MANA NEWS LETTER

CONVERGENCE

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International Center for Materials Nanoarchitectonics (MANA)

Nano Revolution for the Future

MANA's Notable Research Achievements

the atomic switch, nanosheets and MSS

An Interview with Director-General Masakazu Aono

On Reaching the 10-Year Milestone at MANA

PROFILE

Dr. Masakazu Aono is currently the Center Director of MANA and also a NIMS Fellow. After receiving his Ph.D. from the University of Tokyo in 1972, he joined the National Institute for Research in Inorganic Materials (NIRIM) as a Research Staff Member. From 1978 to 80, he worked at the Synchrotron Radiation Center of the University of Wisconsin-Madison, USA, as a Visiting Professor with an IBM group headed by Dr. Dean Eastman. In 1986, he moved to the Institute of Physical and Chemical Research (RIKEN) as a Chief Scientist and organized the Surface and Interface Laboratory. From 1996 to 2005, he was concurrently a Professor of Osaka University. In 2002, he moved to NIMS as the Director of the Nanomaterials Institute and was then appointed to his present position in 2007. He has done various pioneering work in surface science, nanoscience, nanoelectronics and nanoscale measurement, symbolized by the words “impact-collision ion scattering,” “atomcraft,” “atomic switch,” “multiple-probe SPM” and “chemical soldering.”

An Interview with Director-General Masakazu Aono

On Reaching the 10-Year Milestone at MANA

— First, could you describe the motivation and aims that you considered when MANA was launched in NIMS as a WPI research center?

In 2000, which was several years before MANA was launched, President Clinton of the United States presented a Presidential Message entitled the "National Nanotechnology Initiative," in which he declared that the United States would devote its energies to research on nanotechnology in the years to come. This news made headlines around the world and created the global nanotechnology fever. Since I took pride in being a pioneer in nanotechnology even before that (laughter), I viewed that move calmly. In fact, I had already organized the "Aono Atomcraft Project" as an ERATO Project under the JRDC (now JST) in 1989 to 1994, and that was considered to be the world's first nanotechnology-related research project with government involvement. For this reason, conversely, I also understood the meaning of this global nanotechnology fever better than anyone – that Japan must be the world's leader in nanotechnology. Coincidentally, we received the news that MEXT planned to launch the World Premier International Research Center Initiative, or WPI, from 2007. After consulting with the then-President of NIMS, Prof. Teruo Kishi, I conceived the idea of creating a world-class nanotechnology research center in NIMS. We prepared the Grand Design for that project, applied to the WPI Project and were selected.

— Could you talk about the birth of the concept of "nanoarchitectonics," which is the framework for MANA, and the direction of research under that concept?

At the time, microtechnology, in which integrated circuits were created by miniaturizing transistors and other devices, had already developed to an extraordinary degree, and as you know, that brought about a revolution in information technology. However, for that reason, nanotechnology was perceived as an extension of microtechnology. In other words, a further refinement of microtechnology along the same lines would be nanotechnology. Even today many people still have that idea, but it is a complete misunderstanding. I strongly feel that nanotechnology is not simply an extension of microtechnology, but is qualitatively different, and a clear recognition of that point is critical for true progress in nanotechnology. Although this fact can be expressed by a combination of existing words, I wanted to express it by a new word, and I decided to use "nanoarchitectonics." While nanoarchitectonics has several connotations, the most important is "unreliability-tolerant reliability." The world of nanotechnology is defined by a scale of one-billionth of a meter. Due to the thermal and statistical fluctuations that occur in this extreme region, it is not always possible to build structures according to a blueprint. Creating science and technology that make it possible to fabricate materials and system with reliable functions within this limitation – this is one key meaning of nanoarchitectonics.

— Although MANA has produced many outstanding research results, could you mention some that you consider particularly noteworthy?

There are so many that's it hard to pick just a few! (laughter) However, let me try . . .

The "Atomic Switch" is a unique, Japanese-original nanoelectronic device that we invented and MANA continued to research. Through joint research with NEC, this has reached practical application as AtomSW-FPGA, and has begun to be used effectively in robots and satellites.*

MANA also developed the technology for fabricating various 2-dimensional substances called "nanosheets," which have monoatomic layer thickness, and also developed a technique for layering these nanosheets in any intended order. This has led to the creation of diverse types of novel artificial substances. For example, by using this technique, MANA created a new material with permittivity 20 times larger than that of conventional substances in the thickness region of approximately 10 nm.*

Among other achievements, without going into detail, I can mention the world's first "observation of a macroscopic superconducting current on a solid surface," development of a "high efficiency photocatalyst" and realization of "monomolecular level memory."

MANA has also developed several original new measurement techniques, such as "high sensitivity olfactory sensor,"* "physical property measurement method under observation by transmission electron microscope" and "nanoscale electrical measurement method by multi-probe scanning probe microscope."

— Four missions were laid out for the WPI centers, 1) Achieving the world's highest level of research, 2) Creating interdisciplinary research domains, 3) Realizing a global research environment and 4) Reforming the research organization. How is MANA grappling with these missions?

We gradually recognized that there is a close mutual relationship among these four missions. For example, in order to achieve the world's highest level of research, it is important to bring together outstanding researchers from Japan and other countries by creating an international research environment, and it is also important to create interdisciplinary research domains. To realize an international research environment, MANA made great efforts to improve and expand its technical support division, and to create an administrative division which is friendly to researchers from other countries. The common language in MANA is of course English. To promote interdisciplinary research, we hold brainstorming sessions called "Grand Challenge Meetings" at hot springs, which gives researchers many

* Articles on these research achievements can also be found at pp. 8-10 in this publication.

opportunities to discuss their dreams all night. We have also set up a "Grand Challenge Fund" that provides financial support for outstanding interdisciplinary research proposals.

The results of these efforts can be seen in objective numbers. For instance, MANA researchers have published 3,480 papers. In 2015, the Impact Factor of those papers was 6.25 and the percentage of internationally co-authored papers was 58%. The number of highly-cited papers (Top 1% in number of citations in the world) was 143, and the FWCI index for evaluation of the quality of papers published by research institutes throughout the world was 2.41 for the period 2008-2015.**

— There's a feeling that the 10 year experience of the MANA project has provided a guideline for the ideal form of basic research in Japan.

