World Premier International Research Center Initiative (WPI)
FY2011 WPI Project Progress Report (Post-Interim Evaluation)

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Research Center	International Center for Materials Nanoarchitectonics (MANA)	Center Director	Masakazu Aono

Summary of State of WPI Center Project Progress (write within the space of this page)

Research of the world's highest level: The following selection from among our research accomplishments represents the vanguard of nanotechnology and materials scinece: A) Revolutionary nanomaterials created by "nanosheet technology", B) Novel "low-dimensional" superconductors, C) Nano-power generation/conversion/storage nanomaterials and systems, D) Boron nitride (BN) "white" nanotubes and nanosheets, E) Revolutionary nanodevices, F) Novel nanoscale characterization/analysis methods, G) Nano-life related materials research, H) Theoretical nanoscience. Although the research at MANA is conducted in the four research fields of Nano-Materials, Nano-System, Nano-Green and Nano-Bio, most of the foregoing research results from collaborative studies in two or three different research fields.

Fusion of various research fields: In order to promote research fusion at MANA, we have set up funding programs such as our Grand Challenge Research Program and Inter-field Projects. The latter specifically aims to enhance the interaction between nano-bio and other fields, and theory and experimentation. MANA researchers are involved in eight of the 11 NIMS InterUnit Seeds Development Research Grants of FY2011. To bring together researchers from different fields, MANA holds frequent seminars and a Grand Challenge Meeting once or twice a year. These meetings have proven to be highly beneficial in the fusion of various fields and in motivating young researchers to tackle new challenges.

Globalization: The Center employs 206 researchers, of which 116 or 56% are foreign nationals. Despite the Great East Japan Earthquake and subsequent nuclear power plant incident, the percentage of foreign researchers has not changed. To strengthen Nano-bio programs, Prof. Francoise Winnik of the University of Montreal was appointed a Principal Investigator in April 2011. To promote the unique concept of nanoarchitectonics and raise MANA's profile, two special issues on MANA were published in *Advanced Materials* and *Science and Technology of Advanced Materials*, and MANA began announcing its research worldwide with the launch of its English newsletter the *MANA Research Highlight.*

Organizational reforms: MANA's role in promoting some of the NIMS system reforms is clearly positioned in NIMS' third five-year plan. The item "building international networks and bases for international research" states that MANA's "experience in developing an international research environment and recruiting and training young researchers will be reflected in NIMS' internationalization efforts made as a whole."

The center's future development over the mid- to long term: MANA was formally incorporated into one of the three priority R&D fields within NIMS' third five-year plan, and has become one of NIMS' research divisions. When the next five-year plan commences, MANA will continue to function as a core research division in charge of one of NIMS' strategic research fields and maintain the overall 200-strong body of researchers including between 80 and 90 of MANA's PIs, MANA Scientists and Independent Scientists. After the WPI funding period ends, MANA will receive operations subsidies from NIMS and its researchers will seek out external funding in order to maintain the Center's size and level of research activity.

1. Conducting research of the highest world level

We take pride in our having conducted world-class materials research in the five years that have passed since MANA was launched. Our materials research covers a wide sweep of programs from basic studies to advanced applications. Also, we regard theoretical/computational research and the development of novel research equipment as important activities. All research is conducted on the basis of "materials nanoarchitectonics", which we regard as an essentially important concept for new materials development. The high quality of our research is reflected in the various parameters presented later in the supplementary materials in the appendices.

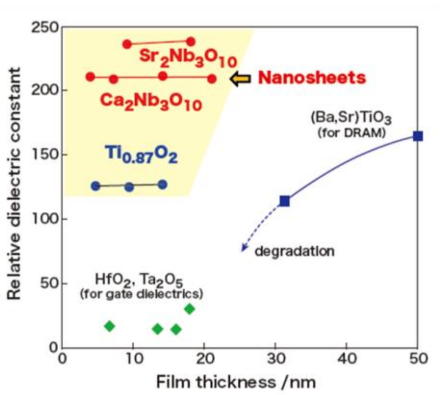
The following is a brief description of MANA accomplishments. MANA conducts research in the four fields of Nano-Materials, Nano-System, Nano-Green and Nano-Bio. Most of the projects below represent the outcome of studies bridging several different research fields.

A) Revolutionary nanomaterials created by "nanosheet technology"

MANA has developed a unique method to create novel materials, which is now well known as "nanosheet technology". The method consists of exfoliating layered compounds into unilamellar nanosheets and re-stacking the nanosheets in a designated order to create a new material with a novel characteristic. By this method, we have created numerous revolutionary nanomaterials, a few of which are shown below.

a. World's-highest-dielectric-constant thin films

We have developed $Sr_2Nb_3O_{10}$ and $Ca_2Nb_3O_{10}$ nanosheet films with a thickness of about 10 nm. They demonstrate the world's highest dielectric constant of more than 200. These materials hold promise as a gate insulator of future field effect transistors (FETs) (Fig.1).



M. Osada et al., *Adv. Funct. Mater.* **21 (2011) 3482.**

Fig. 1 Revolutionary nanomaterials created by "nanosheet technology".

b. Surprising ferroelectric ultrathin films

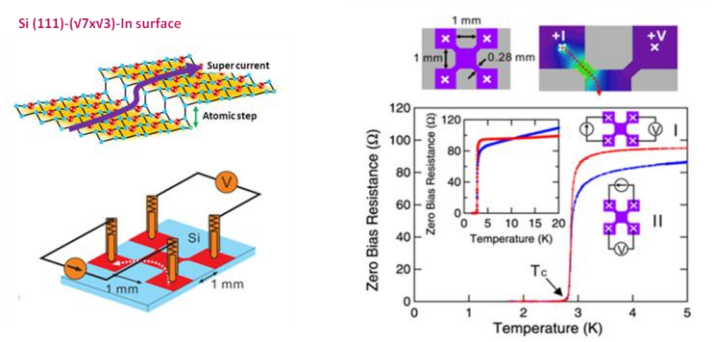
The $LaNb_2O_7$ and $Ca_2Nb_3O_{10}$ nanosheet films are usually paraelectric, but, surprisingly enough, their hetero-assembled (superlattice) film becomes ferroelectric. This behavior may be ascribed to the formation of soft interface between the two different nanosheets, resulting in loss of centrosymmetry.

