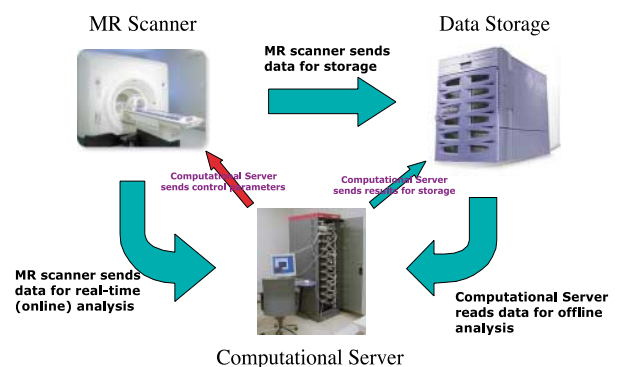
1. Measure gene expression levels with DNA microarray technology in time. 2. Our algorithm optimizes mathematical network models to fit to observed expression data.

# Development of a Fully Real-Time Functional MRI Analysis System

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(2003) 13

A system for the real-time analysis of functional magnetic resonance imaging (fMRI) time series is developed. The system is composed of an MR scanner subsystem for data acquisition and paradigm control, a computational server (a PC cluster) for real-time fMRI data analysis, and a storage device for storing data. The system exploits the advantages of parallel computing, coupled with an efficient general linear model (GLM) coefficient estimation algorithm, to overcome several issues constraining the analysis of the whole-brain fMRI data in real time. The highly parallel, voxel-wise processing of fMRI data motivated the use of a cluster of personal computers for parallel computation. Aside from gaining a significant increase in computational speed, PC clusters provide a ver-

satile way to handle the computational requirements of the system. The use of GLM in the supporting software allows substantial parametric analysis to be performed.



Schematic diagram of the real-time functional magnetic resonance imaging system composing of an MR scanner, a data storage device, and a computational server.



## A Tele-Operated Humanoid Robot Drives a Backhoe in the Open Air!

The Intelligent Systems Institute of AIST, Kawasaki Heavy Industries, Ltd., and Tokyu Construction Co., Ltd. have achieved a world-first success in their joint development of a tele-operated humanoid robot that wears protective clothing and drives an industrial vehicle (backhoe) outdoors in lieu of a human operator as shown in Fig. 1. It shows us that a humanoid robot can expand its capability by using machines designed for the human even in the rain. The use of a tele-operated humanoid robot has a possibility to make all machines tele-operated without any modifications and do also incidental tasks instead of the human.



Teleoperated humanoid robot drives a backhoe.

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*AIST Today* Vol. 3, No.3  
(2003) 14

# Development of an Organotin Removal Process Utilizing Marine Bioremediation

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 AIST Today Vol. 3, No. 3  
 (2003) 18

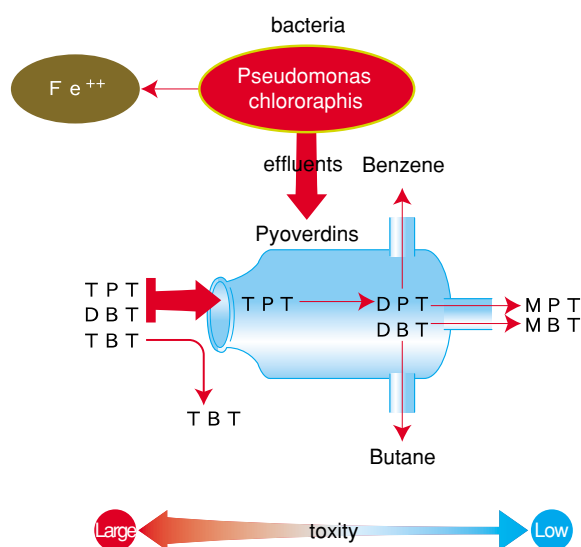
Tin and organotins are toxic to a wide variety of marine organisms at levels present in polluted environments and thus may be an ecological and safety problem. Organotin compounds have been used as biocides in antifouling paints applied to the surface of ship bottoms and fishing nets. The various environmental problems produced by organotins are demonstrated by that triphenyltin (TPT) being degraded with a culture solution of the bacteria *Pseudomonas chlororaphis*, and that TPT, diphenyltin (DPT) and dibutyltin (DBT) being broken down to monophenyltin (MPT) and monobutyltin (MBT) with the yellow compounds from *P. chlororaphis*.

The identify of the yellow compounds obtained from *P. chlororaphis* was confirmed by the UV and spectrum, NMR spectrums, fast atom bombardment mass spectrometry (FAB-MS) and amino acid analysis. The yellow substances gave a molecular peak at  $m/z=1161$  and have similar UV spectra ( $\lambda_{\max}=400\text{nm}$ ) to pyoverdine from *P. fluorescens*. The acid hydrolysis of the yellow compounds indicated that they are constituted of three amino acids, possessing 2 mol of serine, 2 mol of lysine and 1 mol of

glycine. Analysis of a 47% HI hydrolysate revealed 2 mol of hydroxyornithine (HOornithine). The pyoverdine structure shows a fluorescent chromophore, which is a quinoline derivatives, and a peptide arm of seven amino acid residues.

The TPT, DPT and DBT in sea water were degraded to monophenyltin and monobutyltin., respectively. Degradation of TPT, DPT and DBT in water can be faster than that in sea water. Optimum degradation was at pH 7-8.5 and a temperature of 30°C. The Fe and Al remarkably inhibited degradation activity. These results suggested that pyoverdine could function as a catalyst not only in a metal-free state, but also in a metal-chelating state.

We investigated an immobilization technique for *P. chlororaphis* to remove the organotin compounds in the environments. Cells were immobilized in 2% alginate beads, and pyoverdine production by the immobilized cells was studied in sea water. The results suggested that immobilized cells could be applied to the *in situ* bioremediation of organotin.



Degradation pathway of organotin by pyoverdins  
 1: TPT and DPT were degraded to phenyltin with the release of benzene.  
 2: DBT was degraded to butyltin with the release of butane.  
 3: TPT, DPT and TBT are many more orders of magnitude more toxic than phenyl- and butyltin.