Our work is based on the policy that outstanding basic research always leads to applications. However, simply shouting "Let's do great basic research!" doesn't heighten motivation. We thought it was necessary to set some kind of targets. Therefore, we set three "Grand Challenge" research topics in MANA. These are "Creation of an artificial brain by nanoarchitectonics," "Realization of room temperature superconductivity" and "Realization of practical artificial photosynthesis." This is our plan to win three Nobel Prizes. (Laughter) When we laid out these targets, some people were concerned, and asked "Aono, are you sure this is OK? What do you intend to do if it's not possible?" I answered by saying, "If you know from the start that something will succeed, it's not much of challenge!" Today, 10 years later, we still haven't completed any of these topics, but we are steadily approaching our goals. What's more, I think this has also inspired the dreams of researchers at MANA.

— MANA has received a high evaluation as the most international research center in the WPI Program.

The experience of the International Center for Young Scientists (ICYS), which NIMS operated for a period of 5 years beginning in 2003, was a huge plus. In particular, the administrative staff accumulated experience in assisting non-Japanese researchers in a friendly and appropriate manner, and they made a smooth transition to MANA. Simply being proficient in English isn't enough; it's important to have administrative people who have really mastered the know-how by experiencing a wide variety of cases. Upgrading our technical support staff was also another key to success. The operation of MANA has given me a strong recognition that improving the administrative division and technical support division is extremely important for the activities of a research organization.

— I'd also like to ask about the role of MANA's Satellite Labs.

When the WPI Program was launched, MANA was the only WPI center that created Satellite Labs. At first, we were criticized for wasting our funding on Satellite Labs in other countries, but we believed that mutual cooperation by establishing Satellite Labs overseas was critical for acting internationally. The result was a success. MANA is currently involved in fruitful joint research with six Satellite Labs, and this has become one of the distinctive features of research activities at MANA. Principal Investigators (PI) from the Satellite Labs are also frequently in residence at MANA, and provide active guidance to our researchers here, and they also enjoy that role. As a result, the Satellites were a success.

— As the Director-General of MANA, you've nurtured the growth of this research center over these past 10 years. What are your hopes for MANA in the years to come?

In FY2016, the WPI Program ended its funding for MANA and three other WPI research centers that were launched at the same time in 2007. However, all of these WPI centers have now been placed under a new organization called the WPI Academy. As a result, we will keep the name WPI-MANA. WPI-MANA will also continue as a permanent organization in NIMS, and President Hashimoto of NIMS has given us a heartening promise of active support.

The current Deputy Director-General of MANA, Dr. Takayoshi Sasaki, will take my place as Director-General, and the Administrative Director is Dr. Tomonobu Nakayama. I hope that MANA will achieve even greater progress in the coming years under the guidance of those two gentlemen. COO Bando and I will also remain as Executive Advisors, and we will support Director-General Sasaki and Administrative Director Nakayama from the shadows, as it were.

Since the new Director-General Sasaki has said that he wants to continue to develop the concept of nanoarchitectonics, there will probably be little change in MANA's basic direction, and MANA will continue to follow this challenging course in the years to come.

** See p. 7 and p. 11 of this publication.

The Brief History of MANA

2007

- NIMS with the project called "International Center for Materials Nanoarchitectonics (MANA)" has been selected to participate as one of five institutions in the World Premier International (WPI) Research Center Initiative, a program sponsored by the Ministry of Education, Culture, Sports, Science and Technology (MEXT)
- Independent Scientist system started


Masakazu Aono, Director in 2007

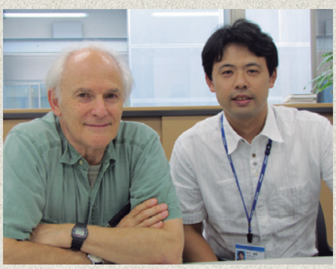
2008

- The 1st MANA Seminar entitled "Nanotechnology, a Key to Sustainability" was given by Dr. Heinrich Rohrer (Nobel Laureate in Physics 1986 and MANA Advisor)
- The 1st MANA International Symposium
- ICYS-MANA Program started
- Short-Term Research Invitation Program started
- MANA opened satellite laboratories in
  - –University of California, Los Angeles (UCLA)
  - –Georgia Institute of Technology (GIT)
  - –Centre National de la Recherche Scientifique (CNRS)
  - –University of Cambridge
  - –University of Tsukuba
  - –Tokyo University of Science
  - –Hokkaido University
- Organizational Reform of MANA


The late Prof. Heinrich Rohrer at MANA International Symposium

2009

- The 2nd MANA International Symposium
- Prof. Harold W. Kroto visited MANA for one-on-one meetings with young scientists
- The Inaugural issue of MANA's *CONVERGENCE* was published


The late Prof. Harold W. Kroto with a young researcher

2010

- The 3rd MANA International Symposium
- The 1st MANA Science Café "Melting Pot Club" on "What is nanotechnology?"
- MANA Director-General Masakazu Aono was selected as a winner of the "Feynman Prize in Nanotechnology" given by Foresight Institute, USA
- The Outreach Team was set up
- The joint IBM and NIMS/MANA symposium on "Characterization and manipulation at the atomic scale"

2011

- The 1st MANA Grand Challenge Meeting
- The 4th MANA International Symposium
- MANA hosted "Prof. Rohrer's Science Class" for junior high-school students
- MANA hosted "Prof. Kroto's Science Class 2011" for preliminary school students and their parents
- MANA opened a satellite laboratory in University of Montreal (UdeM), CANADA
- The 200th Commemorative MANA Seminar
- MANA Research Highlights was started transmitting via Online News
- MANA was featured in special issue of STAM

2012

- MANA was featured in a special issue of the journal Advanced Materials
- The 5th MANA International Symposium
- The 2nd MANA Grand Challenge Meeting
- The Commemorative Ceremony for the Completion of the new WPI-MANA Building
- The MANA 5th Anniversary Memorial Symposium
- The 3rd MANA Grand Challenge Meeting (for young researchers)
- The 2nd WPI Joint Symposium: Inspiring Insights into Pioneering Scientific Research
- The MANA Second-term started


