CONVERGENCE

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International Center for Materials Nanoarchitectonics (MANA)

Masakazu AONO

Ph.D. in Engineering, Graduate School of Engineering, University of Tokyo (1972). Research Scientist (1972-1977) and Chief Scientist (1978-1986), National Institute for Research in Inorganic Materials. Chief Scientist, RIKEN Institute (1986-2002). Professor, Graduate School of Engineering, Osaka University (1996-2005). Director-general, Nanomaterials Laboratory, NIMS (2002-2007). Director-general, International Center for Materials Nanoarchitectonics (MANA), NIMS (2007 to present). Also, Visiting Professor, University of Wisconsin, USA (1978-1980), Project Director, Aono Atomcraft Project, Exploratory Research for Advanced Technology (ERATO) Program, JRDC (1989-1994), Project Director, Nanoscale Quantum Conductor Array Project, International Cooperative Research Program (ICORP), JST (2003-2008), etc. Honors and Awards: Fellow, American Vacuum Society (2003 to present). Fellow, Institute of Physics, UK (2004 to present). Fellow, National Institute for Materials Science, Japan (2004 to present). Fellow, Japan Society of Applied Physics (2007 to present). Minister of Science and Technology Award (1998). Kumagai Memorial Prize for Vacuum Science (1983). Surface Science Society of Japan Prize (2004). Minister of MEXT Award (2007). Feynman Prize in Nanotechnology, USA (2010).

4 Years Following the Establishment of MANA:

Results so far and Challenges from Here on

❖ Interviewer: Akio ETORI, NIMS publishing adviser

From Nanotechnology to Nanoarchitectonics

——Almost 4 years have passed since the International Center for Materials Nanoarchitectonics (MANA) was founded. How did you first become involved in establishment of MANA as a research center of the World Premier International Research Center Initiative (WPI) Program by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) ?

In the past quarter century, nanotechnology has achieved an amazing development. I was promoting research in that field, felt that in order for nanotechnology to see true innovative development, we need a new paradigm. While discussing that with my colleagues, we finalized the idea and decided to refer to the concept as "nanoarchitectonics." Nanoarchitectonics signifies an architecture technology system to arrange nanoscale structural units. The significance of this word is that it provides an essential shift from the conventional analytic view of nanotechnology must yield to a certain synthetic approach to one that comprehensively observes the new cooperative functions that originate as the result of the mutual interactions nanoscale structural units exert with each other. As to why it was essential, I believe that nanoarchitectonics will innovate in materials development. In 2007, when MEXT established the WPI program, I thought that an ideal opportunity had come to found a world leading research center in Japan, and we applied with the tagline "new materials development by nanoarchitectonics."

——Would you explain the difference between nanoarchitectonics and nanotechnology in detail?

Just now I said that nanotechnology had achieved remarkable development in this quarter century. The driving force for the development was the research results that interesting unexpected new functions appeared one after another once material is reduced to nanoscale dimensions. For example, let's take up the case of carbon. That is, in the nanoscale world, it takes the shape of a closed structure (fullerene) formed from dozens of individual atoms, a cylindrical structure (carbon nanotubes) with a nanoscopic diameter, a plane structure (graphene) formed by atoms lined up in two dimensions, as well as others, and each of those shows unexpected properties of an exceedingly interesting nature. Some people think that nanotechnology is just a small change on microtechnology which made great efforts for the micro-manufacturing of semiconductor integrated circuits, but it is not so. In contrast to micro-construction, which is based on and accordingly built with well-known information, nanotechnology is being developed with research on nanoscale structures possessing as yet unknown properties; the two are quite different.

Next, nanoarchitectonics further exceeds the nanotechnology. The nanoscale structures I described just now, even though they have properties of great interest, from a application standpoint, if that is the sole attraction or as far as the extent to which these simple assemblies exist is concerned, the value of that is limited.

It is important to pay more attention to the various new cooperative functions that originate as the result of the mutual interactions nanoscale structural units exert with each other. And nanoarchitectonics constitutes a new branch of technology to apply the cooperative functions to a practical use.

——What kind of research will be conducted as part of nanoarchitectonics

In nanoarchitectonics, be careful about the fundamental change in the existing so-called "deterministic" concept of design and manufacturing. Both design and manufacturing, and moreover the functions brought forth by them, include an ambiguity by nature. This is not a defect or some such thing but instead an unavoidable inevitability. We carefully analyzed what is the most important key technologies as far as nanoarchitectonics is concerned and drew out four: 1) controlled self-organization 2) chemical nanomanipulation 3) field-induced materials control 4) atom/molecule novel manipulation. Each partially includes ambiguities. The four rings that can be seen in MANA's logo represent those four key technologies. Supporting those, 5) theoretical modeling and designing, is also exceedingly important, and at MANA we consolidate these, calling them "the five key technologies."

These fundamental methods of nanoarchitectonics are harnessed for scientific pursuit organized to realize a sustainable society in the 21st century. That is MANA's goal. As a result of that, the intended aims fall into object-oriented four research fields: 1) Nano-Materials 2) Nano-System 3) Nano-Green 4) Nano-Bio, and the research in each of these realms is advancing.

From a management perspective: present state of MANA

——As the MANA Director-General, what do you think about the state of affairs at the MANA organization?

The MANA organization is managed exceptionally well due to a great effort by those concerned. The fact that 57% of the researchers are residing in foreign countries is a testament to our achieving internationalization, and our skillful business and technology support staff provides them support in English. Immediately after the huge earthquake in March, 80% of foreigners temporarily returned to their home countries, but at present most people have come back. That's probably because as far as MANA's foreign researchers are concerned, they are already in pleasant circumstances.

——What kinds of ideas do you have about internationalization?

Before talking about internationalization, we need to know why to internationalize first. MANA's research area is interdisciplinary, so in order for MANA to be able to advance in world leading research, it is essential to gather researchers from all over the world. Just now I said that more than half of MANA's researchers reside in foreign countries, but we are seeing that in reality that is something greatly stimulating MANA's research. Also, young Japanese researchers and students are placed in the middle of an international atmosphere, and another important goal of internationalization is that they receive an international sense as quickly as possible.

——How would you secure excellent, talented researchers?

Research institutions gather excellent, talented researchers based on three points: reputation, treatment, and living circumstances. Reputation means the research center's degree of global familiarity, what kind of great researchers are there, what kind of research facilities are there, and more, and MANA is certainly in the process of boosting those. Concerning treatment, in general, I think MANA is higher than the world average. Concerning living circumstances, I have never heard of dissatisfaction from foreigners finding employment or staying at MANA. This is also related to the fact that MANA is in Tsukuba Science City. From here on as well, I would like to promote improvement with all my power on all three points.