# Feasibility Study of Photovoltaic Systems in Gobi Desert, Mongolia

In Gobi Desert, Mongolia, the Photovoltaic Systems Group set up two types of photovoltaic modules and the checking devices (e.g. I-V Curve Tracer, etc.) as well as the meteorological monitoring devices to study the characteristics of the photovoltaic system operation in the severe natural environment, in corporation with National University of Mongolia. Purpose of this study is to verify the output simulation technique for the vary-large-scale photovoltaic system (VLS-PV) to confirm the efficiency of using the large scaled concentrated photovoltaic system to be in this area, and also to clarify the specification requirement for the system design. The latest monitoring results are presented.



Photovoltaic System Operation Monitoring System at Sainshand, Mongolia. Irradiation, temperature, wind, ground albedo, and I-V characteristics of two types of PV modules are measured every ten minutes.

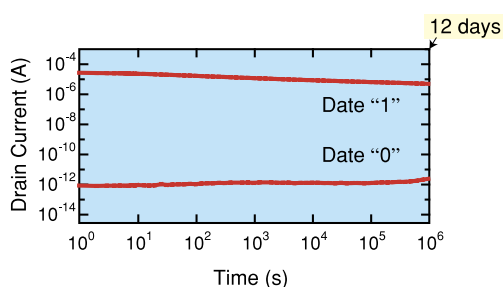
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*AIST Today* Vol. 3, No. 3  
(2003) 10

# Development of a Ferroelectric Gate Memory FET with a Long Data Retention

A ferroelectric gate field effect transistor (FET) has been developed. A hafnium composite oxide has been used as a buffer layer between the silicon and ferroelectric  $\text{SrBi}_2\text{Ta}_2\text{O}_9$ . Since this FET itself has functions of data storage and non-destructive read out, application to a next-generation memory was expected for a long time. However, the data retention properties reported so far were poor. The FET developed in AIST has superior data retention characteristics even after experiencing 12 days from the data entry. This success is a large breakthrough that opens up the way for the practical application to one transistor type fer-

roelectric random access non-volatile memory (1T-FeRAM).



Data retention characteristics of a ferroelectric gate memory FET

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*AIST Today* Vol. 3, No. 1  
(2003) 18

# One-Dimensional Organization of Copper Nanoparticles

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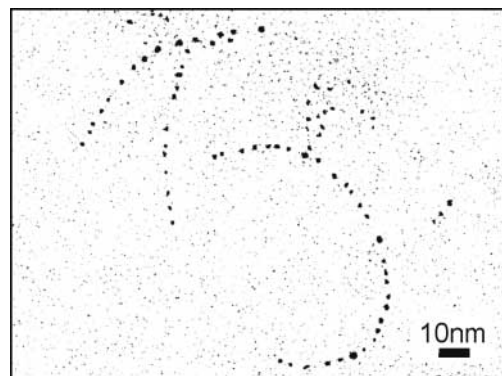
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AIST Today Vol. 3, No. 1

(2003) 19

One-dimensional copper nanoparticles have been easily organized by one-step wet chemical technique. Dicarboxylic peptide bolaamphiphile coordinated with copper ions to form metal-lipid hybrid nanofibers in water. When copper ions were reduced by hydrazine using hybrid nanofiber as a template, a gray colloidal dispersion was obtained. TEM of the colloidal dispersion show the existence of fibrous assemblies and large aggregates. High-magnification TEM also clarified that nanoparticles with diameters of 1-3 nm are organized one-dimensionally at intervals of 2-5 nm.



TEM image of the colloid

## A New Method to Construct Single-Molecular Arrays

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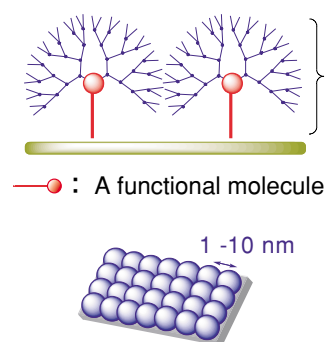
We have developed a new method to construct nanospace around a single molecule using dendrimer architectures on surfaces so that the individual molecules can function without intervention from the neighbors, like electrical cross-talk, mechanical contact and so on.

Our new method is as follows: First, a self-assembled monolayer of dendrimers having a functional molecule with a sticky group on the surface is formed on Au or Si surface. The func-

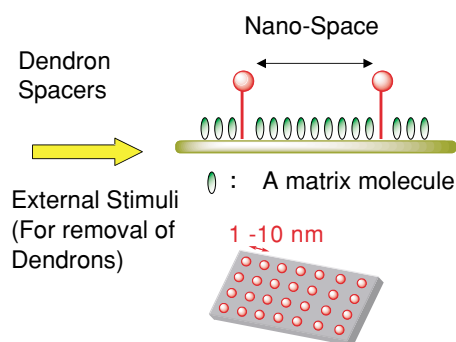
tional molecule is focally-substituted with the dendrons through bonding labile to external stimuli such as a base, light, etc. Second, the dendron spacers are removed by external stimuli so that a single-molecule-array with a lattice spacing dependent on the size of the dendron is left on the surface.

Taking advantage of this new method, we are now developing complicated single-molecular devices.

(1) Dendrimer Monolayer



(2) Single-Molecular Array



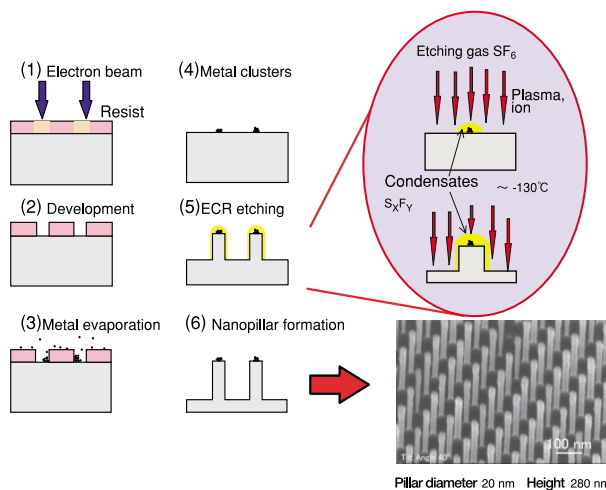
A new method to construct single-molecular arrays using dendron spacers