WPI-MANA building

2013

- The 6th MANA International Symposium in Tsukuba
- The International Symposium MASA 2013 on "Material Architectonics for Sustainable Action" at MANA

2014

- The 7th MANA International Symposium
- The first edition of the TNT Japan (Trends in Nanotechnology) conference with a "MANA Day"
- The MANA/ICYS Reunion Workshop
- The International Symposium on Material Architectonics for Sustainable Action (MASA 2014)
- The 2nd International Symposium on the Functionality of Organized Nanostructures (FON'14)


FON'14

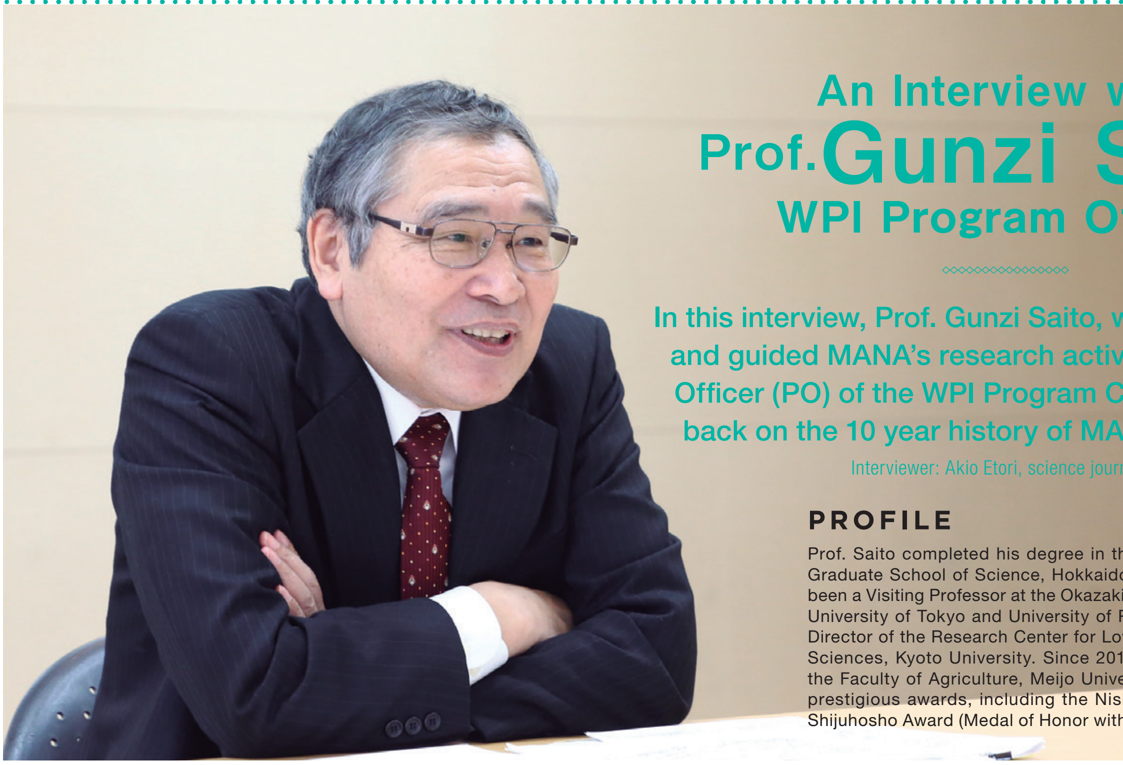
2015

- The 4th MANA Grand Challenge Meeting
- The 8th MANA International Symposium
- The 5th MANA Grand Challenge Meeting

Visitation of G7 Science andTechnology Ministers

2016

- The 6th MANA Grand Challenge Meeting
- The 9th MANA International Symposium
- Nano-Theory Field was established
- G7 Science and Technology Ministers visited MANA



An Interview with Prof. Gunzi Saito
WPI Program Officer

In this interview, Prof. Gunzi Saito, who has evaluated and guided MANA's research activities as Program Officer (PO) of the WPI Program Committee, looks back on the 10 year history of MANA up to today.

Interviewer: Akio Etori, science journalist

PROFILE

Prof. Saito completed his degree in the Department of Chemistry, Graduate School of Science, Hokkaido University in 1972, and has been a Visiting Professor at the Okazaki National Research Institutes, University of Tokyo and University of Rennes 1 (France), as well as Director of the Research Center for Low Temperature and Materials Sciences, Kyoto University. Since 2012, he has been Professor of the Faculty of Agriculture, Meijo University. He has received many prestigious awards, including the Nishina Memorial Prize and the Shijuhosho Award (Medal of Honor with Purple Ribbon).

— First, what is your overall evaluation of the activities of MANA?

MANA's activities are extremely outstanding. Looking at its work as a whole, it is perfectly fair to say this: MANA laid out "Three Grand Challenges"* as targets, and it has made great progress toward achieving those goals.

— Among the centers in the WPI Program, MANA is the only one that is not affiliated with a university. Could you comment on the distinctive features of MANA because it is one of national laboratories?

The universities with WPI centers have faculties of around 4500 to 7500 people in the total university corporation. In contrast to this, the number of full-time researchers at NIMS, which is the host organization of MANA, is only around 400. The annual budget of NIMS is also about 1/5 to 1/9 that of the universities. For this reason, the annual WPI budget of somewhat over a billion yen was very important for NIMS, and the people at MANA had to take this very seriously.

In addition, at the universities, the host organization is too large, and the individual departments are too strong. In contrast, NIMS is small in scale, and it doesn't take too long to convince people who may oppose some idea. The organization and operational capabilities of NIMS were strong. On the other hand, scientists at national laboratories excel in producing results that can be obtained quickly by following an outstanding path, but they aren't accustomed to grappling boldly with "crazy" research. Thus, activating research based on truly innovative ideas was an issue.

— The Missions of the WPI Initiative are 1) Achieving the world's highest level of research, 2) Creating interdisciplinary research domains, 3) Realizing a global research environment and 4) Reforming the research organization. How was MANA doing in realizing these Missions?