B) Novel "low-dimensional" superconductors

We have discovered various novel superconductors. Three examples are shown below.

a. World's first observation of surface macroscopic superconducting current

Macroscopic superconducting current through a solid surface has been observed for the first time. Namely, the (111) surface of silicon modified with a small amount of indium, i.e. the Si(111)$\sqrt{7}$x$\sqrt{3}$-In surface, allows superconducting current to flow over a millimeter distance. This is surprising because numerous atomic steps existing on the surface do not disturb the transport of Cooper pairs of electrons. Systematic measurements of critical current and further analysis suggest that each surface atomic step works as a Josephson junction (Fig. 2).



T. Uchihashi et al., *Phys. Rev. Lett.* 107 (2011) 207001.

Fig. 2 Novel "low-dimensional" superconductors.

b. Flexible fibriform superconductor

We have developed flexible fibriform nanowhiskers made of C_{60} molecules. The C_{60} nanowhiskers can be doped with potassium (K) by heating the nanowhiskers in the vapor of K. Interestingly, a Meissner effect is observed for the K-doped C_{60} nanowhiskers at temperatures below about 15 K, indicating that the nanowhiskers are superconducting below the temperature.

c. Ultrathin film superconductor

Recently, we have discovered $FeTe_{1-x}Se_{x}$, a superconductor with a superconducting temperature (T_c) of about 15 K. Interestingly, even when the material is in the form of an ultrathin film with a thickness as small as 20 nm, T_c is unchanged as compared with bulk $FeTe_{1-x}Se_{x}$.

C) Nano-power generation/conversion/storage nanomaterials and systems

One of the main concerns of MANA is the generation/conversion/storage of "power" at the nanoscale, where the term "power" represents "usable energy". We have developed various nanomaterials and nanosystems for this purpose. Here are several examples of this cutting-edge technology.

a. World's highest photo-catalytic efficiency

A new material was developed by incorporating phosphor (P) block element into a simple silver oxide (AgO) with a narrow band gap. The new photocatalytic material, Ag_3PO_4, demonstrates an extremely high quantum yield (~90% for photons with a wave length of ~420 nm) regarding water oxidation as well as organic contaminates decomposition under visible light. This study not only supplies a new strategy for developing visible-light-driven photocatalysts, but also shows a giant step toward realizing an artificial photosynthetic system.

b. Nanogenerators for self-powering nanosystems

We have developed a simple and effective approach called the scalable sweeping-printing-method for fabricating a flexible high-output nanogenerator (HONG) that can effectively harvest mechanical energy for driving a small commercial electronic component. The HONG consists of two main steps. In the first step, the vertically-aligned ZnO nanowires (NWs) are transferred to a receiving substrate to form horizontally-aligned arrays. Then, parallel stripe type electrodes are deposited to connect all of the NWs together. Using a single layer of HONG structure, an open-circuit voltage of up to 2.03 *V* and a peak output power density of ~11 mW/cm^3 have been achieved. The generated electric energy was effectively stored utilizing capacitors, and it was successfully used to light a commercial light-emitting diode (LED), landmark progress toward building self-powered devices by harvesting energy from the environment.

D) Boron nitride (BN) "white" nanotubes and nanosheet

We have studied how to prepare boron nitride (BN) nanotubes and nanosheet (monomolecular layer) and have measured their physical properties comprehensively by transmission electron microscope (TEM). BN nanotubes and nanosheet are similar to carbon nanotubes and graphene in structure, but their electrical is far less than carbon nanotubes and graphene; we therefore call them "white" nanotubes and graphene. Recently, we have developed a new BN nanosheet synthesis process which we call "chemical blowing". The nanosheet with thickness of 1-2nm can be created with high yield. We have also found that BN nanotubes have a high tensile strengths (~50 times stronger than steel) and BN nanosheet ("white" graphene) is a semiconductor.

E) Revolutionary nanodevices

MANA has developed various novel devices for the innovation of information and communication technology and has succeeded to materialize several new promising atomic, molecular and quantum devices as follows.

a. Atomic switches as "Beyond CMOS" memory and logic devices

The atomic switch is a unique switching device developed by MANA. Compared with the conventional CMOS transistor switch, the atomic switch is characterized by a nonvolatile character, simple structure, small size and low power consumption. In collaboration with NEC Corp., we have studied the use of atomic switches to fabricate a compact and high-performance field-programmable gate array (FPGA) and reached the technological level necessary for commercialization (Fig. 3).