Challenges for the realization of research useful to society

——Please talk about the research results in MANA in this 4 year period?

There are so many that I cannot choose, but why don't I cite some representative ones? One result is the discovery of the new materials layer known as the "nano-sheet" and the variety of new materials creation based on its lamination. While creating many of these materials with new functionality, it is best to call these innovations "soft" chemical nanoarchitectonics in that they pioneered a new realm, but they do indeed deserve a special mention. Another important result, having focused on the limits of the silicon CMOS device underlying today's computers, amidst the development of devices with a new fundamental principle, we are holding great expectations for the "Atom Switch" we developed based on the advantageous points of non-volatility, small size, low power consumption, unnecessary low-temperature cooling, simple manufacturing, and more. Regarding further important features, we understand that the atom switch possesses a learning function resembling that of synapses in neural network, and we have commenced research on construction of neural network type computing circuit with inorganic materials. Also there is the experimental and theoretical suggestion for new devices for the quantum data processing in the future. Finally there is the success of the development of photocatalytic materials sensitive to light in the visible spectrum. This opens the prospect of the realization of artificial photosynthesis in the future.

——Would you inform us about the prospects and dreams for future research at MANA?

I have three dreams for research at MANA. Although, because all are grand challenges, I can't tell you what extent they can be realized. One is the realization of brain-type computational circuits based on the construction and integration of neuromorphic networks made only of inorganic materials. From the detailed analysis of the special characteristics of the atom switch we developed, we gradually came to understand that this is a possibility. Next is the realization of room-temperature superconductivity. Many researchers from all over the world are inclined towards that research with a passion and are trying to realize the construction of room-temperature superconductors with 3-D bulk materials. We, from a slightly different nanoarchitectonics point of view, challenge them to do so. The third is the realization of artificial photosynthesis. In order to realize that, exceedingly interdisciplinary cooperation is probably necessary. We would like to proactively participate in research that would be the foundations for that achievement: research on photocatalysts sensitive to light in the visible spectrum as well as plasmonics research for the sake of the effective use of sunlight.

——I hope your dreams are sure to come true. Thank you very much for the extremely interesting talk.

In cooperation with the actual medical institutions, making a great contribution study to society

Françoise M. WINNIK

- Satellite Principal Investigator, Nano-Bio Field
- University of Montreal

Prof. Françoise Winnik, who is now with the University of Montreal in Canada, joined the International Center for Materials Nanoarchitectonics (MANA) as a Satellite Principal Investigator (PI). Looking to apply her research background, Dr. Winnik, who is also the Executive Editor for the renowned journal Langmuir published by the American Chemical Society, gave us her activities today, and described also what approach she hopes to take in turning her research results at MANA into practical applications.

Broaden the horizons extensively

——Could you please tell us briefly what kind of research you are conducting at the University of Montreal, in Canada?

Well, actually although the underlying theme in my research group is polymer chemistry, I would not say I am confined to this subject, as I am in fact involved in a wide range of research areas involving material science, biology, photonics, and more. I like to discuss with my colleagues, whatever their field, which leads me to undertake new collaborative projects fearlessly. A number of current projects focus on the "nano-bio" area, including the preparation of nanoparticles for drug delivery and medical imaging, as well as studies in the field of nanoparticles toxicity, an area which is very important for the welfare of society given the expanding use of nanoparticles in consumer products. I suppose I would term my research as covering an eclectic mix of science and technology.

Conduct really helpful research, as an intermediary between Japan and Canada

——What kind of research are you going to conduct at MANA as a Satellite Principal Investigator? Also, please tell us what was your motivation to join to MANA?

The research I am involved in currently at the University of Montreal will form the basis upon which my work as MANA Satellite PI will be conducted. As I have noted earlier, I have broad fields of interest, all somehow related to nanomaterials. As a MANA Satellite PI, I plan to collaborate with MANA researchers in the area of nanoarchitectonics, the design and fabrication of well-defined functional surfaces and bio-interfaces. I am particularly determined to bring aspects of this knowledge from the lab to the patient, in collaboration with clinicians in Japan and Canada. I currently collaborate with cardiologists and orthopedic surgeons in various aspects of new therapies and personal medicine. I am convinced that linking the MANA expertise to the Montreal medical environment will be beneficial to both institutions… and ideally lead to better therapeutic treatments in both Japan and Canada.

I see MANA offering new possibilities for me as well as my research career; I was looking for new challenges so the great networking potential available at MANA and NIMS in Tsukuba was a big factor in my decision to join. I expect new types of projects to be forthcoming, where I can make optimal use of my previous knowledge. In addition, the synergy that may be brought forth between the research teams in Japan and Canada truly excites me.

——Could you please tell us, in your opinion, how MANA should proceed with future internationalization as a World Premier International Research Center (WPI)?

From what I have seen and experienced so far, I think MANA is proceeding on the right track, thanks to the international community being fostered in Tsukuba. In the past I have witnessed various settings in which researchers from various countries worked with Japanese scientists.

Often communication issues and divergences in ethics and culture create barriers between scientists, misunderstandings, and lack of trust. MANA seems to function in a way where ideas can be translated effectively, where researchers work together to make "things happen" for which differences are ironed out. I think the MANA culture, based on the so-called "melting pot" approach, is working. It has people who have been chosen well, it promotes mutual understanding and cooperation. Meanwhile, there seems to be freedom from undue pressure, such as tenure, because of the way projects are set up. Scientists have all the tools to carry out their project… excellent science is the target!

——Can you provide female scientists currently involved in materials research activities with words of encouragement?

Many women have decided to be involved in science as a career in addition to looking to family life, even in Japan. I have met exceptional young women who had obtained a Masters degree in Chemistry, torn between either obtaining an industrial position or continue their studies towards a doctorate, which means grueling years of studies, with at the end a fulfilling job often perceived to be in conflict with family life. The choice seems easier for women in Western Europe and North America where the infrastructure facilitating the practical aspects of "career mothers" is in place and available to all. This may not be the case in Japan yet, and there are many cultural aspects too, which discourage young women. I believe that it won't be long before Japan recognizes that these women represent a wealth of under-exploited talent that cannot be ignored. Indeed innovative research that is not "stuck in the groove" can be produced, regardless of the gender of the researcher.