When MANA was selected, I told them that there were many excellent people, but please develop "supermen" who were even more exceptional. Initially, MANA responded by assembling a group of truly excellent researchers from other countries. This was followed by outstanding young researchers from overseas. The Japanese researchers see the work of those people and make their own best efforts. As a result, the Japanese researchers have grown to the point where they are also producing extremely good results. In this way, MANA has come to function as global hub of nanotechnology research.

MANA's organization-building capabilities were also extremely good. In management and operation, MANA could cope with a variety of jobs thanks to the "troika system" of the Director-General, COO and Administrative Director. I think that this has worked effectively in achieving the goals of MANA, including the creation of a friendly research environment for non-Japanese researchers, and it has also made a substantial contribution to organizational reform in the host organization, NIMS.

It was good that MANA selected Nobel Laureate scientists to serve as Advisors. To compete with that, the level of the Evaluation Committee that evaluates MANA has also been raised, and MANA's reputation has increased as a result of very vigorous discussions aimed at improving the research center.

Although there are various patterns for "Creating interdisciplinary research domains," the concept of "nanoarchitectonics" advocated by Director-General Aono is basis for this at MANA, and interdisciplinary research has progressed in the new paradigms that were born from that concept. During FY 2016, MANA established the new field of Nano-Theory and added theorists to its organization. I hope that this will spur a further friendly rival, accompanied by keen disputes, between MANA's experimental scientists and theoretical scientists.

— MANA has also put great effort into developing young human resources.

The quality of MANA's human resources development is on the highest level, even among the WPI centers. Prof. Kishi, who was the President of NIMS when MANA was selected for the WPI Program, put considerable effort into developing young international human resources even before MANA was launched. At MANA, Director-General Aono and COO Bando encouraged bottom-up type research projects, and not projects directed from above. The flexible thinking and way of responding of these top managers (Prof. Kishi and former President of NIMS Prof. Ushioda, and Dr. Aono and Dr. Bando of MANA) was also very fortunate. I am truly impressed by the large number of young researchers who have achieved astonishing growth.

— In April of 2017, Prof. Sasaki will succeed Prof. Aono as Director-General of MANA. What are your expectations for the new Director-General Sasaki?

The word "nanoarchitectonics" is really wonderful, but there are still many issues for deepening this concept from the viewpoint of materials science, for example, development of devices for manipulating atoms and molecules, pursuing original research in the life sciences field and so on. If new concepts are created, this should give birth to new fields, and the future should be very interesting. Therefore, I hope that the new Director-General Sasaki will actively pioneer new fields and encourage even greater development of "nanoarchitectonics."

* Three Grand Challenges: Three goals of realizing "Nanoarchitectonic artificial brain," "Room-temperature superconductivity" and "Practical artificial photosynthesis" which MANA has adopted with the aim of achieving innovative research results.

Commemorating 10 Years of MANA

First, I wish to thank all the researchers at MANA for their hard work in the WPI-MANA activities during these last 10 years. I would like to say a sincere "thank you" for the high-level results of the individual researchers in the field of nanotechnology, and for the achievements realized through the fusion of those results. I also understand that these wonderful achievements are of course the result of the efforts of each researcher and the supporting administrative staff, together with the outstanding leadership of Director-General (CEO) Aono and the collective management by Chief Operations Officer (COO) Bando, Chief Administrative Officer (CAO) Fujita and Senior Administrative Officer Kobayashi.

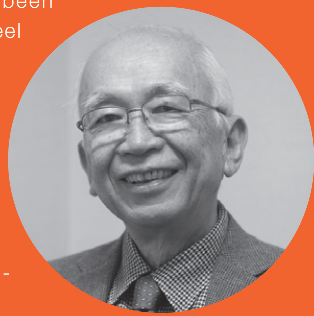
I recall the Evaluation Committee that we employed 10 years ago. All of the examination of documents and interviews were conducted in English. This was quite a struggle for Director-General Aono and myself. However, Director-General Aono pressed ahead with the Nano-Material, Nano-Systems, Nano-Bio and Nano-Green fields, and on the other hand, proposed the creation of a "melting pot environment" of different fields, different cultures and different nationalities, leading to adoption.

Finally, I wish to express my special appreciation to those concerned in NIMS, all our international advisors, Prof. Kuroki and Prof. Saito for their encouragement. I hope that the spirit of these activities and the research system will live on forever in NIMS.

Teruo Kishi — **Former President, NIMS**

As I look back on MANA during the past 10 years, my strongest impression is that MANA has succeeded in creating a truly international research platform. Thanks to this achievement, MANA has produced new, high level achievements as a result of the mutual stimulation of different thought processes and cultures through frank and open exchanges between many researchers from overseas and their Japanese counterparts. In particular, MANA made English a unified "infrastructure language." This was perhaps the first time that this bold measure has been taken in Japan, and I feel that it has been a major factor in the success of the MANA project.

I hope that MANA will continue this form in the future as well, and will establish a lasting reputation as a world-class research center.



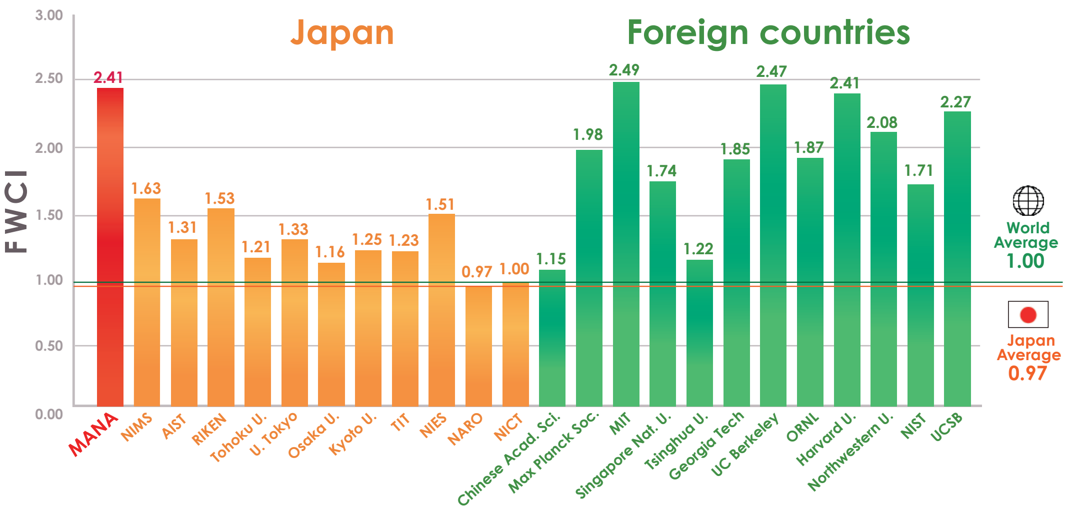
Yoshio Nishi

Professor Emeritus, School of Engineering, Stanford University / MANA Evaluation Committee Member