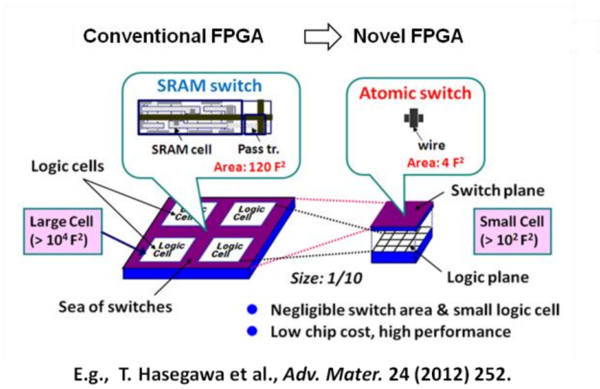
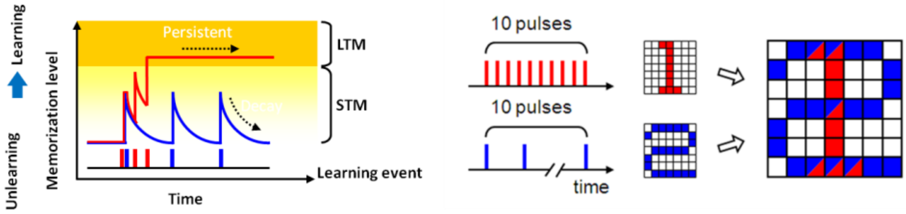


Fig. 3 Practical application of atomic switches to materialize compact FPGA.

b. Atomic switches for neuromorphic computational network circuits

Memory is believed to occur in the human brain as a result of two types of synaptic plasticity: short-term plasticity (STP) and long-term potentiation (LTP). STP is achieved through the temporal enhancement of a synaptic connection, which then quickly decays to its initial state. However, repeated stimulation causes a permanent change in the connection to achieve LTP; shorter repetition intervals enable efficient LTP formation from fewer stimuli. Development of artificial (inorganic) synapse that emulates the STP and LTP behaviours is the key-issue in the realization of the Brain-type computer, which we have achieved using an Ag_2S-based gap-type atomic switch (Fig. 4). Namely, pulse input with a lower repetition rate only caused the temporal increase in conductance, corresponding to the STP-mode. Conversely, pulse input with a higher repetition rate achieved a persistent transition to the higher conductance state, corresponding to the LTP mode. The synaptic behaviours are useful for developing artificial neural networking systems made of all solid-state devices, which do not require any pre-programming. Preliminary studies have been made with promising results.

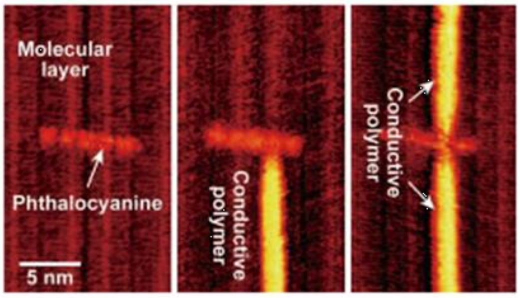


T. Ohno et al., *Nature Mater.* 10 (2011) 591.

Fig. 4 Application of synaptic characteristics of atomic switch.

c. Novel molecular devices

We have found the following surprising fact for a C_{60} thin film. Two adjacent C_{60} molecules at any designated position in the film can be chemically bound into a dimer by the tip of the scanning tunneling microscope (STM), and moreover, if the polarity of voltage applied to the tip is reversed, the C_{60} dimer is dissociated reversibly. As an application of this phenomenon, we have demonstrated ultradense data storage with a bit density of 190 Tbit/in^2.



STM images

Y. Okawa et al., *J. Am. Chem. Soc.* 133 (2011) 8227.

Fig. 5 Novel molecular devices toward single-molecular electronics

We have developed a method to create a single conductive linear polymer chain (polydiacetylene) at designated positions by initiating chain polymerization of monomers (diacetylene) with a scanning tunneling microscope (STM) tip. Using this method, we have studied construction of a two-terminal nanowiring for a single phthalocyanine molecule and have succeeded in making nanowiring through chemical soldering or firm covalent bonding (Fig. 5).

d. Novel quantum devices

MANA has developed a superconductor-based light emitting diode (LED). In this LED, electron Cooper pairs in a superconductor recombine with normal holes in a semiconductor emitting quantum-mechanically entangled photon pairs. This LED is expected to be the key device in quantum information technology because of its promising giant oscillator strength due to the large coherence volume of the superconducting pairs together with the possibility of the on-demand generation of entangled photon pairs.

We have also developed an ultimate superconducting quantum interference device (SQUID), i.e. a nano-SQUID, which can detect even single or several spins. We have clarified the quantum interaction between a nano-SQUID with embedded quantum dots and spins in the quantum dots. This leads to the implementation of an entangled state between a superconducting qubit and spin qubit. The combination of these qubits is a promising candidate for a quantum interface that will be indispensable in the future quantum information network.

F) Novel nanoscale characterization/analysis methods

a. *Multiple-probe scanning probe microscopes*

We have been conducting a series of pioneering work for the development of multiple-probe scanning tunneling microscopes (MP-STMs) and atomic force microscopes (MP-AFMs). Recently, we have developed a quadruple-probe AFM (QP-AFM) in which four conductive AFM probes are operated independently and simultaneously in frequency modulation mode using tuning-fork type sensors. By using this QP-AFM, we have succeeded to make four-probe measurement of the electrical conductivity of a flake of graphene put on an insulating substrate (SiO_2) (Fig. 6).

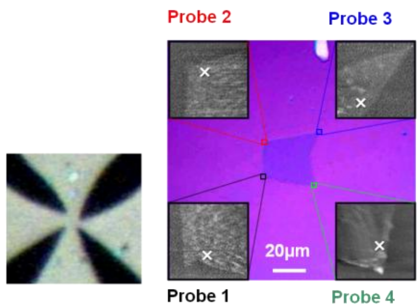


Fig. 6 Four-probe measurement of the resistivity of a single layer graphene

b. *Novel ultrasensitive/ultraparallel molecular sensors*

We have developed a membrane-type surface stress sensor (MSS), which is useful for high-sensitivity sensing of various analytes ranging from gaseous to biological molecules. The analyte-induced isotropic surface stress on the membrane is efficiently transduced onto the piezoresistive beams as an amplified uniaxial stress. Experimental evaluation of a first prototype MSS demonstrates an ultrahigh sensitivity which is more than 20 times higher than that of a standard piezoresistive cantilever and comparable to that of optically read-out cantilevers. To demonstrate the capability of MSS for ultraparallel sensing, we have microfabricated a 2D array of MSS. By using this 2D MSS as a gas sensor, we succeeded in "visualizing smells" in real-time by converting signals from each channel in the 2D array into colored-pixels of the "picture."

