World Premier International Research Center Initiative (WPI)
Executive Summary (For Extension application screening)

Host Institution	National Institute for Materials Science (NIMS)	Host Institution Head	Sukekatsu Ushioda
Research Center	International Center for Materials Nanoarchitectonics (MANA)	Center Director	Masakazu Aono

About filling out this form:
This summary is to be based on the Center's Progress Report and Progress Plan, with reference to the following items, prepare the summary within a space of up to 6 pages.

A. Progress Report of the WPI Center

I. Summary

MANA has grown into a world-class research hub for the fields it handles after the 6.5 years since its launch. MANA has accomplished remarkable research achievements from the basics to application.

MANA's excellence is apparent from several indicators. For example, A) the number of papers in the world's top 1% by the number of citations has reached 80, B) MANA has achieved a very high field-weighted citation impact (FWCI) – a new indicator devised by Elsevier to fairly compare the quality of papers published by interdisciplinary research institutes – of 2.5, and C) the average impact factor (IF) of journals in which MANA researchers have published papers is very high 5.24. These figures exceed those of many other world-class research institutions.

MANA has a unique characteristic as compared with many other materials science research institutions around the world. Namely, MANA is operated on the basis of our new concept of "nano-architectonics", which is a new paradigm of nanotechnology. We believe that this unique concept has been an important key in accomplishing the remarkable research achievements of MANA.

In 6.5 years, MANA has made various outstanding research. Typical examples are a) "nanosheet technology" and its application, b) "atomic switch" and related devices, c) various single-molecule level devices, d) highly-efficient photocatalysts, e) nanoarchitectonic diagnosis and treatment, f) transmission electron microscopy combined with mechanical, electrical and optical measurements, g) multiple-probe scanning probe microscopes for nanoscale electrical conductance measurement, etc.

MANA has established one of the most internationalized research centers in Japan with a foreign researcher ratio of more than 50%. MANA has succeeded in developing a near perfect research environment by providing swift administrative and technical support to all researchers regardless of nationality. We have provided our knowledge of running an international research center to the rest of NIMS and outside institutions in Japan. We have made dramatic improvements in NIMS's ability to provide support in English to foreign researchers.

The cultivation of young researchers is another key pillar of MANA in addition to the four pillars of the WPI Program. The Independent Scientist (about 20% of permanent researchers) and ICYS Researcher (about 20% of postdocs) systems, in which researchers conduct independent research without belonging to a specific group, have posted good results.

The research undertaking at MANA is recognized as one of NIMS's priority R&D fields, and MANA is positioned as the Nanoscale Materials Division, one of NIMS's three research divisions. In other words, MANA has become a permanent unit of NIMS's research organization. Thus NIMS has supported MANA extensively by providing approximately 90 tenure positions, allocating about ¥1.5 billion annually.

II. Items

1. Overall Image of Your Center

<Vision and Background>

When MANA was established 6.5 years ago, nanotechnology (and its foundation, nanoscience) was progressing rapidly and fast becoming indispensable in the field of materials science. Amid this backdrop, we designed MANA with the intention of creating a world-leading research center that could boldly promote the development of new materials through the effective use of nanotechnology. We were keenly aware that the true power of nanotechnology could not be harnessed without acknowledging that nanotechnology was essentially different from conventional microtechnology and that the usual view of nanotechnology as an extension of microtechnology was incorrect, so that we put our vision in:

"Pioneering a new paradigm of nanotechnology for new materials development".

At the same time, to express the new paradigm of nanotechnology succinctly and clearly, we proposed the concept of "nanoarchitectonics", which is discussed in Progress Report in detail. This concept has made MANA's research distinctive among the world's nanotechnology research institutions. We are happy that the concept of nanoarchitectonics is starting to gain acceptance around the globe.