A decade has passed since MANA was launched in 2007 as part of Japan's landmark WPI Program. This bold initiative transformed NIMS from a rather classical materials institute into a leading center for nanoscience, and enabled it to establish world-class programs in, among others, nano devices, nanomaterials, and (later) nanobio systems. I was privileged to become the chairman of the External Evaluation Committee, a job that was made easy by the outstanding leadership of Aono-san, Bando-san and others. My only regret is that the ministry decided not to renew the program for a second time. The legacy of MANA will nevertheless continue, especially through its dedicated building on the Namiki site, and the whole of NIMS can be grateful for the transformation that was made possible by the creation of MANA.

Anthony K. Cheetham — **Professor, Cambridge University / MANA Evaluation Committee Chairman**

PROGRESS OF MANA



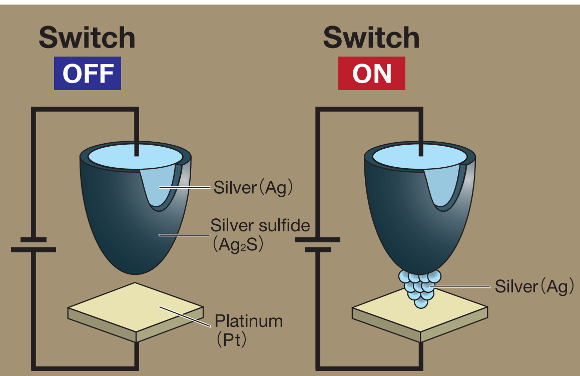
FWCI of MANA and other institutions in the world (2008-2015)

FWCI

FWCI (Field-Weighted Citation Impact) is a new index created by Elsevier B. V., which shows how the number of citations of a group compares with the world average for similar publications, normalized for the research field across the world. MANA's FWCI of 2.42 is extremely high and reached a level of performance comparable to top-ranked universities in the world.

Atomic switch

An atomic switch is an extremely small switching element that operates by the movement of metallic atoms (ions) as the result of a redox process as voltage is applied. Many highly sophisticated devices are now being developed using this atomic switch, taking advantage of its characteristics such its absolutely minimal power consumption for activation, or its ability to achieve an on/off status by the presence or absence of just a few atoms in the gap between the electrodes. In addition, at MANA, it was discovered that the atomic switch could operate as a "synaptic element," that is, it autonomously reproduces the characteristics of a brain's neural activity, to remember necessary information and to forget unnecessary information.



Schematic diagram of a gap-type atomic switch in which the switch turns on when silver atoms come out of a silver sulfide needle.

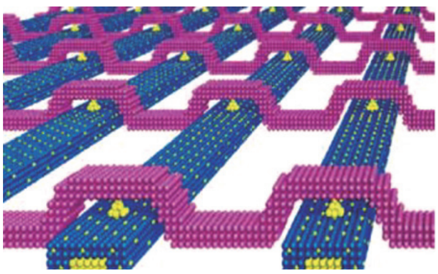
Electronic elements utilized in the smartphones and computers we use in our daily lives operate by the movement of electrons within semiconductors. Though electronic elements have seen remarkable progress with technological development in miniaturization and integration, currently the progress is beginning to slow, and in order to develop the next generation of the advanced information society, elements that operate on a completely new set of principles are also required. MANA was the first in the world to invent an atomic switch that utilizes the movement of atoms (ions), up to now, and has continued its research and development.

According to Kazuya Terabe, MANA's Principal Investigator (PI), who discovered the phenomenon of the atomic switch when he was a postdoctoral fellow, the invention of the atomic switch did not come about in estimation at his desk. Originally, he was working on an experiment where atoms were arranged into lines in order to draw on a substrate by generating a high electric field at a tip of a scanning tunneling microscope's needle-like probe made of ion-conductive materials and dripping metal atoms one at a time from the tip. In doing so, without forethought, he found that by controlling the voltage applied to the tip of the needle-like probe, the protrusion at that tip, consisting of a few metallic atoms, could be extended or retracted. It was this serendipitously obtained fundamental technology that led to the invention of the atomic switch.

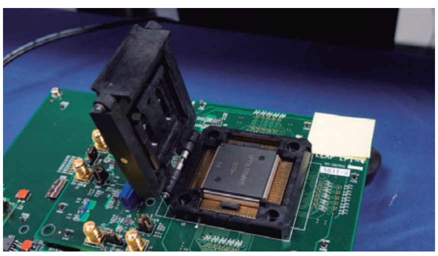
Presently, the atomic switch has become one of the leading candidates as an element advancing the performance of nonvolatile memory, which retains information even after the power supply is turned off; field-programmable gate arrays (FPGAs), which are among the most advanced semiconductor integrated circuits; and neuromorphic circuits. Under NIMS's philosophy that "materials mean nothing if they are not used," Terabe et al. are leading the world in research and development in order to bring out the fullest value of the atomic switch so it can become commercially viable. High reliability and stability are required to productize any material, and as such, great effort has been expended by NEC Corp., which is a joint researcher to develop a new FPGA using the atomic switch. This became a reality in 2011, and compared to previous FPGAs, this new FPGA is a quarter the size, consumes one-third the power, and costs less as well. It is expected to be used in and contribute greatly to the development of artificial intelligence (AI) and the Internet of Things (IoT); it also hardly suffer malfunctions due to electrical noise near movable parts in robots or due to cosmic rays in satellites.