# Fabrication of Si Nanopillars and its Application

We have developed a fabrication process using self-formation of etching masks with metal clusters as formation nuclei. When Si substrates deposited with metal clusters are subjected to electron cyclotron plasma etching with  $\text{SF}_6$  at around  $-130^\circ\text{C}$ , reaction products in the plasma,  $\text{S}_x\text{F}_y$ , condense preferentially at the clusters, leading to the self-formation of nanoscale etching masks. As a result, Si pillars, about 10 nm in diameter and 100 nm tall, have been formed with remarkably narrow size-distributions when we use Au clusters (diameter: 1–3 nm). We have also found that Si nanopillars with a very high aspect ratio ( $\sim 20$ ) can be fabricated by using Fe clusters.

This process has been easily combined with electron beam lithog-

raphy technique, which enables us to define pillar positions. Using this process, we have fabricated field emitters, 2-dimensional photonic crystals with waveguides *etc.*



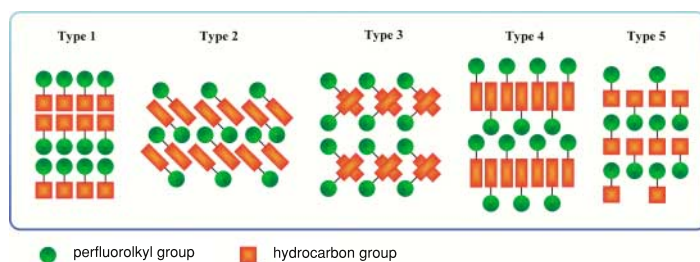
The fabrication process of Si nanopillars

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AIST Today Vol. 3, No. 2  
(2003) 10

# New Crystal Engineering Based on Fluorine-Containing Hybrid Compounds

We have recently proposed new crystal engineering utilizing so-called fluorophilic nature of the perfluoro compounds. Our idea is based on the fluorine-containing hybrid compounds,  $\text{RF-X-RH}$ , consisting of a junction group (X), perfluoroalkyl (RF) and hydrocarbon (RH) moieties. Systematic investigation of the crystal structures of such hybrid compounds revealed the ex-

istence of five motifs (Type I to V) in their crystal packings and their relationships with the topology of the molecules. Based on the topology-packing relationship, we designed polymerizable diacetylene derivatives with the Type II packing motif and actually obtained black polymer crystals with metallic luster by solid-state polymerization under uv irradiations.



Five motifs (I-V) found in the crystal packing of the hybrid compounds  $\text{RF-X-RH}$ .

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(2003) 11



# Fabrication of Gold Nanoparticle / Silica Composite Aerogel via Spontaneous Nanocomposite Formation

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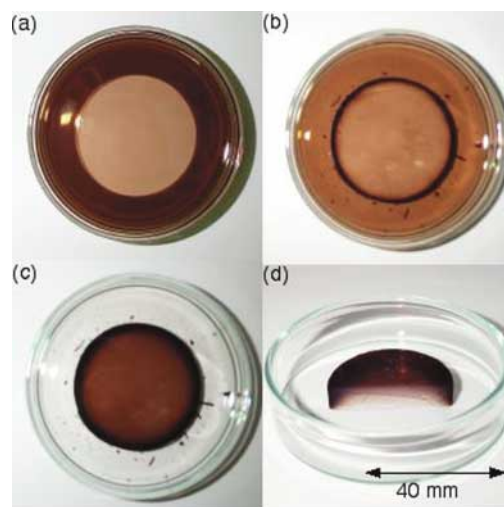
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*AIST Today* Vol. 3, No. 2

(2003)12

A nanocomposite of dodecanethiol-passivated Au nanoparticles (average diameter 2.6 nm) and a silica aerogel has been fabricated. It was found that the Au particles were efficiently adsorbed on a silica wet-gel in organic solvents and that the particles were not flushed out by supercritical CO<sub>2</sub> drying. The size distribution of the Au cores did not change in the drying process. The composite formation from the preformed nanoparticles and silica gel, and the formation of composite aerogel without changing the particle sizes can lead to a simple and efficient way to production of devices with non-linear optical property or high catalytic activity.



Photographic images of silica wet-gel in the Au nanoparticle-toluene solution at (a) 0, (b) 5, and (c) 57 hours after immersion. (d) a photographic image of the nanoparticle /silica composite aerogel. The product aerogel was cut into two to show the spatial distribution of the nanoparticles.

## Active Micromixer Array for Microfluidic Systems

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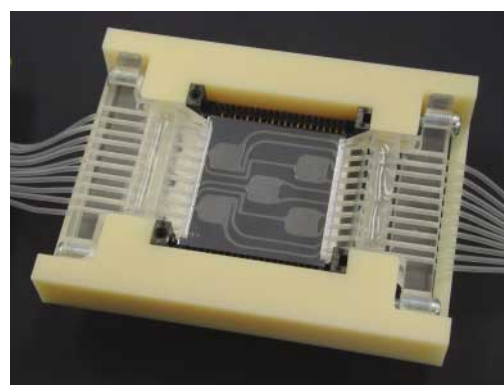
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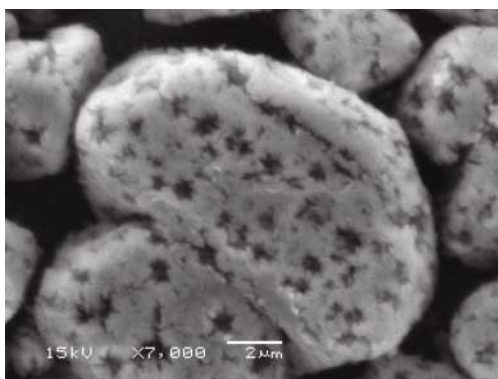
A micromixer array for continuous flow has been developed. The device is fabricated using micromachining technologies. The pattern of inlets, outlet and mixing chamber are formed in glass. The entire flow path is encapsulated by anodic bonding of a Si wafer to the glass. A bulk piezoelectric PZT ceramic is adhered on the back-side of each mixing chamber. When a piezoelectric ceramic is excited by a 60 kHz square wave, mixing occurs directly from the ultrasonic irradiation. Both qualitative and quantitative evaluations have been done. It shows an effective and reliable solution with fully controlling for integrated microchemical synthesis systems or for micro total analysis systems.