Françoise M. Winnik

Born and educated in France, she went to the University of Toronto, for her doctoral research. She was offered a position as a scientist within the XEROX Research Centre of Canada, where she carried out work related to new materials for printing applications for over 10 years. Then, she joined McMaster University in Hamilton and more recently, the University of Montreal. Indeed, she has been working in the academic arena in Canada for many years. She is concentrating on not only chemistry but also physics. She is fulfilling as well the role of editor for the American Chemical Society journal Langmuir.

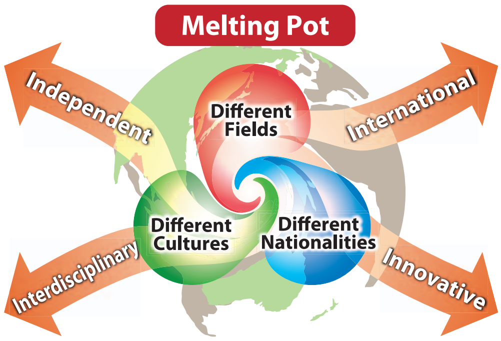
Looking back upon the MANA's past 4 years

Since its inception in October 2007, MANA is striving to extraordinary business that has continued reputation. Here, let's look back upon the results of four years of MANA.

Management Reforms are Positively Promoted

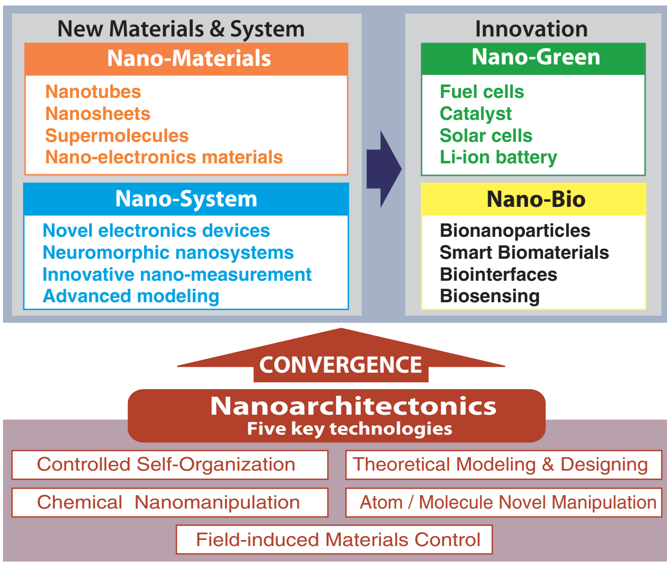
MANA aims to develop innovative materials and technology by using nano-technology under the original research concept of materials nanoarchitectonics. Its mission is summarized in the following four.

1. To promote interdisciplinary research by materials nanoarchitectonics.
2. To serve as a “Melting Pot” where top-level researchers gather from around the world.
3. To secure and cultivate outstanding, innovative young scientists.
4. To construct a network of nanotechnology centers throughout the world.



Reformation of the organization

When MANA was established in October 2007, a research organization was formed tailored to the five key technologies: “Controlled Self-Organization”, “Chemical Nanomanipulation”, “Field-induced Materials Control”, “Atom/ Molecule Novel Manipulation” and “Theoretical Modeling and Designing”. The organization was reformed in October 2008 into four research fields: “Nano-Materials”, “Nano-System”, “Nano-Green” and “Nano-Bio” to make the research at MANA more explicit and clarify its missions. The five key technologies of nanoarchitectonics were converged into these four fields to promote fundamental studies on nanomaterials and nanosystem and clarify the direction of applications in environmental and life sciences, which will lead to new innovations.



Instead of three vice directors, MANA now has a Chief Operating Officer (COO) under the Director General. The new system has reduced the management load of the Director General and has enabled efficient and fast decision making. There are also field coordinators to promote research in each field, enhance coordination among fields and promote convergence studies.

Recruiting excellent researchers

Various activities have been performed to recruit excellent Principal Investigators from around the world. We succeeded in headhunting Prof. Traversa from the University of Rome in Italy. We also invited Dr. Han from a private enterprise and Dr. Tsukagoshi from a national institute.

Efforts for internationalization

On the fifth floor of the MANA Building is a cafeteria called the Melting Pot Café, where there are always researchers relaxing and chatting.

Researchers from various countries and clerical staff have a chat and enjoy their coffee. Various languages are spoken, but the common language is English.

MANA consists mainly of principal investigators (PIs), young scientists (MANA Scientists), postdoctoral fellows, graduate students, and MANA Independent Scientists and ICYS-MANA Researchers. The total number of members in MANA and its satellite institutes in and outside Japan exceeds 200, of which over half are non-Japanese. Over 200 researchers visit MANA every year.

The MANA Administration Office and the secretaries of PIs are in charge of office work in English, which is the common language at the institute. Accompanying families receive assistance in matters such as finding hospitals, childcare facilities, schools, residences, and other necessary information through the support system of NIMS.

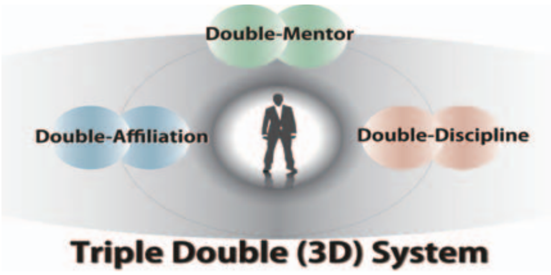
For researchers from abroad, there is a guidebook in both English and Japanese that covers the necessary items for working at NIMS, including useful information about coming to Japan, starting work at NIMS, conducting research, and leaving NIMS. The guidebook is revised about once a year. A laboratory tour, newcomers are required to join, is held every month using the guidebook.

Melting Pot Café

Human resource development —MANA Independent Scientists

One of the most stimulating experiences for promising researchers is meeting world-leading scientists and hearing their stories first-hand. If the experience is personal, the impact is even more profound. The MANA Independent Scientists system provides the real environment for this purpose.

Most of MANA Independent Scientists are young researchers in their thirties and engaged in independent studies at MANA. Among the systems enjoyed by Independent Scientists, the most distinctive is the 3D system.



"3D" stands for Double mentor, Double discipline and Double affiliation. The objective is to cultivate independence in research by allowing these scientists to obtain advice from two or more mentors, enhance interdisciplinary ability by requiring the study of two or more themes, and strengthen the spirit of independence by having them working at two or more organizations. Satellite institutes and overseas cooperating institutes are fully used for this purpose.

Dr. Naoki Fukata visited Prof. Zhong Lin Wang at the Georgia Institute of Technology and Dr. Tadaaki Nagao visited Prof. Venky Narayanamurti at Harvard University. They are greatly stimulated and get outstanding research results.