G) Nano-life related materials research

a. *Novel bioimaging method*

Using the surface modification technique, several types of nanoparticles were prepared for bioimaging. Er-doped yttrium oxide ($Er:Y_2O_3$) nanoparticle emits not only near infrared (NIR) light but visible light under NIR excitation. The latter emission is called infrared-to-visible upconversion (UC) emission. Poly(ethylene glycol) (PEG)–based PEG-b-poly(vinylbenzyl phosphoric acid) (PEG-b-PVBP) stabilized the UC-nanoparticle, which can be utilized as near-infrared bioimaging tools. PEG-b-PVBP also stabilized ion oxide and can be utilized in vivo. Ion oxide nanoparticles thus prepared can be utilized as an MRI imaging probe as well as magnetite-assisted hyperthermia.

H) Theoretical nanoscience

a. Manipulation of quantum entanglement of nonlocal electron pairs

We propose to measure Josephson current which is purely contributed from entangled electron pairs, by either co-tunneling or split-tunneling. In order to figure out how much split Cooper pairs contribute to the total Josephson current, the oscillation of maximal Josephson current is detected with response to the magnetic flux applied through the area enclosed by the two paths. When the contribution from split Cooper pairs equals to that from co-tunneling ones, the oscillation period is $2\Phi_0$, whereas it should be Φ_0 without split tunneling. This measurement gives an unambiguous evidence for the nonlocal quantum entanglement of electrons.

b. Topological-superconductor Majorana-particle quantum bit system

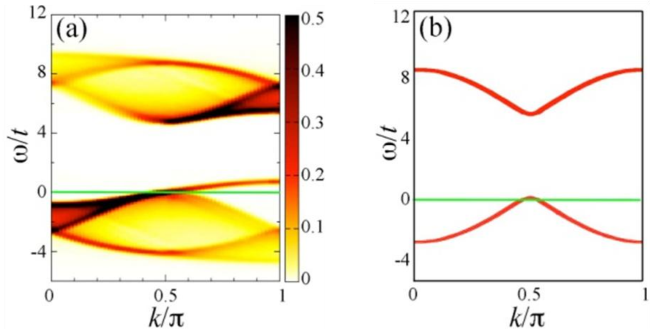
In a heterostructure consisting of a superconductor, semiconductor with large spin-orbit coupling and ferromagnetic insulator, if an odd number of fluxes exist in the superconductor, Majorana particles appear in the flux cores and at the edge of the superconductor. If we connect three such heterostructures through a gated pathway, we can control the exchange of Majorana particles between the heterostructures, so that we can make non-Abelian quantum bit operation.

c. Mass-less Leggett mode in three-band superconductors

The Leggett mode associated with out-of-phase oscillations of the superconducting phase in multiband superconductors usually is heavy due to interband coupling, which makes its excitation and detection difficult. We found the existence of a massless Leggett mode in three-band superconductors with time-reversal-symmetry breaking. The mass of this Leggett mode is small close to the time-reversal-symmetry-breaking transition and vanishes at the transition point, and thus locates within the smallest superconducting energy gap, which makes it stable and detectable, e.g., by means of the Raman spectroscopy. The thermodynamic consequences of this massless mode and possible realization in iron-based superconductors also attract our attention.

d. Loss of charge character in Mott transition

By using exact solutions and numerical simulations, single-particle spectral properties near the Mott transition are investigated in the one-dimensional Hubbard model. The results show pseudogap, hole-pocket behaviors, anomalous spectral-weight transfer, and the upper Hubbard band, which are reminiscent of anomalous features observed in cuprate high-T_c superconductors. In contrast with conventional metal-to-band-insulator transitions, the Mott transition turned out to be characterized as a loss of charge character from the mode having both spin and charge characters, while the spin part remains almost unchanged. Or, from the insulating side, the Mott transition is characterized by the emergence of a gapless mode whose dispersion relation extends up to the order of hopping integral t [spin exchange J] in the weak [strong] interaction regime (Fig .7).



M. Kohno, *Phys. Rev. Lett.* 108 (2012) 076401-1.

Fig. 7 Theoretical studies of Loss of charge character in Mott transition

2. Advancing fusion of various research fields

Since the start of MANA of five years ago, we have regarded the fusion of different research fields as a key to accomplish advanced research. MANA's research organization consisting of four research fields itself is designed so as to promote the fusion of different research fields. Namely, generally speaking, basic research in Nano-Materials and Nano-System fields is fused to application research in Nano-Green and Nano-Bio fields. We believe this scheme has worked considerably well particularly over the past two years. It should be pointed out that MANA's seven research satellites placed in the USA, UK, France, Canada and Japan have also contributed significantly to research fusion.

In order to promote research fusion at MANA, we have established a variety of programs.

The MANA Grand Challenge Research Program was launched in FY2011 as a way to encourage researchers to undertake innovative, "outside-the-box" interdisciplinary research not only limited to materials science. This initiative sought applications for risky yet challenging topics that matched the concept of nanoarchitectonics; seven applications were accepted.

MANA Seminars have been held on a frequent basis since our inception. At these seminars, researchers from both within and outside MANA present hot research topics and engage in discussions with MANA researchers of different fields. Thus, each seminar comes into its own as a true "melting pot." As a result, the seminars play a key role in promoting field integration.