A 5-micromixer array chip mounted on a testing socket. Each mixer has two inlets and one outlet. The volume of each mixing chamber is 0.7  $\mu$ l.

# Sonochemical Fabrication of Porous Zinc Oxide Film

Given its potential as semiconductor and optically active materials, ZnO is an attractive material both from scientific and technological points of view. A new form of ZnO, porous zinc oxide films were prepared by a sonochemical deposition of  $\text{Zn}(\text{OH})_2$  and the following low-temperature annealing. The deposition process is based on a destabilization of zinc hydroxide/ammine complex by power ultrasonic irradiation in an aqueous solution. The porous ZnO films affords promising industrial applications such as sensors and catalysts.

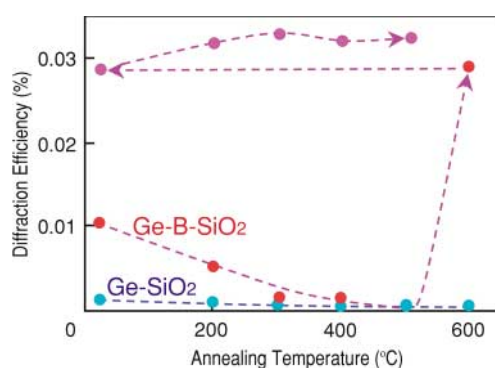


SEM image of the porous ZnO film

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AIST Today Vol. 3, No. 2  
(2003) 14

# Waveguide Filter with Thermally Stabilized Photo-Induced Bragg Grating

Bragg gratings were printed in Ge-B-SiO<sub>2</sub> thin glass films by KrF excimer laser irradiation through a phase mask. Although the gratings were almost erased upon annealing at temperatures lower than 500°C, a grating with much high diffraction efficiency was formed after annealing at 600°C. The diffraction efficiency of the grating was approximately one order of magnitude greater than that of the Ge-SiO<sub>2</sub> film. The diffraction efficiency of the grating was unchanged upon repeated heating between room temperature and 600°C. Thermally stable waveguide wavelength filter could be obtained by using the thermally stabilized photo-induced Bragg grating.



Changes in diffraction efficiencies of the fabricated gratings

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AIST Today Vol. 3, No. 3  
(2003) 15

# Preparation of Boron Nano-Cluster Solids

- A challenge to the novel functional materials using nano-cluster solids -

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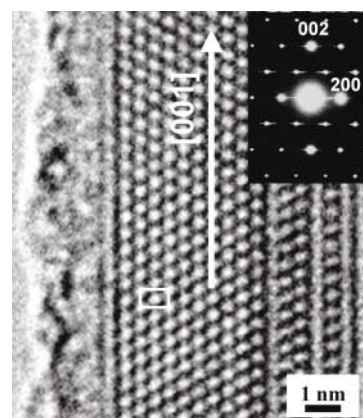
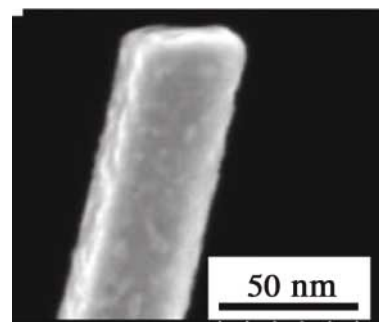
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Nano-cluster solid materials show unique physical properties depending on the cluster structure and are considered as new functional materials. For example, doped boron crystals are expected to be a high  $T_c$  superconductor. We have succeeded in the preparation of a boron nano-cluster solids with a belt-like shape by a low vacuum PLD method. The boron nano-belt shows a tetragonal single crystal structure that is unstable for the bulk without impurities.



"SEM image showing belt-like shape (a) and HRTEM image with a inset of electron diffraction pattern. (b) for a boron nano-cluster solid. "

## Role of the Atomic Modulations in Aperiodic Composite Crystal

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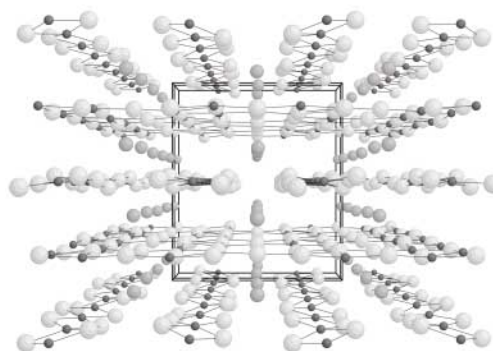
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*AIST Today* Vol. 3, No. 3

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Recently, advanced materials with unusual electronic and/or magnetic properties have been desired. Aperiodic crystals with long range ordered atomic arrangements, for example, present interesting structural properties for the functional materials above mentioned. Especially, in the composite crystals with plural substructures, a variety of interesting properties for superconductors or thermoelectric materials have been observed because there are mutual lattice modulations between the substructures. The (3+1)-dimensional superspace group symmetry is the most convenient method to describe the modulated structures of aperiodic crystals. By the use of the superspace group approach, the mechanism of hole transfer

in  $(\text{Sr}_2\text{Cu}_2\text{O}_3)_{0.70}\text{CuO}_2$ , " $\text{Sr}_{14}\text{Cu}_{24}\text{O}_{41}$ " has been investigated.