Dr. Fukata (left) and Prof. Wang (right)

Prof. Narayanamurti (left) and Dr. Nagao (right)

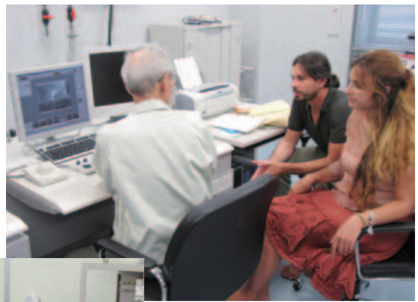
Research support

It is the research support that is the pride of MANA. The MANA Foundry, which is equipped with first-class facilities, is contained in the same building to support research of nanoarchitechtonics. Moreover, MANA has many shared facilities in addition to the MANA Foundry that are supported by a technical support staff (TSS) that is proficient in English.

The cleanroom facility consists of six areas in its 235m^2 floor space: Lithography Area, Dry Process Area, Nano Fabrication Area, Nano Structure Processing Area, Nano Measurement Area and Thermal Treatment Area.

We are able to provide consistent processes from test piece preparation to structural observation and functional verification including nano-gap electrode patterning by electron beam lithography on complicated structures such as nano dots, nano wires and nano sheets made of various materials like organic, inorganic, metal, insulator, magnetic, superconductor and composite.

Experienced technical and administrative staff, fluent in English, assist foreign researchers. The MANA TSS Team has 5 technicians that can speak English, and a variety of other support is provided to allow researchers to focus on their research, such as equipment maintenance, laboratory cleaning, reagent support, safety measures, and technical studies, transport, and installation when purchasing equipment.



Technical team providing research support

The cleanroom facility in the MANA Foundry

Satellite research

One element that is absolutely essential to the carrying out of research by MANA is satellite research.

There are 25 Principal Investigators (PIs) at MANA, and of these 8 are guest researchers affiliated with outside research institutions. Satellite offices are set up at the home institutions of these guest researchers.

Satellite institutions provide support for joint research in fields that cannot be covered by NIMS alone. The satellite PIs act as mentors to young researchers at MANA. It goes without saying that the satellites also serve as bases for disseminating and collecting information.

At present MANA has a total of seven satellite institutions, in Japan and overseas. They collaborate closely with MANA to advance innovative research related to nanotechnology.

The seven MANA satellites

Career advancement

For young researchers the most important thing is to make steady progress in the advancement of their own careers.

We are always strongly aware of the importance of MANA as a place where young researchers can advance their careers. In particular, we endeavor to satisfy the demands of researchers from overseas as far as possible, and we see MANA as a place where they can gain career experience that will enable them to make a more valuable contribution at their next place of employment. The results of this approach are attested by the active roles played at institutions all over the world by young researchers after leaving MANA.

Name	In MANA	Present post
 Dr. Martin Pumera	2008.10-2009.12 MANA Scientist	Professor at Nanyang Technological University, Singapore
 Dr. Samuel Sánchez Ordónéz	2009.3-2010.4 ICYS-MANA Researcher	Assistant Professor at Leibniz Institute for Solid State and Materials Research Dresden, Germany
 Dr. Jun Chen	2008.12-2010.3 ICYS-MANA Researcher	Researcher, Advanced Electronic Materials Center, National Institute for Materials Science, Japan
 Dr. Cesar Pay Gómez	2007.3-2010.2 ICYS-MANA Researcher	Assistant Professor at Uppsala University, Sweden

Examples of career advancement

Outreach

It is one of the important roles for researchers to disseminate the practical side of research results and activities to citizens arouse their interest in science and technology.

MANA appeals the importance of science research through the active outreach to the general public and children to win recognition.

The 1st MANA Science Cafe "Melting Pot Club" has been held in October 2010 by Dr. Aono, MANA Director-Genral and "Dr. Rohrer's Science Class 2011" was held by Dr. Heinrich Rohrer as Nobel laureate in March 2011. These are very popular and we continue to plan various events from now on.

Dr. Rohrer lecturing at the science class

Dr. Rohrer with junior-high school students

4-year history of MANA

Year	Month	Day	Items
2007	10	1	The International Center for Materials Nanoarchitectonics (MANA) was launched
	10	18	Launching Ceremony of MANA
2008	3	10-13	**MANA International Symposium 2008** 
	4	16	First inspection by the WPI Program Committee
	10	1	MANA reorganization
	11	27-28	Second inspection by the WPI Program Committee
2009	2	25-27	 **MANA International Symposium 2009**
	10	13	MANA-URTV Joint Workshop at University Rome Tor Vergata 
	10	23	**Symposium on Frontiers in Nanotechnology and Materials 2009**
	11	12-13	2nd NIMS-WUT-EMPA Workshop with Warsaw University of Technology (WUT, Poland) and Swiss Federal Laboratories for Materials Testing and Research (EMPA, Switzerland)
2010	1	7-8	Third inspection by the WPI Program Committee 
	1	14	GCOE Mini Symposium on Mesoscale Chemistry
	1	31	**Prof. James Gimzewski, MANA Satellite PI, was showcased as part of the series of NHK satellite TV program "The Proposal for the Future".**
	3	3-5	**MANA International Symposium 2010** 
	3	24	Hakone International Workshop : Materials nanoarchitectonics for sustainable development
	6	14	IBM-NIMS Symposium on Characterization and Manipulation at the Atomic Scale
	10	28	The 1st MANA Science Cafe "Melting Pot Club"
	12	21	Dr. Masakazu Aono, MANA Director-General, received 2010 Feynman Prizes for Experimental work
2011	1	1	MANA's two researchers were featured on NHK Special program "CAN JAPAN SURVIVE?"
	1	17-19	Workshop on Dirac Electron Systems 2011
	3	2-4	**MANA international Symposium 2011** 
	3	5	"Dr. Rohrer's Science Class 2011"
	4	1	MANA reorganization according to NIMS 3rd Five-Year Plan
	9	17	"Prof. Kroto's Science Class 2011"
2012	3		**The new research building will be completed** 
	3		MANA international Symposium 2011

Tailor-Made Nanoelectronics from Building Blocks

Minoru OSADA
MANA Scientist
Nano-Materials Field

Assembly of functional nanoarchitectures, in the same way that children play with building blocks, is one of the dreams of nanotechnology. We are investigating new fabrication procedures for future nanoelectronic devices using solution-based bottom-up assembly of functional nanoblocks (Figure 1).