Once or twice a year, MANA holds a "camp"-type approach called "Grand Challenge Meetings." About twenty MANA researchers are selected from among those who are interested in joining this meeting and they engage in free discussions about future grand challenges at MANA at a remote country site for two days. We have observed that this meeting proves remarkably useful for triggering fusion research between MANA's scientists in different research fields.

Furthermore, we launch inter-field projects to promote more joint research among the four fields including those developing interaction between nano-bio and nano-materials/nano-system, and theory and experiment. With the same objective in mind, MANA's host institution, NIMS, began the InterUnit Seeds Development Research Grants in FY2011, and MANA researchers are currently involved in eight of the 11 projects initially selected.

At MANA, various interesting fusion studies have been carried out. The following section introduces three examples of ongoing fusion research that is attracting attention.

1) *Fusion research between nanobiology and nanotechnology*

This is a shining example of fusion research in MANA. Prof. Winnik of the University of Montreal is an authority of near-infrared (IR) in-vivo bioimaging. She became a PI at MANA a year ago. After arriving, she recognized that fusing research with Dr. Naoto Shirahata (who developed novel nanoparticles that are active in near-IR region) and Dr. Tadaaki Nagao (who has made advanced studies of plasmonic nano-antenna in the near-IR region), could open the way to development of a new method of highly-sensitive near-IR in-vivo bioimaging. Already, a close collaboration has started.

2) *Fusion research between theoretical nanoscience and nanotechnology*

Dr. Xiao Hu, a MANA PI, recently made the following theoretical prediction which is attracting great interest. If a heterostructure consisting of a superconductor, semiconductor with large spin-orbit coupling and ferromagnetic insulator is constructed, a Majorana particle appears at the edge of the heterostructure in a certain condition. If three such heterostructures are connected through a gated pathway, it is possible to control the exchange of Majorana particles between the heterostructures, achieving non-Abelian quantum bit operation for quantum computation without decoherence. Independently, Dr. Takashi Uchihashi, a MANA scientist, has observed macroscopic superconducting current through a certain solid surface (a Si surface modified with a small amount of In) for the first time. If these two studies are fused, the quantum bit without decoherence mentioned above will be materialized relatively easily.

3) *Fusion research between fuel cell technology and nanoelectronic device technology*

MANA maintains its own nanofabrication facilities, the MANA Foundry. Well equipped with fabrication and analytical equipment, the foundry's clean rooms provide a comprehensive nanofabrication environment for nearly all kinds of research in-house. The head of the MANA Foundry, Dr. Toshihide Nabatame, has much experience in various kinds of nanofabrication. Dr. Daniele Pergolesi, a MANA scientist who has studied solid oxide fuel cells extensively, recently reported the world's highest value of proton conductivity in his $BaZr_{1-x}Y_xO_{3-y}$ sample. Dr. Nabatame has used this sample to fabricate a novel non-volatile field effect transistor demonstrating promising preliminary results. This is the outgrowth of the MANA Fusion Research Program launched in FY2009.

3. Globalization of the institution

- Efforts being developed based on the analysis of number and state of world-leading, frontline researchers; number and state of visiting researchers; exchanges with overseas entities

As of March 31, 2012, the Center employs 206 researchers, of which 116, or 56%, are foreign nationals. 45 of these researchers, or 22%, are women.

Due to the Great East Japan Earthquake and subsequent nuclear power plant incident, approximately 2/3 of the research staff evacuated Japan temporarily, but almost all of them returned to MANA so the percentage of foreign researchers has not changed.

That being said, the number of foreign researchers visiting MANA fell drastically for a period of time after the disaster. In the first half of FY2011, visitor numbers fell by one-third year-on-year, and the decrease in visitors from Europe and the United States was nearly 90%. Visitor numbers have been recovering in the second half of the year.

To strengthen Nano-bio, Prof. Winnik from the University of Montreal was appointed as a Principal Investigator in April 2011. Prof. Winnik is a world-renowned researcher in the fields of polymer science, interfacial chemistry and nanoscience, and she serves as the Executive Editor of *Langmuir*, the journal of the American Chemical Society. Concurrent with her appointment, a new satellite was established at the University of Montreal. Prof. Winnik has labs at both MANA and the University of Montreal, and her teaching load was reduced to zero to allow her to focus her energies entirely on research. In FY2011, Prof. Winnik spent 146 days conducting research at MANA. Going forward, she plans to spend approximately five months out of the year conducting her research at MANA.

One of MANA's missions is to become a hub and build a network connecting the world's nanotechnology centers. In FY2011, the Center concluded new MOUs with six foreign research institutes, bringing the total number of MOUs to 36. The Center holds workshops with these institutes and engages in joint research and personnel exchange with them.

MANA Research Workforce (as of March 31, 2012)

Position	Number	Non-Japanese	Female
Principal Investigators	25	10	2
MANA Scientists	58	7	8
Independent Scientists	9	2	0
ICYS Researchers	11	8	1
MANA Research Associates	43	40	15
JSPS Fellows	16	12	3
Junior Researchers*	44	37	16
Total	206	116	45

*PhD Students

- Proactive efforts to raise the level of the center’s international recognition

In FY2011, special issues on MANA were published in two original journals, thereby publicizing the unique concept of nanoarchitectonics and raising MANA's profile. One was a special issue of *Science and Technology of Advanced Materials* (August 2011; impact factor: 3.226), a journal edited and published by MANA's host organization NIMS, and the other was a special issue of *Advanced Materials* (January 2012; impact factor: 10.880), a journal published by John Wiley & Sons.