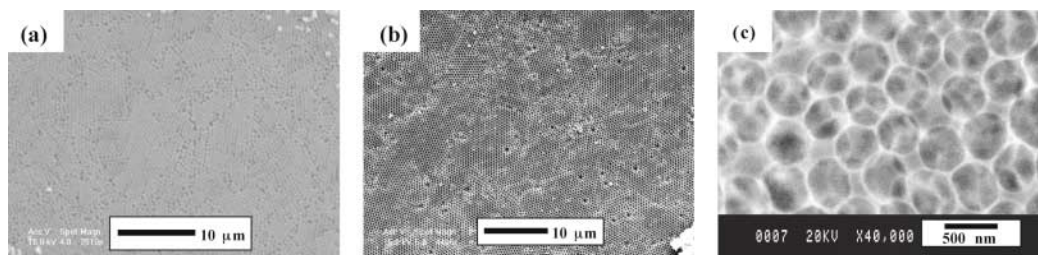
Modulated composite structure of  $(\text{Sr}_2\text{Cu}_2\text{O}_3)_{0.70}\text{CuO}_2$ , " $\text{Sr}_{14}\text{Cu}_{24}\text{O}_{41}$ ".

## Ceramic Macroporous Structures with Controlled Pores

We researched fabrication of porous ceramics with controlled pores with Dr. P. Alberius and Dr. L. Bergström who belong to YKI, Institute for Surface Chemistry, Sweden. Polystyrene (PS) colloidal particles have been used as templates to produce ordered silica macroporous structures. The silica-films were deposited from ethanol solution containing acidic water and tetraethyl orthosilicate. The silica covered PS spheres were

characterized using transmission electron microscopy, and the film thickness determined by scanning electron microscopy. Ordered macroporous structures were formed by centrifugation of silica-coated PS spheres. Calcination of the close-packed spheres yielded a continuous silica matrix consisting of a three-dimensional well-ordered network of monodisperse pores.

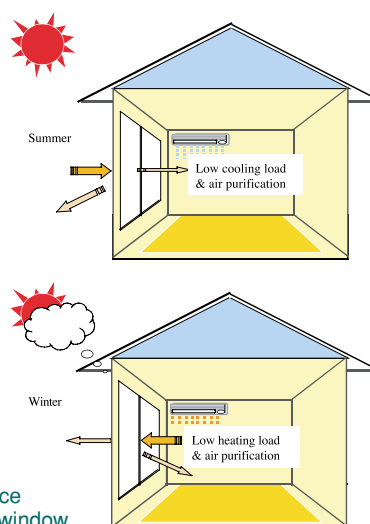
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AIST Today Vol. 3, No. 1  
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SEM micrographs of close-packed structures formed by centrifugation of silica-coated PS particles. (a) Prior to calcination; (b) After calcining at 500 °C; and (c) The structure at higher magnification.

## The Development of a Multifunctional Energy Efficient Window

Researches have been carried on to make energy efficient windows which also make the living space more comfortable. We are developing a novel multifunctional window for automatic solar/heat control using a phase-transition material in combination with a photocatalytic coating for antireflection and environmental purification. The window is highly visible transparent, almost totally ultraviolet stopping, with automatic solar/heat control and a variety of photocatalytic performance for environment purification.



Schematic performance of the multifunctional window

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(2003) 22

# Development of Air-Floating-Like Easy-to-Slide “Mirror-Polished Diamond Slider”

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AIST Today Vol. 3, No. 1  
(2003) 23

AIST tohoku has developed a mirror-polished diamond slider with a low friction coefficient close to air-floating conditions. A coating technique has been established for Chemical Vapor-Deposited (CVD) diamond film onto machinable titanium silicon carbide. This technology affords a much improved degree of freedom in selecting the shape of the substrate.

The superior sliding performance is attributed to the mixed lubricant effect resulting from a combination of the solid diamond lubricant and the fluid lubricant brought about by the intervening air. It becomes also possible to use a machinable titanium silicon carbide as the substrate for diamond deposition. Until the present, fabrication of CVD diamond has only been possible on flat substrate surfaces or for small cutting tools. With the new technology, however, it will be possible to use this process for coating any shape of sliding surfaces. In the past, the suitable materials as substrates for CVD diamond were limited to brittle silicon or very hard silicon carbide and silicon ni-

tride, or tungsten carbide that are heavy and difficult to machine.

The newly developed diamond sliding surface essentially presupposes the use of a diamond-to-diamond combination. At low contact pressures, however, it is also possible for the diamond surface to mate with a metal surface, since the diamond film will provide a smooth air-floating like sliding performance also with machined surfaces such as stainless steel.



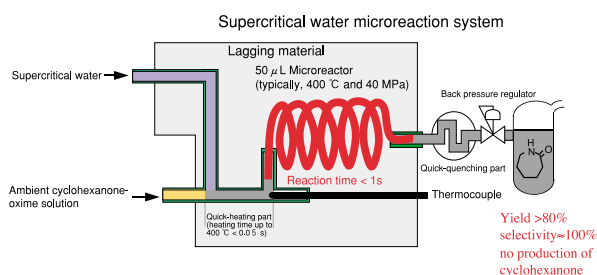
CVD diamond slider put on a stainless steel guide.

## Innovation in Chemical Reactions using a Supercritical Water Microreaction System

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(2003) 15

The Beckmann rearrangement into  $\epsilon$ -caprolactam is one of the most industrially important acid-catalyzed reactions, which is the starting monomer for the production of nylon 6. However, its practical production has suffered from serious disadvantages of using environmentally damaging catalysts such as highly concentrated sulfuric acid and of forming large quantities of valueless by-products such as ammonium sulfate. We demonstrate that our supercritical water microreaction system can achieve a

high selectivity in a satisfactory yield for the  $\epsilon$ -caprolactam production even in the absence of any acids.



Yield >80%  
selectivity=100%  
no production of  
cyclohexanone

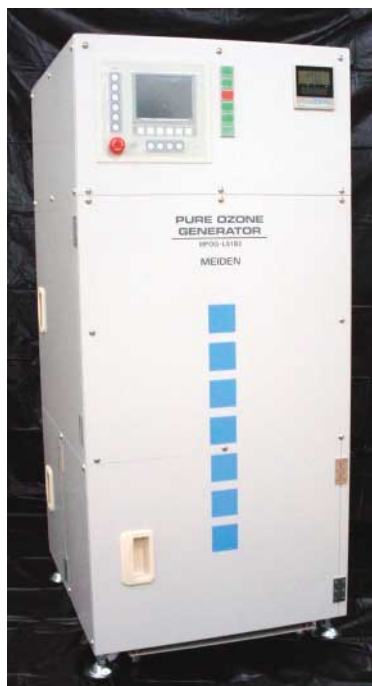
Supercritical water microreaction system



# Development and Commercialization of 100% Ozone Gas Generator

We have succeeded in the development of a new ozone generator that can supply 100% (over 93% at sample position) ozone gas, and its commercialization through the collaboration with Meidensha Co. at the product name of "Pure ozone generator". The outlook of the generator is shown in Fig.1.