Furthermore, the atomic switch's behavior, which creates or eliminates conductive paths depending on the frequency and magnitude of an electric signal input, is quite similar to the changes in the neuron connection strength of a living organism's brain. This indicates that it could be possible to create a device in which not the software, but rather the element itself, which is hardware, undergoes changes to make determinations, and MANA has thus begun research and development on neuromorphic computing incorporating atomic switches.

Kazuya Terabe,
Principal Investigator



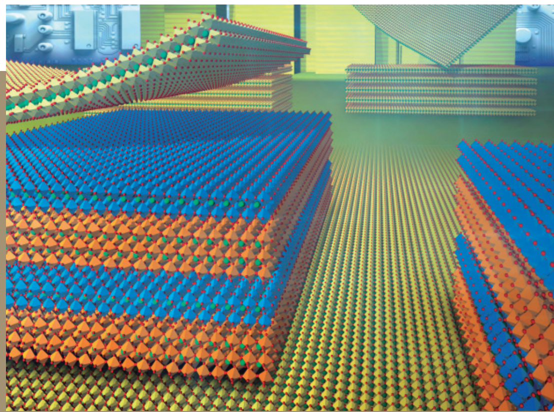
Schematic diagram of original atomic switches



A new FPGA using the atomic switch (Source: PC Watch, Impress Cooperation)

Nanosheets

Nanosheets are two-dimensional nanoscale materials that have a molecular-level thickness of approximately 1 nm and several hundred times more in width in the μm scale. At a time when new nanomaterials that can be applied to next-generation electronic devices are called for, MANA has focused on oxides as a 'treasure trove of functions' and succeeded in synthesizing oxide nanosheets that have dielectric, photocatalytic, or redox properties. MANA is developing functional materials such as dielectric thin film elements by assembling a variety of nanosheets in the manner of LEGO block game, and expects it to be used in a broad range of applications.



An artist's rendering of element fabrication by the bottom-up method. It is possible to create elements with superior performance by stacking nanosheets that have a variety of functions.

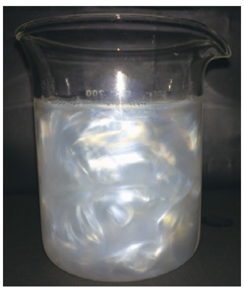
Ever since the initial report on graphene in 2004, there has been a variety of exciting studies on two-dimensional nanoscale materials (nanosheets) conducted around the world. Because graphene consists only of carbon and lacks diversity in its composition and structure, there is an ongoing active exploration on various two-dimensional materials such as chalcogenides and oxides under the watchword, "beyond graphene."

MANA's Deputy Director, Takayoshi Sasaki, was engaged in research on nanosheets before it became popular in the 1990s. As a result of synthesizing various nanosheets, starting from titanium oxide sheets, and diligently continuing to explore their structure and applications, MANA now leads one of the world's top groups in nanosheet research. The basic research policy is to use "well-defined" and "true nano" materials. In nanomaterials research, unless samples that are precisely controlled in its composition, structure, and shape are used, the research that follows one after another will only increase in ambiguity, so the team is working hard to have a fundamental understanding of the materials at the atomic and molecular level and to grasp the characteristics that are truly unique at the nano-scale.

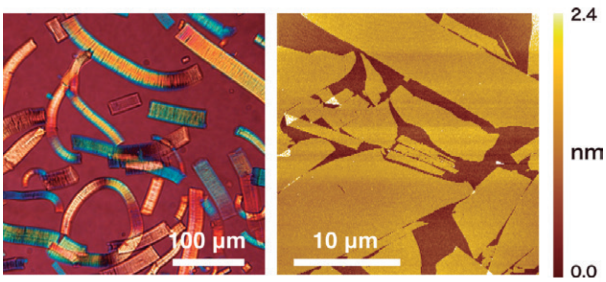
The oxide nanosheets developed by MANA are obtained by a unique method: hydrating and swelling lamellar compounds via a chemical reaction and then disintegrating the compounds down to a single layer, which is the elementary unit of crystal structure. The starting point in establishing this method was to clarify how the swollen lamellar compounds are delaminated and to determine whether they really peel into single layers. By gaining a deep understanding of the swelling and delamination process, it became possible to apply this to other lamellar compounds, and now, starting with titanium oxide, a variety of nanosheets have been successfully synthesized. To go a step further, in recent years, a variety of material development efforts are underway to create nanofilms, nanocomposites, and gels by precisely organizing the synthesized nanosheets at nano to mesoscale.

In the process of studying the property and structure of nanosheets, which are unique materials with their atomic/molecular-level thinness and ultimate two-dimensionality, there were unexpected discoveries in function and phenomena. For example, the superconductivity of cobalt oxide was discovered when attempting to create a nanosheet by delaminating layered cobalt oxide. Many new developments were made by people from all backgrounds and specializations who came to MANA and shared ideas with one another.

Because nanosheets are considered basic materials that form a huge genre in themselves, there is much anticipation for their potentially wide-ranging applications including electronic devices, photocatalysts, and functional coatings. Currently, MANA is conducting joint research with many corporations. In particular, high-functioning thin-film capacitors using oxide nanosheets are being targeted for early commercialization in cooperation with a major electronic device maker. Additionally, MANA has a challenging goal of establishing a method to integrate nanosheets at will to realize precise control over nano-structures, comparable to that of artificial lattice construction as a functional materials creation technology.



A colloidal suspension of titanium oxide nanosheets

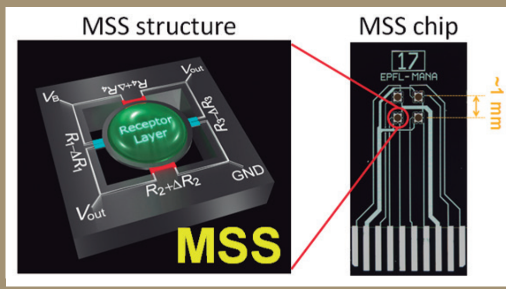


Titanium oxide nanosheet (right) obtained from large hydrated swollen crystals (left).