In the past, MANA only issued domestic press releases on its excellent research results, but in FY2011 the Center began publicizing its research worldwide with an English newsletter called *MANA Research Highlight*. The newsletter, which contains English articles written by the former editor of *Nature Nanotechnology*, is distributed to over 4,000 media outlets and science journalists and to about 2,000 MANA mailing list members. Particularly outstanding research results are sent to 10,000 researchers around the globe via *Science* e-mail alerts. With these efforts, we are working to increase MANA's name recognition throughout the global science community.

- Efforts to make the center into one that attracts excellent young researchers from around the world (such as efforts fostering young researchers and contributing to advancing their career paths)

In addition to the four pillars of the WPI Program—world-class research, interdisciplinary research promotion, internationalization and systemic reform—the cultivation of young researchers is another key pillar of MANA.

Under the 3D System, MANA Scientists and Independent Scientists receive mentoring from renowned researchers from foreign research institutes. They visit their mentors to obtain research advice and are encouraged to pursue independent research. This system is incredibly effective in producing international and interdisciplinary young researchers. In April 2011, two MANA Scientists and three Independent Scientists were promoted to Group Leader positions based on their achievements.

A new system will be launched in FY2012 in which outstanding young researchers under the age of 45 who have excellent future potential and can be expected to engage in activities equivalent to Principal Investigators are named Associate Principal Investigators. This is a career track position that can eventually lead to promotions to Principal Investigator or Group Leader, and the objective is to have young researchers undertake their research with higher goals in mind.

114 of the Center's 206 researchers are post-doc researchers and graduate students, of which 97, or 85%, are foreign nationals. In this manner, MANA has achieved an environment in which a large number of young researchers from around the world can hone their skills through friendly rivalry.

4. Implementing organizational reforms

MANA is clearly positioned and has an important role in NIMS' third five-year plan, which came into effect in April 2011, with regard to two of NIMS' four missions; namely, promotion of fundamental research and training and improved qualification of researchers. Furthermore, the item "building international networks and bases for international research" within the five-year plan states that MANA's "experience in developing an international research environment and recruiting and training young researchers will be reflected on internationalization efforts made by NIMS as a whole." Thus, MANA's role in promoting some of NIMS system reforms is clearly positioned in the five-year plan.

In terms of the recruitment and training of young researchers, the Independent Scientist and ICYS Researcher systems, in which researchers conduct independent research without belong to a specific group, have posted good results. In particular, the 3D System, which encourages young researchers to train abroad and pursue interdisciplinary research under the tutelage of top-tier mentors, has contributed greatly to developing global perspective in these researchers. NIMS also encourages young researchers to partake in long-term research abroad. It plans to extend the maximum length of research abroad from one to two years and has recently begun giving research abroad participants preferential treatment on their performance evaluations.

In addition, ICYS has proven successful as a system for selecting and training young outstanding post-doc researchers from around the world and handpicking the best candidates for permanent researcher positions at NIMS. In FY2011, seven ICYS Researchers competed for permanent positions at NIMS, and three were successful. This is an extremely high pass rate when considering that the rate of competition for publicly-offered positions is several dozen times higher. This is proof that ICYS functions very well as a tenure-track system that allows outstanding young researchers to gain experience conducting independent research in fixed-term positions.

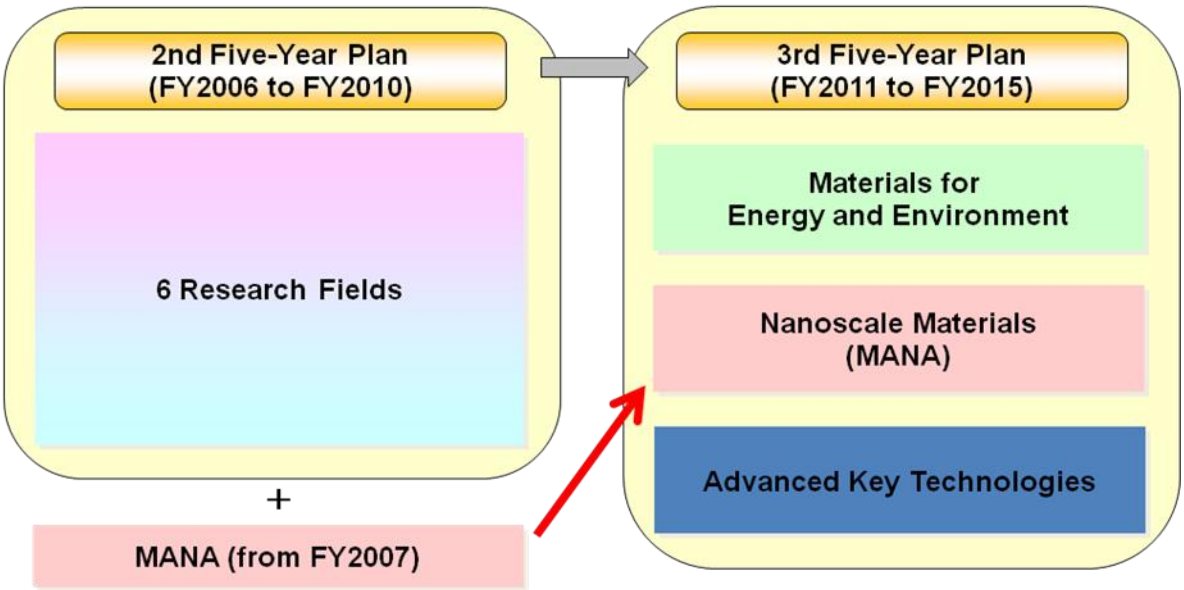
NIMS is working to make operating systems throughout the organization bilingual, and has made efforts to raise the English abilities of its administrative staff. Since FY2010, NIMS has been placing priority on hiring employees with strong English ability. NIMS also uses operations subsidies to provide English conversation lessons, correspondence education and overseas language training geared toward young permanent staff. Every year, staff members are required to sit TOEIC exams to check their language proficiency. A dramatic increase in the average score over the past two years, from 381 to 462, points to the effectiveness of this training.