The generator adopts distillation process to obtain highly concentrated ozone gas. That is, 5%-ozone/oxygen mixture gas generated by a commercial ozonizer is let through an ozone vessel kept at 90 K to accumulate pure liquid ozone, with oxygen gas being evacuated by a vacuum pump. Then the ozone vessel is heated to a selected temperature (usually between 95K and 120K) to supply pure ozone gas having an equilibrium vapor pressure at the temperature. The highest ozone pressure and the maximum amount of ozone gas supplied with the generator are 2000 Pa and 3.7 m<sup>3</sup> (at 100 Pa), respectively. The supplied ozone flux is very stable, typically with 2% fluctuation, since the vessel temperature is controlled with an accuracy of 0.1 K,



Pure ozone generator which has been put on sale since Dec. 2002 by Meidensha Co.

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*AIST Today* Vol. 3, No. 1  
(2003) 24

# Synthesis of Metal Oxycarbides Hard Films by Plasma Assisted Sputtering

- New hard coating method using carbon dioxide, methane and metal -

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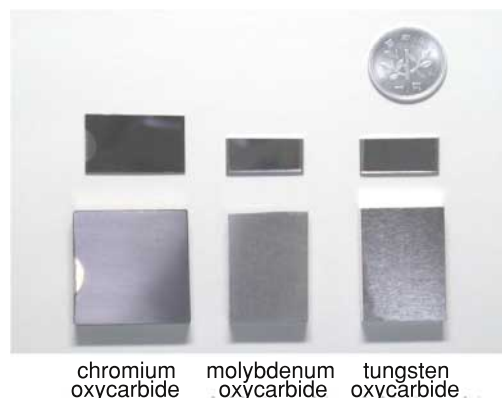
AIST Today Vol. 3, No.2

(2003) 16

It has been well known that metal hexacarbonyl can be prepared by chemical vapor deposition to give a range of oxycarbide which shows high hardness and high anti-corrosive properties.

Recently, instead of the decomposition of metal organic sources by the chemical vapor deposition, there has been a growing interest in synthesis by reactive physical vapor deposition because of the operation without use of metal organic toxic sources. We have synthesized chromium oxycarbide and molybdenum oxycarbide films from metals and carbon dioxide without metal hexacarbonyl by the inductively coupled rf plasma assisted magnetron sputtering method. But cubic tungsten oxycarbide with high hardness has not been synthesized well by the method. In order to increase activated molecules of carbon dioxide in the plasma and to promote the reaction of tungsten atoms with carbon dioxide in reactive sputtering, a mixture of Ar, He, CO<sub>2</sub> and CH<sub>4</sub> was

used as sputtering gas for the sputtering method, and tungsten oxycarbide films were synthesized with metal and carbon dioxide by this method. In near future, the metal oxycarbides are expected to be used widely as hard coating materials.



Chromium oxycarbide, molybdenum oxycarbide and tungsten oxycarbide synthesized on stainless steel substrates (upper side) and aluminum alloy substrates (lower side) by inductively coupled rf plasma assisted magnetron sputtering. The micro-Vickers hardness of the films is more than 21GPa. [The diameter of a coin is 20 mm.]

## Standards and Measurement Technology

### Measurement of Frequency Dependence of Fused-Silica Standard Capacitor

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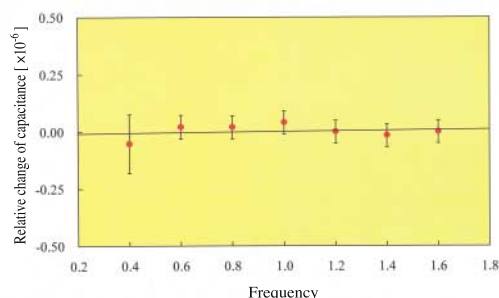
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AIST Today Vol. 3, No. 1

(2003) 25

The frequency dependences of fused-silica standard capacitors have been measured precisely. The capacitors used in the measurements are commercially available. The results have shown that their capacitances are frequency independent in the range between 0.4 kHz and 1.6 kHz.



Frequency dependence of a fused-silica standard capacitor.

# Naked Eye Detection of Anions

Luminescence sensing systems, which enabled “naked eye detection” of fluoride ion and catecholamines (adrenaline, noradrenaline, and dopamine), were constructed. These systems are based on the ligand exchange reaction between the analyte ion and a luminescent probe ligand at a ternary complex. Ligand exchange reaction between fluoride ion and flavonol in the ternary complex, [Zr(IV)EDTA(flavonol)] depresses the intensity of blue fluorescence, providing a simple fluorescent detection system of fluoride ion. The ternary complex consisting of Tb(III)-EDTA and sulfosalicylic acid as a signaling molecule exhibits the characteristic sharp emission due to energy transfer luminescence, is utilized for the facile determination of catecholamines.