<Present Status>

MANA has four research fields, Nano-Materials, Nano-Systems, Nano-Power and Nano-Life fields. At present, 22 PIs, 2 Associate PIs, 75 permanent researchers, 72 postdoctoral researchers and 36 students are working in the four research fields and they are supported by 29 administrative and technical staff. The present status of MANA can be summarized in the following five points:

- MANA has realized world's top-level research activities;
- With a foreign researcher ratio of 51%, MANA has become a truly international research center;
- MANA is actively engaged in research that combines nanotechnology with other fields;
- MANA has fulfilled its responsibility to promote reforms in the host institution NIMS very well;
- MANA has produced outstanding young researchers who are now active around the world.

<Future Perspective>

Based on our experience and confidence in the successful 6.5 years, MANA will further promote the development of nanoarchitectonics and its fusion with various research fields. Our final goal is of course to develop earth-shaking new materials for realizing various revolutionary technologies.

2. Research Activities

<Outstanding Research Results>

Research in MANA has been conducted in the four research fields (Nano-Materials, Nano-Systems, Nano-Power and Nano-Life fields) as mentioned already. Selected outstanding research results from the four research fields are:

A) Opening a "nanosheet"-based new horizon for novel materials creation. We are proud of having developed an original method to create various new materials with novel useful properties. The realization of metamaterials and novel superconductors with this method is our next challenge.

B) Development of the "atomic switch" and related prospective devices and systems. We are also proud of having invented the atomic switch, which is a promising beyond CMOS device (in collaboration with NEC Corp.). More importantly, the atomic switch in a certain condition is similar to the synapse of our brain in functionality. The realization of neuromorphic network circuits consisting of such atomic switches is our next challenge.

C) World's top level efficiency of photocatalysts: We have also succeeded in artificial photo-synthesis of methane, for example. Our next challenge is to increase the efficiency of artificial photosynthesis dramatically using various nanoarchitectonic systems.

D) Development of an original ultra-sensitive/ultra-parallel molecular censing method (membrane-type stress sensor: MSS): The sensitivity of this method is over 100 times higher than conventional cantilever sensors. We have succeeded to distinguish between cancer patients and healthy persons by breath analysis (in collaboration with Basel University, Switzerland).

E) Development of innovative nanoscale characterization methods: We have developed a trans-mission electron microscope (TEM) in which the mechanical, electrical and optical properties of a nanoscale sample can be measured under high-resolution image observation. Also, multiple-probe (2, 3 or 4 probes) scanning tunneling microscopes (STM), atomic force microscopes (AFM) and Kelvin force microscopes have been developed; this has enabled electrical conductance measurements at the nanometer scale.

<MANA's Three Grand Challenges>

MANA has declared the following three grand challenges:

★ Nanoarchitectonic artificial brain
★ Room-temperature superconductivity
★ Practical artificial photosynthesis

We consider these as long-term research objectives, but some intriguing preliminary outcomes have already been obtained. Such results concerning the first and third grand challenges were in part touched in B) and C) of the previous section. Regarding the second grand challenge, we have attempted to transform insulators or semiconductors into superconductors by injecting electrons or holes by field effect. So far, we have succeeded to make pure diamond metallic. Apart from this, we have found theoretically that when heavy atoms, such as gold, are formed into a two-dimensional buckled honeycomb lattice and an electric field is applied perpendicularly, current will flow along its edge with zero resistance even at temperatures above room temperature up to 600 K. An experiment has been launched in an attempt to prove this theory.

<Application of Research Results>

Many fundamental researches at MANA have led to applied researches in collaboration with various companies such as NEC, HONDA, Murata, Tokyo Chemical Industry, etc. In 2007-2013, MANA researchers applied for 640 patents (435 in Japan and 205 overseas) and had 416 patents registered (318 in Japan and 98 overseas).

3. Interdisciplinary Research Activities

<Strategies>

To promote interdisciplinary research across MANA's four fields (Nano-Materials, Nano-Systems, Nano-Power and Nano-Life fields), MANA has established the following internal special funds:

A) Fusion Research Fund,
B) Theory-Experiment Fusion Research Fund,
C) Nano-Life Fusion Research Fund,
D) Grand Challenge Research Program.