These reforms show that the various system reforms and efforts to change employee awareness that MANA has implemented within its organization thus far are showing progressive penetration into the host institution.

5. Efforts to secure the center's future development over the mid- to long term

- Future Prospects with regard to the research plan, research organization and PI composition; prospects for the fostering and securing of next-generation researchers

MANA's development of innovative new materials based on nanoarchitectonics was formally incorporated into one of the three priority R&D fields within NIMS' third five-year plan, which came into effect in April 2011, and MANA has become one of NIMS' research divisions. Research fields will also be reviewed in FY2016 when the next five-year plan commences, and MANA will continue to exist as a core research division in charge of one of NIMS' strategic research fields.



MANA's position in NIMS

Principal Investigator numbers will be kept around 20, and all PIs will be NIMS permanent researchers. As needed, young researchers may be appointed as PIs to invigorate the Center. MANA will continue usingthe networks it has developed during the WPI funding period to foster active exchange with research institutes around the globe. Overseas satellites will be established when deemed necessary.

The Associate PI, Independent Scientist and ICYS systems will be maintained since they are effective tools for the retention and training of young researchers. The 3D System for young researchers will also be maintained as an extension of the NIMS research abroad scheme.

- Prospects for securing resources such as permanent positions and revenues; plan and/or implementation for defining the center's role and/or positioning the center within the host institution's institutional structure

Between 80 and 90 of MANA's PIs, MANA Scientists and Independent Scientists are already tenured NIMS researchers. We will maintain this number going forward as well as the overall 200-strong body of researchers, including post-doc researchers and graduate students. Personnel expenses for tenured researchers involved in MANA will be covered by NIMS operations subsidies, while external funding aside from operations subsidies will be used to hire post-doc researchers, graduate students and other fixed-term researchers.

One issue that remains is acquiring MANA operating expenses to cover personnel expenses for staff, expenses for the 3D System and other young researcher training programs, and expenses for symposia and other outreach events. MANA and its host institution NIMS will discuss those administrative duties that can be transferred to NIMS, all while ensuring that the level of activity in the Center does not decrease.

- Measures to sustain the center as a world premier international research center after program funding ends (including measures of support by the host institution)

As mentioned earlier, after the WPI funding period ends, MANA will receive operations subsidies from NIMS and its researchers will seek out external funding in order to maintain the Center's size and level of research activity. However, since there is no prospect of increased operations subsidies, for MANA to maintain the same level of activity as a "World Premier International Research Center" will absolutely require a constant stream of external funding to the tune of at least 2 billion yen as well as the creation of a system for allocating those funds to post-doc researcher hiring and research project expenses.

6. Others

In March 2012, the construction of a new research facility (14,777m^2) located next to the current MANA Building was completed. This new facility is comprised of two buildings, the WPI-MANA Building and the NanoGREEN Building, with MANA occupying the entire WPI-MANA Building and part of the NanoGREEN Building. With this, all of MANA's researchers are now concentrated in three adjacent buildings.

The new building was designed to promote interdisciplinary research. To transform the standard practice of researchers "putting up walls" and promote communication, partitions were used as little as possible in the offices and labs with glass partitions used only where necessary. On each floor, the office layout was designed so that researchers from two or three different fields, not just researchers in a single discipline, occupy the same space.

The glass-walled atrium connecting the WPI-MANA and NanoGREEN building also serves to encourage interaction among researchers. The Cafeteria on the first floor and the Interaction Spaces on the second through fifth floors are expected to promote exchange both among MANA researchers and with visiting researchers and company engineers who gather in the NanoGREEN Building.

The Auditorium on the first floor of the WPI-MANA Building has a tiered theater with 97 seats, a large screen and the latest video projection equipment, and it will likely become a venue for lively discussions in workshops and seminars.

The transfer of offices and labs to the new buildings is scheduled to be completed by the summer of 2012.

Front façade of the new building

7. Center's response to interim evaluation

1) In comparison to other WPI centers, MANA's goals seem modest and not "earthshaking" outside of the material science community. It needs to create greater exposure outside of that field.

MANA is focusing its research resources on the three challenging, top priority research topics of neuromorphic computational circuits, room temperature superconductors and artificial photosynthesis.

The MANA Grand Challenge Research Program was launched in FY2011 as a way to encourage researchers to undertake innovative, "outside-the-box" interdisciplinary research not only limited to materials science. This initiative sought applications for risky yet challenging topics that matched the concept of nanoarchitectonics; seven applications were accepted. MANA will continue to provide financial assistance for groundbreaking research proposals.

2) Nano-bio is still not well adopted in MANA, in which "nanoarchitectonics" expertise is not intensively used. Further efforts are needed to advance highly competitive research subjects, e.g., nano-DDS and drug-eluting stent.

By conducting joint research combining materials, nanotechnology and biology, Nano-bio will pursue basic research oriented toward human-related nano-biotechnology, specializing in bioimaging, nanomedicine, regenerative medicine and bio-nanointerfaces, with the hope that this will lead to clinical trials. In line with this, MANA plans to change the name of this research field from Nano-bio to Nano-life.

To encourage original Nano-bio research rooted in nanoarchitectonics, a research fund to bolster the field of Nano-bio will be established. Within this framework, MANA will promote interdisciplinary research involving its strong areas of Nano-materials and Nano-system.

3) More theoreticians should be integrated into the projects in order to guide and support the research.