Takayoshi Sasaki,
Deputy Director

MSS

The MSS (Membrane-type Surface stress Sensor), which MANA co-developed through the international collaboration, is a novel, high-performance nanomechanical sensor based on the fusion of four basic sciences: structural mechanics, materials science, crystallography and electric circuitry. The MSS is a highly sensitive and very compact sensor — the sensitivity is more than 100 times higher than that of conventional nanomechanical sensors, and enables the integration of more than 100 elements per square centimeter. The device is capable of detecting a wide range of substances, including gaseous molecules and biomolecules such as DNA and proteins, and its application as an artificial olfactory sensor is under development.



(Left) Schematic of the MSS. Surface stress induced by the adsorption of gaseous molecules on the receptor layer coated on the center membrane is efficiently detected electrically by piezoresistors embedded in the four surrounding bridges. (Right) Enlarged photo of an MSS chip.

Many studies have reported the development of chemical sensors capable of detecting and identifying a variety of molecules, but it is very difficult to actually develop practical sensor products. The performance of conventional sensors, such as gas leak sensors, specialized to detect certain molecules has been improving progressively. However, sensors based on completely novel working principles have not entered widespread practical use, partly because of the difficulty of designing sensor devices that meet all the requirements for commercialization such as sensitivity, selectivity, reproducibility, response time, size and cost. It is also necessary to develop peripheral hardware and software, such as reading circuits, sample flow paths, data analysis methods and data libraries. A comprehensive development approach is therefore vital in order for sensing systems to reach widespread practical use.

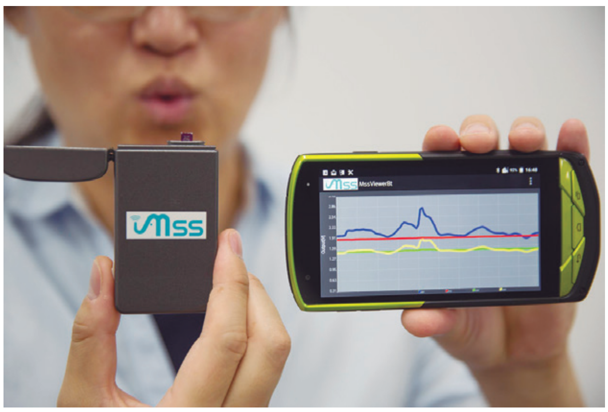
Genki Yoshikawa, a MANA group leader, began studying nanomechanical sensors in 2007 as a visiting scientist at the University of Basel in Switzerland. Based on the collaboration with the late Dr. Heinrich Rohrer and the researchers from the Swiss Federal Institute of Technology in Lausanne (EPFL), he announced the development of the new high-performance nanomechanical sensor MSS in 2011. The MSS achieved both high sensitivity and compact size at the same time, and meets the requirements for a practical sensor.

According to Yoshikawa, several critical breakthroughs were made so far, especially toward a practical olfactory sensor. The first breakthrough was the sudden flash of inspiration which allowed him to conceive of the MSS structure. Through the international collaboratioin described above, he finally arrived at the MSS structure, capable of efficiently detecting subtle forces generated by the adsorption of target molecules. This innovation brought a dramatic increase in sensitivity. The second breakthrough was the discovery of new coating materials for the receptor layer. The research group initially planned to use polymers as receptor layer materials. However, the experimental application of inorganic nanoparticles by Kota Shiba, a NIMS researcher who has been collaborating with Yoshikawa, greatly increased both the sensitivity and durability of the receptor layer. After this discovery, many materials that had been developed by MANA/NIMS were also found to be suitable as receptor layer materials. This rapidly accelerated the development of receptor layers enabling various types of analysis.

The third breakthrough was the launch of the MSS Alliance in September 2015 by the six organizations: NIMS, Kyocera, Osaka University, NEC, Sumitomo Seika and NanoWorld. This alliance represents an industry-academia-government collaboration framework designed to involve all of the key players in Japan, thereby accelerating the introduction into practical use and popularization of MSS-based odor sensing/analysis systems and setting a de facto standard for olfactory sensors. The fourth breakthrough was the fusion of sensor technologies and data science. The MSS Alliance is fostering the development of new data science-driven analytical methods through the close collaboration between NIMS, Professor Takashi Washio at Osaka University and NEC, and the contributions of ICYS-MANA researcher Gaku Imamura. These new methods will establish a novel concept for practical use of various sensing systems.

Genki Yoshikawa,
Group Leader

The new sensors are expected to contribute to realizing safe, healthy and peaceful society by providing practical odor sensing/analyzing capability anytime, anywhere for anybody, creating a new sense of values.



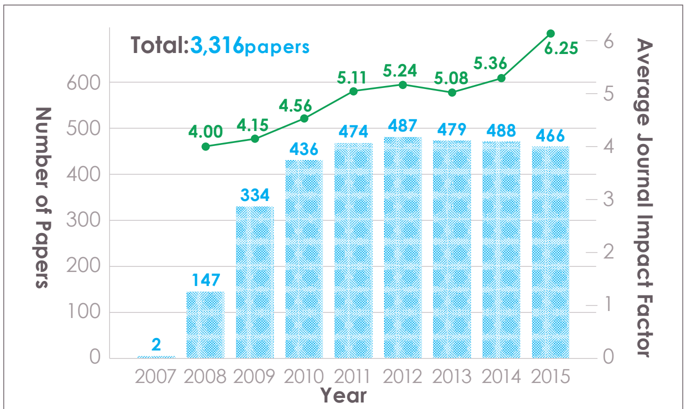
Research papers and International collaboration

Research papers published

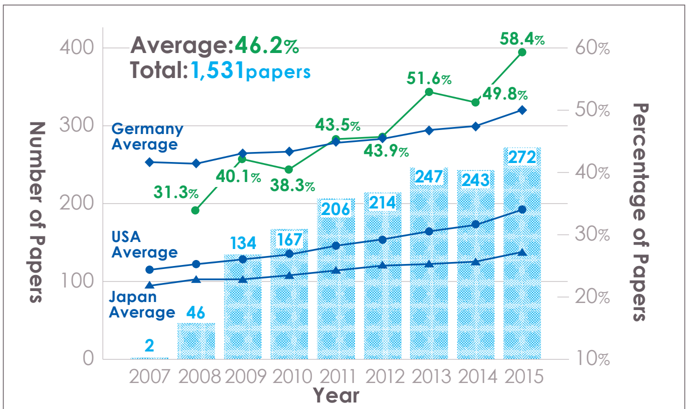
In 2015, MANA researchers published a total of 466 papers. The average of impact factor* of the journals in which these papers were published was 6.25 in 2015, which reflects the high quality of research results at MANA.