The key requirement for such a building-block approach is to create functional nanoblocks with advanced physical properties such as conducting, dielectric, and magnetic properties. In designing electronic devices, we focus on oxide nanosheets, which are obtained by delaminating a layered compound into its single layers through soft-chemical procedures. The nanosheets often exhibit novel physical properties that are inherent to their highly two-dimensional nature with a molecular thickness. Recently, we found that perovskite nanosheets (A = $Ca_{2-x}Sr_xNb_3O_{10}$) realize superior high-κ performance (ε_r = 210~240), the largest value observed in high-κ nanofilms with the thickness down to 10 nm. Also, nanosheet-based multilayer capacitor films (Figure 1a) exceed textbook limits in the performance, opening the way to next-generation capacitor devices.

The availability of high-κ perovskite nanosheets will open up possibilities for designing complex devices by forming artificial superlattices. To demonstrate this next level of complexity, we fabricated an artificial superlattice by alternately stacking of two dielectric nanosheets (B = $Ca_2Nb_3O_{10}$, C = $LaNb_2O_7$) *via* solution-based layer-by-layer assembly (Figure 1b). By artificial structuring, we found that, in contrast to the paraelectric nature of $Ca_2Nb_3O_{10}$ and $LaNb_2O_7$, the ($Ca_2Nb_3O_{10}$/$LaNb_2O_7$) superlattice possesses a new form of interface coupling, which gives rise to ferroelectricity at room temperature. This artificial superlattice exhibited robust ferroelectric properties even at several nanometer thicknesses, which is essentially required for future electronics.

Our work is a proof-of-concept, showing that high-performance electronic devices can be made from oxide nanosheets *via* the solution process in beakers. Our new recipe is not suitable for immediate use but it could offer the next big change in our computers in the coming decades.

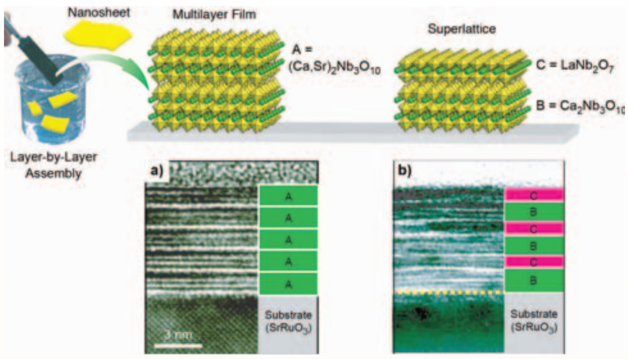


Figure 1. Solution-based bottom-up assembly using oxide nanosheets. Cross-sectional TEM images of multilayer ($Ca_{2-x}Sr_xNb_3O_{10}$) film (a) and ($Ca_2Nb_3O_{10}$/$LaNb_2O_7$) superlattice (b).

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Highly Sensitive Membrane-type Surface Stress Sensor

— For Medical, Biological, Security, and Environmental Applications —

Genki YOSHIKAWA
ICYS-MANA Researcher

The detection and identification of analytes ranging from gaseous to biological molecules with unprecedented sensitivity are the basis of various innovative technology required in this century. Consequently, a wide variety of sensors has been developed so far, while cantilever array sensors (Figure 1) possess the advantages of real-time and label-free detection in parallel based on the unique nanomechanical detection. However, the commonly used optical read-out method has several practical problems for actual applications, *e.g.* bulky, complex, time-consuming, low applicability for large arrays, and the difficulty in performing measurements in opaque liquids, such as blood. One of the most promising solutions to these problems is a use of lever-integrated piezoresistive sensing, which does not require bulky and complex peripheries related with an optical read-out and can be used for the detection in any opaque liquid with large multidimensional arrays. In spite of these inherent advantages, piezoresistive cantilevers have not been widely in use for sensing applications because of its critically low sensitivity.

In this study, we made a comprehensive optimization, breaking the bounds of common practice of "cantilever", and finally developed a Membrane-type Surface stress Sensor (MSS; Figure 2). Experimental evaluation of a first prototype MSS demonstrates a high sensitivity which is a factor of more than 20 higher than that obtained with a standard piezoresistive cantilever and comparable with that of optically read-out cantilevers. Furthermore, the finite element analyses indicate its high potential for further substantial enhancement in sensitivity just by changing the dimensions of the adsorbate membrane and sensing beams. Since the MSS measures surface stress which is basically induced by steric repulsion of adsorbed analyte molecules, it can detect virtually any kinds of molecules under various conditions including vacuum, gas, and any opaque liquids, such as blood. In addition, it can be miniaturized and integrated with a multidimensional array by batch fabrication with its CMOS compatibility, and the whole sensor unit including read-out parts can be integrated into common semiconductor devices, *e.g.* mobile phones. Therefore, it is expected to open a new era of sensors for various fields including medical, biological, security, and environmental applications.

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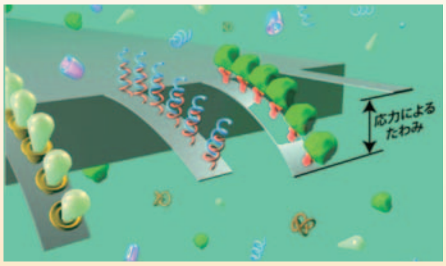


Figure 1. Schematic image of the measurement of various analytes ranging from gaseous to biological molecules using an array of microcantilevers. The deflection induced by an adsorption of analyte molecules is measured as a signal.

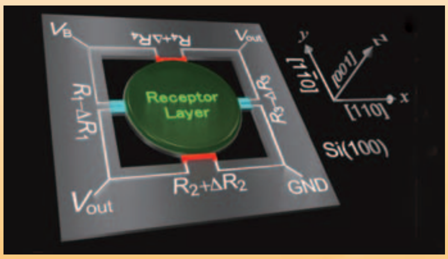


Figure 2. Newly developed Membrane-type Surface stress Sensor (MSS). The surface stress induced by an adsorption of analytes on the center membrane is efficiently detected by the piezoresistors embedded at the four peripheral beams.

Autologous Scaffolds for Tissue Engineering

Guoping CHEN
Principal Investigator (PI)
Nano-Bio Field

Tissue engineering has been rapidly developed as a promising approach to restore or replace lost or malfunctioning tissues and organs. In this approach, the cells are cultured in a biodegradable three-dimensional porous scaffold supplemented with growth factors to regenerate new tissues or organs. The scaffold provides necessary interim support for cell adhesion, proliferation, and differentiation; offers biochemical and biophysical cues to modulate the new tissue formation by mimicking the functional and structural characteristics of the microenvironment in human body. Although scaffolds can be prepared from biodegradable synthetic polymers and natural polymers, they may induce undesirable inflammatory and immunological reactions because of their compositional and structural difference from the extracellular materices (ECM) that surround cells in human body. Development of autologous scaffolds has been highly desired for implantation without eliciting adverse host inflammatory and immunological responses. However, it has been difficult to obtain autologous scaffolds by tissue decellularization because of the restricted availability of autologous donor tissues from a patient.