In April 2011, the Nano-System Computational Science Group was established, and MANA Independent Scientist Dr. Yoshitaka Tateyama was named Group Leader. Dr. Tateyama is a computer scientist who is currently actively engaged in joint research projects with experimental researchers from within and outside of MANA. To strengthen this group's activities, MANA researchers with computer science expertise are scheduled to be appointed to the group in April 2012.

MANA also plans to involve more theoreticians, including those from foreign research institutes, in its research projects.

Furthermore, a research fund to promote the integration of theory and practice will be established in FY2012, and materials research supported by theoreticians will be pursued.

4) There is a concern about so few PIs choosing to take sabbaticals to high quality foreign laboratories and institutions staffed with high-caliber researchers.

Not only does MANA invite researchers from overseas, it also encourages its own researchers to take initiative and go abroad.

This policy applies to young researchers as well as Principal Investigators, and the period of stay will be extended from one month to two years. In FY2011, MANA sent Dr. Yoshiyuki Yamashita to MINATEC in France for one year. In FY2012, MANA plans to send a handful of researchers, including Principal Investigators and Independent Scientists, for long-term research abroad. NIMS also supports research abroad initiatives by giving participants preferential treatment on their performance evaluations.

5) MANA relies on support by NIMS. Especially, shared use of big equipment and delivery of high-quality starting materials are essential for research at MANA. The high percentage of foreign scientists at MANA can only be maintained if the technical support by NIMS continues.

NIMS continues to provide its full support to the administration of MANA. In FY2011, as with previous years, NIMS provided financial support for research project fees and MANA Foundry operating expenses as well as operations subsidies to be used at MANA's discretion.

8. Center's response to the site-visit report used in the interim evaluation

1) Nano-bio

- Since there are many institutes and universities where bio materials are treating for many applications, it is very important to clarify the identity of MANA compared to others.

To create an identity for Nano-bio research at MANA, the name of the field will be changed to Nano-life, and Nano-life will pursue basic research oriented toward human-related nano-biotechnology, specializing in bioimaging, regenerative medicine and the like, with the hope that this will lead to clinical trials (See 7.2 for a partial explanation).

2) Theoretical approaches

- It is recommended that efforts be maintained to continually incorporate theory, ranging from physics, chemistry, biology to mathematics, in order to form a powerful infrastructure that can frame difficult problems in a conceptual structure and to aid in visualizing and interpreting data via advanced theory simulations. This has the potential to lift simple materials development and device building into highly powerful science.

The new Computational Science Group was established in FY2011, and an Independent Scientist with a passion for experiments and collaboration was named Group Leader. MANA also plans to involve more theoreticians, including those from foreign research institutes, in its research projects. We will also pursue theoretician-supported materials research by establishing a research fund to promote the integration of theory and practice (See 7.3 for a partial explanation).

3) Collaboration

- Much more collaboration among the 4 groups should be enhanced. Each group seems to be working rather independently.

We will expand opportunities for the exchange of information among researchers by holding Grand Challenge Meetings and MANA Seminars, and we will promote more joint research among the four fields by launching inter-field projects. With the same objective in mind, MANA’s host institution NIMS began the InterUnit Seeds Development Research Grants in FY2011, and MANA researchers are currently involved in eight of the 11 projects initially selected.

- The interaction with the local institutions within the science city Tsukuba, typically the nanotechnology group of AIST, should be promoted to be recognized as a real hub of nanotechnology.

We will cooperate with AIST's Green Nanoelectronics Center (Director: Dr. Naoki Yokoyama) and the Tsukuba Innovation Arena for Nanotechnology (TIA-nano), among others, as we push forward with efforts to collaborate with research institutions within the Tsukuba area.

- Some collaboration with industry seems to be successful and the achievement might have the innovative nature of the society. These activities could be more emphasized.

In FY2011, MANA researchers conducted 50 joint research projects with private companies, and secured a total of 145 million yen in funding. These researchers are currently conducting basic research towards the commercialization of said output. While the details of the joint research must be kept confidential, we will publicize these efforts by announcing—where possible—the outcomes of these research endeavors in the newsletter and on the homepage.

4) Grand Challenge

- It is recommended to establish second-term strategy more clearly. It should include mission, strategy and road map.

MANA will indicate a clear research strategy before the second term begins. In particular, we will declare our aim to realize three major research goals, namely, 1) neuromorphic computational circuits, 2) room temperature superconductors, and 3) artificial photosynthesis, as well as our intention to pursue challenging materials science projects that will be game-changing for MANA.

- As the research objectives, the development of new materials, that is potential forte to NIMS, has been emphasized. We expect to reinforce the contribution from the materials research sides to the activity in Nano-green and Nano-bio fields. These directions are not easy to be practiced, but if they have been issued in good shape so as to explore unconventional aspects, the reputation of this institute as an innovative center will be raised.

MANA has a stellar track record in developing novel nano-materials, such as nano-sheets, nano-tubes and supramolecules, and will put these achievements to work to advance research in the fields of Nano-green and Nano-bio. To do this, MANA will launch inter-field projects to further strengthen ties among the fields of Nano-materials, Nano-green and Nano-life.

- It is recommended that each thrust lay out the major challenges blocking quantum leap progress, even if they seem insoluble. This will give some impetus to dreaming of solutions and put the work on a potential path for breakthroughs as opposed to just doing similar things over and over hoping for an accidental breakthrough. It would be good to see each presentation started off or ended with what are the grand challenges in the field for the thrust and are any ideas on the table to solve the grand challenges.

By eliciting the issues inhibiting quantum leaps in each research field, we will find ways to solve these problems and undertake challenging research that will generate breakthroughs. Several PIs are scheduled to give presentations to clearly explain these issues and initiatives at the next site visit.