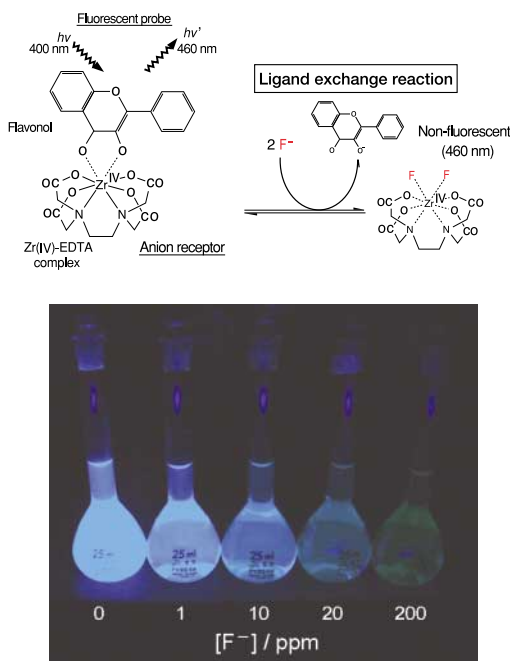
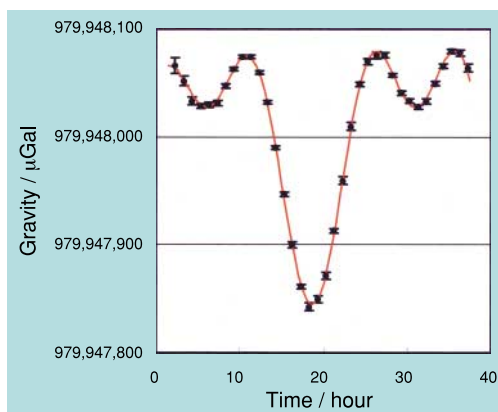


Figure photograph of fluorescence irradiated by handy UV lamp (Ex: 365 nm).

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AIST Today Vol. 3, No. 2  
(2003) 17

# Gravity Measurement for Reliable Mechanical Standards

The NMIJ/AIST is responsible for establishing and disseminating measurement standards in Japan. The measurement standards include force, pressure, and torque standards. In order to realize these mechanical standards, weight force is utilized. Therefore it is necessary for us to determine the local gravitational acceleration at a calibration room. Figure shows an example of gravity data using the FG5 absolute gravimeter. The periodic change in gravity due to tides is clearly observed. The NMIJ/AIST participated in the International Comparison of Absolute Gravimeters in 2001 held at the BIPM. As a result, international consistency in gravimetry is ensured among the participating laboratories.



An example of the result of gravity observation.

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AIST Today Vol. 3, No. 2  
(2002) 18

# High-Accuracy Mass Measurement for Preparation of Reference Gas Mixtures

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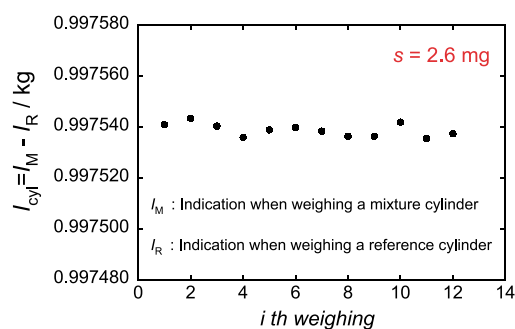
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(2003) 19

Reference gas mixtures are used for calibration of gas analyzers for environmental measurements. Gravimetric preparation method is one of the methods to be able to realize high-accuracy gas mixtures. In this method, concentration of mixture can be calculated from mass of each component gas. However, the buoyancy effect on large gas cylinder interferes high-accuracy mass measurement. Then, it is required to minimizing the effect by an appropriate balance. We have successfully developed unique equipment that has automatic alternative loading mechanism of gas cylinders (Mixture and reference cylinders) for mass measurement with accuracy of several milli grams (Photograph and Figure). The reference gas mixtures prepared using this equipment have been validated in the international comparisons, for example, CCQM-P41 "Greenhouse gases".



NMIJ Balance for gravimetric preparation of reference gas mixtures



Result of weighing the difference between mixture and reference cylinder using NMIJ balance

## AIST International Symposium 2002 “Bioinformatics in the Post-Genomic Era”

The AIST International Symposium 2002 “Bioinformatics on the Post-Genomic Era” was held at the Tokyo International Exchange Center on November 8<sup>th</sup>, 2002. The symposium received nearly 400 participants, and a lively exchange of views took place during the discussion sessions. The exhibitions and the reception party were also well attended.

Currently, post-genomic research draws a great deal of attention given its contribution to the elucidation of the gene carrying information, so-called mechanism of life. Post-genomic research can directly benefit a wide-range of spin-off effects for health promotion and the creation of a new industry that includes the identification of causal agents of diseases and countermeasures against them resulting in development of new drugs.

The main topic of the symposium was bioinformatics utilized in post genomic research. The leading researchers in each field attending from overseas spoke on its current situation and future prospects.

The program was divided into three sections. Firstly, Dr. Cameron, Joint Acting Head of European Bioinformatics Institute, lectured on the complex process from a data base construction to its application to the commercial services for the end users. He also pointed out the increasing importance of technology in the future. In the afternoon session, Dr. Cantor from SEQUENOM, Inc. introduced a high throughput “time of flight” SNP analyser using the mass spectrometry technique that helps to determine the medical relevance of single nucleotide polymorphism (SNP). Following that, Dr. Wright of Scripps Research Institute discussed proteins which have no



specific structure and are coordinated only by interactions with other proteins. Finally, Dr. Ress of the California Institute of Technology gave a lecture on the possibility of predicting the ultimate gene product, that is a three-dimensional protein structure taken from primary gene sequences. He furthered his discussion on the relationship between the 3-D structure and its functions, and the possible application of such information to the development of new drugs.

The symposium has provided an opportunity to grasp the current situation and issues of bioinformatics in the post genomic era researches, and serves as a guideline for future basic research and R&D that leads to the creation of a new industry.

## The 4<sup>th</sup> Japan-Korea Joint Forum on Science and Technology



From Monday, November 18<sup>th</sup> to Wednesday, November 20<sup>th</sup>, the 4<sup>th</sup> Japan-Korea Science and Technology Forum was held with about forty participants from both countries at the Tokyo International Exchange Center. The forum was based on the Korea-Japan Agreement on Cooperation in Science and Technology.

On the 18<sup>th</sup>, two keynote presentations were made by Mr. Naotaka Oki, Vice-President of Japan Science and Technology Corporation (JST), and by Dr. Choi Soo Hyun, President of the Korea Institute of Science and Technology, Evaluation and Planning (KISTEP), followed by two separate sessions where lecturers were given by specialists of life science and nanotechnology. The subsequent discussion focused on the future scheme of research cooperation. During the general meeting held on the following day, the proposal for the scheme was presented and adopted. Dr. T. Sakamoto, Deputy Director of International Affairs Department of AIST, and Mr. K. Yase, Deputy Director of Photonics Research Institute (PRI),



attended the nanotechnology session as a coordinator and a lecturer, respectively. On the 20<sup>th</sup>, a lab tour was organized for the participants at the National Institute for Material Science (MIMS) and AIST.