We have developed a novel method to prepare autologous scaffolds by culturing autologous cells in a polymer template that can be selectively removed after the cells deposit autologous extracellular matrices. The intracellular components and the polymer template are selectively removed after cell culture to obtain the autologous ECM scaffolds. A large variety of cell types can be used in preparing the autologous scaffolds by this method. We confirmed the effectiveness of the method by using human mesenchymal stem cells, chondrocytes and skin fibroblasts. The autologous ECM scaffolds showed a three-dimensional structure that was composed of microscale and nanoscale ECM fibers. The compositional biomolecules in ECM scaffolds are dependent on the cells used for cell culture. The scaffolds can be tailored by selecting appreciate cell type.

The autologous ECM scaffolds showed excellent biocompatibility when implanted. They were demonstrated to promote chondrogenic differentiation of mesenchymal stem cells and regeneration of dermal tissue. By using autologous ECM scaffolds for the culture of autologous cells, "full autologous tissue engineering" can be realized to make the tissue engineered construct more biocompatible with the host.

Reference
H. Lu *et al.*, *Biomaterials*, 2011, **32**, 2489-2499.

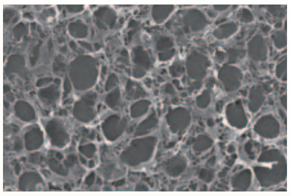


Figure 1. SEM image of autologous ECM scaffold

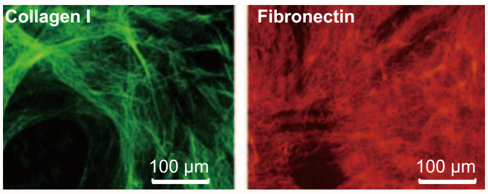


Figure 2. Immunofluorescence collagen I (left) and fibronection composing autologous ECM scaffold (right).

Oxygen-ion and Proton Conductivity in Solid Oxide Electrolytes

Daniele PERGOLESI
MANA Scientist
Nano-Green Field

Solid oxide fuel cells (SOFCs) are electrochemical devices based on a ceramic oxide electrolyte separating anode and cathode electrodes. In operating condition, SOFCs convert chemical into electrical energy with high efficiency and low pollutant emission. The full exploitation of this technology is mainly limited by the high operating temperature (above 800°C) required by the present electrolyte materials, resulting in high operating costs. The challenge of reducing SOFC operating temperature can be addressed searching for new electrolyte materials and tuning the electrode microstructures toward innovative design and device architectures.

My primary research target is the investigation of the relation between microstructure and charge transport properties in materials of interest for SOFC application. By pulsed laser deposition (PLD) it is possible to grow thin films of complex oxides with large differences in structure and morphology. Appropriately designed samples can be fabricated as probe tools to measure specific physical and chemical properties allowing the complete characterization of the transport mechanisms of the materials, an essential prerequisite to address the challenge of their optimization toward the fabrication of more performing devices.

As an example, the micro-structural properties of Y-doped barium zirconate, a proton conducting electrolyte, dramatically affect its proton conductivity due to the blocking effect for proton conduction at grain boundary, together with the relatively small average grain size characterizing this material when processed following standard ceramic routes. By PLD, highly textured thin films of BZY were grown on insulating substrates[1]. These films showed the largest proton conductivity ever reported so far for a ceramic oxide (Figure 1).

A further example concerns the study of the conducting properties of interfaces of oxygen-ion conducting based hetero-structures. The so-called space charge layer effect and the induced crystallographic strain at the interface might have significant influence on the oxygen-ion conductivity. Appropriately designed superlattices fabricated by coupling doped and un-doped oxides have been grown (Figure 2) and their conductivity measured. Preliminary results showed that coherent heterophase interfaces do not offer a preferential oxygen-ion conduction path. This research line is currently going to be extended over different micro-structures, i.e. incoherent hetero-interfaces (to investigate the role of interface dislocations) and low doped material based superlattices in which the space charge effect in expected to have a significant contribution.

Reference
[1] D. Pergolesi *et al.*, *Nature Materials*, 2010, **9**, 846.

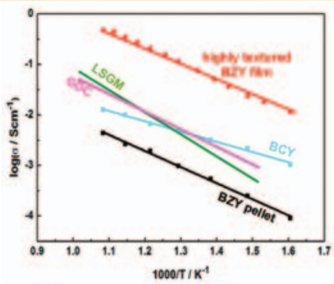


Figure 1. Comparison between the electrical conductivity values of the highly textured films of Y-doped barium zirconate (BZY), and of BZY and BCY (Y-doped barium cerate) sintered pellets, measured in the intermediate temperature range. Conductivity values of the best-performing oxygen-ion-conducting materials, $La_{0.8}Sr_{0.2}Ga_{0.8}Mg_{0.2}O_3$ (LSGM) and $Ce_{0.8}Gd_{0.2}O_{1.9-\delta}$ (GDC), are also reported.

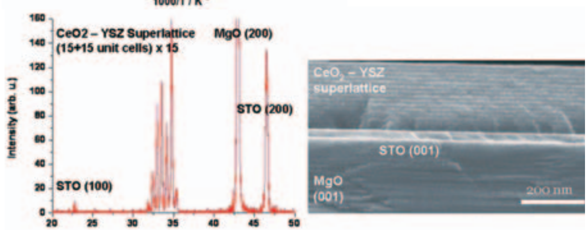


Figure 2. XRD pattern and SEM cross sectional micrograph of a CeO_2-YSZ heterostructure grown (001) epitaxially oriented with the MgO substrate by means of a thin buffer layer of $SrTiO_3$ (STO).

Hang in there, Japan/NIMS/MANA!

——Messages from WPI/MANA members in the wake of the Great East Japan Earthquake

On March 11, 2011 the memorable 200th MANA Seminar was scheduled to get underway at 3:30 in the afternoon. However, the outbreak of the Great East Japan Earthquake 40 minutes before the event was to start forced us to cancel this Seminar*. Even here in Tsukuba the tremor was felt quite strongly, registering a 6 on the Japanese scale of earthquake intensity. There were many instances of damage to research equipments at MANA, but thankfully no one was injured.