Progress of internationally co-authored papers

The number of internationally co-authored papers released by MANA has been increasing each year. More than half of the total number of papers since 2013 have been internationally co-authored. The proportion of internationally co-authored papers in 2015 reached 58.4 %.



MANA Affiliated Research Papers (Oct 2007 – Dec 2015)



Internationally co-authored papers from MANA (Oct 2007 – Dec 2015)

*impact factor: The degree of influence is measured and numerically expressed based on the frequency of citation of published articles in scholarly journals.

Message from a Satellite PI

President Bill Clinton advocated nanotechnology development in 2000 leading to the US National Nanotechnology Initiative (NNI). However, under the leadership of Masakazu Aono, ERATO's "Aono Atomcraft Project" was the very first government sponsored nanotechnology program starting in 1989 for 5 years. The invention of the scanning tunneling microscope and the discovery of fullerenes created a scientific shift in the mid 80's. Nanotechnology was promoted by Eric Drexler to be a deterministic engineering problem rather than stochastic one. By the year 2000 Aono started to think about the use of interactions on the nanoscale differently. In terms of nondeterministic systems a new term: Nanoarchitectonics was proposed by Aono as paradigm shift involving convergence of disciplines but utilizing the awareness that thermal and statistical fluctuations can be used to assemble new functional systems with emergent properties from assemblies of nanocomponents.

The "First International Symposium on Nanoarchitectonics Using Suprainteractions" was subsequently held in Tsukuba in 2000 followed by a second conference at UCLA in 2002. Search "Nanoarchitectonics" today and you find 85,000 hits whereas in 2000 there were none at all. On the 30th August, 2007, I came to Japan for 24 hours, together with (Sir) Mark Welland, to speak for 3 minutes to support a 20 minute presentation by NIMS President Kishi and Professor Aono to the WPI selection committee in Tokyo. When I landed at LAX I received a message on my Blackberry from Aono informing me that MANA had been successful and the opening ceremony was held in Tsukuba later in that year. MANA had moved from concept to reality. Today some 10 years later MANA is a world leading nanotechnology organization in every metric including a new building dedicated to Nanoarchitectonics in 2012.

By 2016, our awareness of complexity and emergent behavior has been recognized in systems ranging from nanoscale interactions to global weather patterns. Today, the slowing down of Moore's law, has promulgated a search for alternative forms of computation and addressed by Obama's "Brain Initiative" (2014). To handle and assess risk in complex environments, Neuroarchitectonic approaches have gained an international interest. MANA and UCLA have demonstrated Atomic Switch Networks inspired by the brains neocortex as one of its missions.

Bill Clinton stated in 2000 at the Cal Tech announcement of NNI that ***"Some of our research goals may take twenty or more years to achieve, but that is precisely why there is an important role for the federal government."***

In summary MANA has at least another 10 years to achieve it goals and to flourish it must continue its successful path in history. I am proud to say I have enjoyed every moment of its existence from birth to its teens.

James K. Gimzewski

Principal Investigator and Satellite Director, MANA
Distinguished Professor of Chemistry, UCLA

Interviewing the next Director

Interviewer: Akio Etori, Science Journalist

Takayoshi Sasaki

PROFILE

Takayoshi Sasaki completed a master's degree at the University of Tokyo in 1980, and joined the National Institute for Research in Inorganic Materials (NIRIM; the predecessor of NIMS), to the present. 1985: Doctor of Science, The University of Tokyo; 1986 to 1987: Visiting scholar, University of California, Berkeley. 2003: Concurrently appointed as a professor of the Materials Science and Engineering, Graduate School of Pure and Applied Sciences, University of Tsukuba. 2007: MANA Principal Investigator, 2009: Fellow, 2016: MANA Deputy Director. Assuming the position of Director in April 2017.

— Please describe your ambitions upon assuming the position of new Director of MANA in April 2017.

MANA has achieved impressive growth in the last decade, and it's a result of the efforts of Director Dr. Aono, and the many people involved with MANA in a variety of roles. I realize that taking over during the period that the World Premier International Research Center Initiative (WPI) budget is ending is a significant responsibility. MANA has now become the world's top hub in the nanotechnology sector in name and reality, and maintaining and further developing MANA is the most important issue.

Although research with nanoarchitectonics is only half way through, it is already beginning to produce achievements. I would like to establish MANA as a center of excellence where great researchers, innovative ideas and new materials from around the world come together; and where such materials driving the next-generation of material science can be produced.

— I hear that the research organization of MANA will be reformed.

There will be no significant changes in the number of research groups, but the current five fields will be consolidated into three: Nano-Materials, Nano-Systems, and Nano-Theory. The aim of this reform is to define the significance of this place in NIMS as a hub that performs bottom-up fundamental research with outside-the-box perspectives, rather than mission-oriented research. Research that takes 1 to 100 is certainly important; however, MANA operates on the concept that we generate the 1 from zero.

— What are the subjects of research MANA will be focusing on?

This is just an example, but research into the integration of nanoarchitectonics and life science has a lot of room for further development. Also, I think more two-dimensional systems including surface or interface conduction are going to be core technologies.

In the world of material science, replicating complex functions such as biological or catalytic functions and controlling them is still challenging. Therefore, it would be important to work on such areas using nanoarchitectonics as a basis.

— How are you going to promote the internationalization in the future?

The existing overseas satellite labs will be reorganized for cooperation with all sectors of NIMS as well as MANA. Meanwhile, NIMS is planning to establish "Materials Global Center (MGC)" to offer a research setting for excellent young researchers. MANA will also participate in this project and proactively work for the development of young human resources. Your continued support for MANA will be greatly appreciated.

MANA NEWS LETTER

CONVERGENCE

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"CONVERGENCE"

is the keyword used to symbolically describe the entire project of MANA, where outstanding researchers from around the world assemble and converge in the "melting pot" research environment to bring together key technologies into nanoarchitectonics for the creation and innovation of new functional materials.

COVER: MANA Director-General Masakazu Aono

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