Japan and Korea essentially reached an agreement on proceeding with plans for cooperation in the above two scientific fields.

[http://www.aist.go.jp/aist\\_j/event/ev2002/ev20021118/old\\_ev20021118.html](http://www.aist.go.jp/aist_j/event/ev2002/ev20021118/old_ev20021118.html)

## International Symposium on Technologies and Applications of Photoelectron Micro-Spectroscopy with Laser-based VUV (Vacuum Ultra Violet) Sources



From Monday, December 2<sup>nd</sup> to Wednesday, December 4<sup>th</sup>, 2002, the above symposium was organized by the research group “Research on Analyzing Technology of Materials and Devices by Photoelectron Micro-Spectroscopy” lead by AIST. The number of the attendees was more than 130 including fifteen overseas participants.

The symposium covered the topics of photoelectron spectroscopy technology, plasma light source and extreme ultraviolet optics technology, all of which are the key technologies for making photoelectron micro-spectroscopy a powerful tool. The invited speakers were the distinguished scientists in their respective fields, and the contributed papers were of the highest quality. The participants listened intently to the talks in the different fields and keen questions were deluged. There were enthusiastic discussions at each poster exhibition booth. We believe that the symposium offered an excellent opportunity to exchange information on the latest

achievements in the different research fields, and that it will accelerate research and the development of “born-in-Japan” technology.

<http://staff.aist.go.jp/t-tomie/eups-sympo/photos.htm>

## Paro Debuts at Council for Science and Technology Policy



On January 28<sup>th</sup>, during the 24<sup>th</sup> Council for Science and Technology Policy held at the Prime Minister’s Official Residence, “Paro”, a seal-type robot developed by the Intelligent Systems Institute of AIST, made its debut.

The current status and future prospects of robot technology in Japan were reported and discussed at the meeting as part of recent trends in science and technology research. Paro of AIST was exhibited as one of the tangible achievements of robotic research. Paro has recently captured public attention as the world’s most “therapeutic (healing)” companion robot.

(Photo: Cabinet Public Information Office)

[http://www.aist.go.jp/aist\\_j/topics/to2003/to20030218/to20030218.html](http://www.aist.go.jp/aist_j/topics/to2003/to20030218/to20030218.html)

## KOCI-AIST Joint Workshop

On November 19<sup>th</sup> - 20<sup>th</sup>, 2002, Korea Research Council for Industrial Science and Technology (KOCI) and AIST held a joint workshop at Cheju, Korea.

This workshop was based on the “Memorandum of Understanding on Industrial Science and Technology Cooperation” signed between the two institutions in February 2002.

From the Korean side, about 50 people attended the workshop including Mr. Won-Hoon Park (President of KOCI)



and Directors of KOCI's seven subordinated organizations.

The AIST delegation of 12 people was headed by Dr. Yoshikawa (President), including Dr. Yoshikai (Trustee) and Dr. Soga (Trustee). The workshop consisted of five sessions where lectures and discussions focused on issues such as research management, evaluation and collaboration.

On November 20<sup>th</sup>, Dr. Yoshikawa, Dr. Yoshikai, Dr. Miyamoto (Director of International Affairs Department) and Mr. Taniguchi (Senior Planning Officer) had a meeting with Mr. Young-Bok Chae, Korean Minister of Science and Technology, in order to exchange ideas and opinions on research and development in industrial technology.

## Australian Minister of Science Visits AIST



On December 18<sup>th</sup>, 2002, Mr. Peter McGauran, the Australian Minister of Science, visited AIST Tsukuba.

During the meeting with Vice-President Dr. Hiraishi and other AIST executives, the Minister eagerly asked many questions about our new organization and management policy, comparing AIST to similar organizations in Australia.

Afterwards, Mr. McGauran was shown the laboratories of the Institute for Environmental Management Technology,

where he had a briefing on their research of the flocculants for treatment of wastewater containing heavy metals.

## “Innovation Center for Start-Ups” Kickoff Symposium



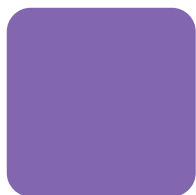
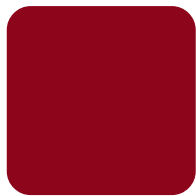
On January 27<sup>th</sup>, 2003, a kick-off symposium for the Innovation Center for Start-ups of AIST was held under the theme of “Looking Forward Return of Research System which enable Technical Resources on the Development of Business Creation.

The opening address by Dr. Hiroyuki Yoshikawa, Director of the Innovation Center for Start-ups (president of AIST), was followed by speeches delivered by several experts: “Expectation and Demand to Innovation Center for Start-ups” by Dr. Kiyonori Sakakibara, professor of Policy Management, Keio University; “The Public Financing for Business Start-ups in Finland”, by Dr. Hannu Hanhijarvi, director of Life Science, Finnish National Fund for Research and Development (SITRA); “New Venture Business Models in the 21<sup>st</sup> Century - A Message from Silicon Valley” by Mr. Yuuji Ide, president and CEO of PIXERA Corporation; and “What are needed for Start-up Businesses in Japan ?” by Mr. Yoshihiro Ohtaki, president of Bio-frontier Partners, Inc.

Additionally, Dr. Masanori Yoshikai, Deputy Director of the Center gave a full description of the basic concept of the organization as his closing remarks of the symposium.

The symposium provided a valuable opportunity to exchange views on the necessities to set up a Japanese-type “Venture (Business) Creation System” with more than 200 participants outside AIST. It assured us that we might be able to be one firm step closer towards building a “future of partnership” for this purpose.

[http://www.aist.go.jp/aist\\_j/topics/to2003/to20030203/to20030203.html](http://www.aist.go.jp/aist_j/topics/to2003/to20030203/to20030203.html)



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Hiroyuki Yoshikawa

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