The earthquake and its associated disasters caught many of our non-Japanese researchers by surprise, and it is perhaps inevitable that they have chosen to return temporarily to their home countries. We rarely receive visitors from overseas, and the lively atmosphere that characterized MANA before the Quake has yet to return. Under the current circumstances, with foreigners giving Japan a wide berth, the WPI Program is enduring something of an ordeal. It is our hope that MANA will soon regain its pre-earthquake role as a "melting pot" where researchers from all over the world can gather and work together in a state of friendly rivalry. With this is mind, we have asked four persons associated with WPI/MANA, and who experienced the Quake and its aftermath, to write about their thoughts.

* One of speakers at the 200th MANA Seminar was Kazuto Akagi, associate professor of AIMR, another WPI Center at Tohoku University, which was heavily suffered from the Quake. The 200th MANA Seminar will be held another time, by inviting Prof. Akagi after recovery of AIMR.

WPI centers on March 11, 2011 and aftermath

The magnitude (M) 9.0 earthquake struck the east Japan on the afternoon (14:46) of March 11, 2011. It was the 4 th largest earthquake of the world since 1900. The epicenter was located at 130 km from the coast of Sendai and 24 km in depth under the Pacific Ocean, causing the devastating tsunami. Thirty min after the quake, 20-meter wall of sea water had swept across towns of the coast, washed away houses, cars, boats and even airplanes and killed nearly 25,000 people living in these areas. Japan has been well prepared for earthquake and tsunami by the world densest monitoring network, the biggest tsunami barriers particularly in these areas and warning systems by catching primary (P) wave of quake. However, M 9.0 quake and 20 m tsunami were far beyond our preparations and imagination.

The quake shook academic facilities in Sendai and Tsukuba. Although nobodies were killed or injured and buildings were not so badly damaged, WPI-AIMR and MANA, which are renowned for material science, had serious damages of fine equipments including STM (Scanning tunneling microscope) by M9 earthquake and the following M7 aftershocks. Most of them were placed on earthquake-proof foundations, but they were vigorously shaken. Damaged equipments are now being repaired by replacing parts or by realignment of optical axis etc. It will take further months to be recovered completely to the level before March 11.

Costs to restore them are estimated approximately 440 million yen (US$ 2.9 million) for AIMR and 200 million yen (US$ 2.4 million) for MANA, which will be compensated by the supplemental budget of the government. However, most serious loss for researchers is loss of time. We sincerely hope that they will catch up rapidly and return to the frontier of research shortly.

IPMU, which locates 25 km south of MANA, was not damaged. Among IPMU-related research facilities, Kamioka was not suffered from the earthquake but KEK and newly opened J-Park were seriously damaged. Professor S.T. Petcov, a visiting scientist of IPMU from Italy, will report his personal experience of March 11 and aftermath in "IPMU News". Another WPI centers, iCeMS, IFReC, I²CNER, which locate far away in south and west Japan, has no damage at all, though they felt unusual shake in Kyoto and Osaka.

In addition of these earthquake and tsunami, we faced the third disaster; the nuclear power plants in Fukushima became out of control totally and nuclear fuel was melted down. However, environmental radioactivities have been at the level of normal background or only marginally high (IPMU)

National Institute for Radiological Sciences estimated cancer risk of habitants in Tokyo on the assumption that environmental radioactivity is 0.5μSv/h and food stuffs contain upper limits of radioactivity (300 Bq / kg) for 90 days. Under these conditions, life-time cancer risk at all sites will increase only marginally by 0.0265%.

As seen in the report of Professor Petcov, there was no panic and everybody was calm even after the triple disasters. However, continuing aftershocks, uncertainty of nuclear plants and lack of information triggered exodus of foreigners from Japan. In particular, some European governments e.g., French, Italian, German and Swiss, strongly advised their citizens to leave Japan and prepared free charter flights. Foreign media also exaggerate the crisis and report that the whole nation is likely contaminated with radioactive materials and foods are not available. Such an overreaction of the governments and media caused unrest among WPI researchers from abroad.

As a result, 29-52% of foreign researchers left Japan in AIMR, MANA and IPMU shortly after the disaster, but most of them now returned and continue their research activity as seen in Table 2. Those who still remain in their home promised to return to WPI centers shortly. However, some newly appointed postdocs cancelled his/her contract.

Internationalization is one of goals under the WPI program. We will further support the international faculties and students by providing comfortable environments and full information for research and daily life.

Taking this opportunity, we would like to express our sincere sympathy and condolence to victims of these triple disasters.

We much appreciate for the support and sympathy given by our colleagues, friends and science communities of the world, which greatly encourage us. We are convinced that we will recover quickly and return to the frontier of science.

Program Director of the WPI program
Japan Society for the Promotion of Science

Toshio Kuroki

What does this disaster teach us?

First of all, I would like to express once again my heartfelt gratitude for the many sympathetic messages and expressions of support that MANA has received from all over the world since the earthquake. This reminds us that MANA is linked to persons and institutions worldwide by string bonds.

This natural disaster, which occurred in an island country in the Far East, has given rise to an extremely high degree of interest throughout the world. I don't think this is primarily because of the large scale of the disaster or the fact that Japan is an economic superpower. Rather, I think it is due to two other reasons.

First, foreign journalists have reported in the international news media, with some amazement, that there was virtually no looting or opportunistic price gouging in the wake of the disaster, and that the Japanese people have endeavored to help each other in an admirable spirit of self-sacrifice. The New York Times extolled, in a top front-page story, "the quiet bravery in the face of tragedy that seems almost woven into the national character." Such reports surprised many Japanese people, who wondered why a lack of disorder, which seemed perfectly natural to them, deserved comment. Archeologists tell us that for a period of around 10,000 years starting approximately 12,000 years ago (the late ice age), the Japanese archipelago saw the flourishing of the Jomon culture in which people lived in equality; disputes and conflict were practically unknown; food was divided up among the populace, who worked together in harmony; and there was general prosperity. It is unconceivable that the modern Japanese people are not related by blood to the people of that time to some extent. Article 1 of Japan's first constitution, written nearly 13 centuries ago, begins with the words, "Harmony is to be valued." I don't need to quote the Dalai Lama, but I believe that Japanese culture can awaken the people of the world to the fact that wars, which continue to arise out of mutual enmity throughout the world, produce nothing of value. If the disaster has created even a small opportunity for the world's people to recognize this, we can say that the blood of those who lost their lives in the catastrophe, and the sweat of those who survived, have not been expended for nothing.

The second reason is the fact that although an emergency shutdown of the reactors at the Fukushima Daiichi Nuclear Plant was successfully carried out when the earthquake struck, radioactive contamination of the air and seawater occurred due to the melting of nuclear fuel after the plant's cooling system was knocked out by the tsunami that followed the quake. This brought memories to people worldwide of the nightmare following the Chernobyl accident. The Fukushima accident was different qualitatively from Chernobyl, but they are alike in that both exposed the dangers inherent in nuclear power plants, erected as monuments of science and technology for the wellbeing of human society. It is not necessarily accurate to say that Chernobyl was a manmade disaster and Fukushima a natural disaster. The latter disaster could have been averted if only greater care had been paid to safety. For this reason the Fukushima accident provides an opportunity not only for nuclear plant engineers, but for researchers in general science and technology as well, to reexamine the relationship between science and technology and society.

We have lost many things as a result of the disaster. However, from it we can surely learn many new things and rise up once again.

Director-General
International Center for Materials Nanoarchitectonics (MANA)
Masakazu Aono

For all the friends at NIMS and MANA

I sincerely extend my deepest sympathies to the disaster victims. Coincidentally, I was in Sendai when the Great East Japan Earthquake occurred, but at that time, I couldn't think that the earthquake is only the introduction of the subsequent tsunami and nuclear accident disaster.

Here in the U.S. and Europe, people are strongly impressed that Japanese individuals cooperate with each other and work together in the catastrophe. And they regard Japanese culture and education with feelings of respect and reverence, a lot of people want to help Japan if they can do something to overcome this predicament. NIMS as the world premier research center for materials science and further Internationalized MANA project. Please remember researchers all over the world sincerely support and pray for you who have been working day and night to recuperate from the earthquake disaster.

A significant aftershock still often occur and unpredictable radioactive contamination from the Fukushima nuclear power plant exhaust you both officially and privately, I hope that you would think this is a good opportunity to show Japanese potentiality and your luck toward a bright future.

Professor of Stanford University
Director of Center for Integrated Systems of Stanford University (CIS)
MANA Evaluation Committee Member
Yoshio Nishi

As determined as ever

During the annual MANA symposium that ended March 4, science was celebrated! New results, new challenges, talented young scientists, new ideas! Little did we know that a week later, the wrath of Nature would cripple Japan! There were hard days, hard weeks, Japan and its people bent, but did not break. I witnessed the determination of all in these difficult circumstances. MANA scientists have discovered new and unforeseen challenges ahead. I am convinced that together, and from all countries, they will succeed! I let J.S. Bach give us a few lines of hope!

Do away with anxiety and dread,
Like the steersman, when the wind is calmed,
Who no more fears or turns pale,
But content on his prow,
Goes singing in the face of the sea.

(Cantata Bwv 209, Non sa che sia dolore)

Personally, as a new principal investigator of MANA, I am determined to answer the "great challenge" and to contribute to the efforts spent by all Japanese towards the recovery of their country.

Professor of University of Montreal
Satellite Principal Investigator
Françoise M. WINNIK

MANA International Symposium 2011

MANA International Symposium 2011 was held at the Tsukuba International Congress Center from March 2 to 4, 2011. Nine distinguished researchers including Prof. von Klitzing, 1985 Nobel laureate in Physics, Max Planck Institute, were invited to give presentations. Also, MANA researchers presented their research results in 28 oral presentations and over 100 poster presentations.

Active discussions were conducted by 410 participants from 29 countries, which exceeded the number of last year.

Dr. Rohrer's Science Class 2011

As a part of outreach activities, MANA hosted "Dr. Rohrer's Science Class 2011" at Namiki Site on March 5th, 2011. Dr. Heinrich Rohrer, 1986 Novel laureate in Physics, gave a lecture for 80 junior-high school students from nearby Tsukuba to help them to understand joys and fun of science.

Dr. Rohrer with junior-high school students

New MANA building is under construction

Construction of MANA's new research building is steadily making progress toward its completion in March 2012, although there has been concern about delay in construction caused by Tohoku-Pacific Ocean Earthquake occurred on March 11.

Photo taken on May 25, 2011

Awards

Received the 6th NIMS President's Award

Four MANA researchers received the 6th NIMS Presidents' Awards on April 1, 2011. The award was given to them for the significant contributions to their research fields.

Research Achievement Award

"For his outstanding accomplishments and publishing an excellent review article on supramolecular chemistry field."

Dr. Katsuhiko ARIGA, MANA PI

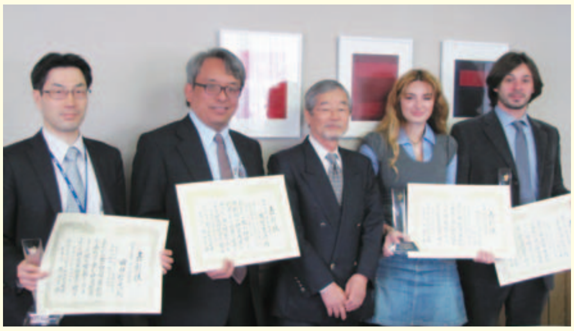
Research Encouragement Award

"For development of high performance and chemically stable oxide proton conductors."

Dr. Emiliana FABBRI, MANA Scientist and Dr. Daniele PERGOLESI, MANA Scientist

"Development of tissue-adhesive materials and technology for biomedical applications."

Dr. Tetsushi TAGUCHI, MANA Scientist



From left to right, Dr. Taguchi, Dr. Ariga, Dr. Ushioda, NIMS President, Dr. Fabbri and Dr. Pergolesi.

Received the FY2010 Commendation of Science and Technology By MEXT

On April 11, MANA Independent Scientist Jun Nakanishi was awarded the Commendation of Science and Technology by the Minister of Education, Culture, Sports, Science and Technology (MEXT). He received the Young Scientists' Prize, which recognizes young researchers with advanced R&D ability, for his work on "Development of Photoresponsive Cell Culture Substrates".

Dr. Nakanishi

Newly Appointed Researchers

Guoping CHEN

Principal Investigator
Nano-Bio Field
Tissue Regeneration Materials Group
Specialty: Biomaterials

Toyohiro CHIKYOW

Principal Investigator
Nano-Materials Field
Nano-Electronics Materials Group
Specialty: Nano electronics materials

Françoise M. WINNIK

Satellite Principal Investigator
Univ. Montreal
Nano-Bio Field
Specialty: Nano-bio by polymer chemistry

Seventeen MANA Scientists, one MANA Independent Scientist and two ICYS-MANA Researchers joined MANA.

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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 nanoarchitechtonics for the creation and innovation of new functional materials.

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