Based on the belief that promoting joint research across different fields can lead to the creation of new research fields, we opened these funds to applications from MANA's young researchers. The selection of proposals was done by organizing a special committee.

<Typical Examples>

Selected examples of the interdisciplinary research activities are as follows:

- A wide range of research on nanosheet technology; from the basics to applications
  (Fusion of soft chemistry, materials physics and electronic device technology)
- A wide range of research on the atomic switch; from the basics to applications
  (Fusion of electrochemistry, electronic device technology and neuroscience)
- Development and application of ultra-sensitive/ultra-parallel molecular sensors
  (Fusion of animal olfactory organs, nanoarchitectonics and medical diagnosis)
- Development of efficient artificial photosynthetic systems
  (Fusion of photocatalytic chemistry, plant photosynthesis and nanoarchitectonics)
- Cancer and Alzheimer's disease treatments using nanoarchitectonics
  (Fusion of medical care and nanoarchitectonics)
- Exploration of decoherence-free quantum bits, room-temperature "superconducting" devices
  (Fusion of theory and experiment)

4. International Research Environment

<International Circulation of Best Brains>

MANA has established satellites in the research institutes to which its external Principal Investigators are affiliated. At present, there are satellites at four overseas institutions: UCLA, Georgia Tech, CNRS-CEMES, Univ. Montreal. These satellites play important roles in each of MANA's research fields and serve as training grounds for MANA's young researchers. In addition, the number of famous scientists, young faculty members, students and other researchers who visit MANA from around the world increases every year.

ICYS Researchers, established as tenure-track positions for permanent researchers at NIMS, are hired twice a year by way of international open recruiting. Over the past 6.5 years, 40 researchers have been hired at MANA from a total of 942 applicants.

Eight postdocs from MANA have been appointed as NIMS permanent researchers, and 171 have leveled up to universities and research institutions in Japan and around the world.

One of MANA's missions is to become a hub and build a network connecting the world's nanotechnology centers. At present, MANA has memoranda of understanding (MOU) with 34 research institutes in 15 countries and promotes research and personnel exchange with these partners.

<System for Supporting the Research Activities of Overseas Researchers>

All of the staff in MANA's Administrative Office are fluent in English, and they provide all researchers, regardless of age or nationality, with the same highly attentive, Japanese-style services: bilingual documentation and communication, livelihood support, technical support, Japanese language and culture courses, etc.

<Others>

The Independent Scientist and ICYS Researcher systems, in which researchers conduct independent research without belonging to a specific group, have posted good results in terms of the recruitment and training of young researchers,.

To cultivate internationally-minded, interdisciplinary Japanese researchers, we encourage young Japanese permanent researchers to go overseas and conduct research at major foreign research institutions for long periods of time. We also established the YAMATO-MANA Program to attract outstanding young Japanese researchers to MANA and cultivate Japan's future research leaders.

5. Organizational Reforms

<Decision-Making System in the Center>

The Director-General has successfully recruited outstanding researchers from around the globe and created an atmosphere in which they can freely engage in research and hone their skills through friendly rivalry. He has exhibited the strong leadership in all aspects of Center administration, including setting research policy, streamlining systems, adopting new measures and distributing research resources. In addition, he has helped to firmly establish the concept of nanoarchitectonics worldwide by holding numerous research forums, publishing special features on nanoarchitectonics in well-known journals and distributing an online newsletter.

<Arrangement of Administrative Support Staff and Effectiveness of Support System>

MANA has succeeded in developing a near perfect research environment in which MANA can provide swift administrative and technical support to all researchers regardless of nationality.

<System Reforms Advanced by WPI Program and Their Ripple Effects>

<u>System reforms at MANA</u>

(1) Promotion of interdisciplinary research by adopting new programs.
(2) Thorough internationalization of MANA by promoting bilingual administration and providing research and livelihood support to foreign researchers.
(3) Cultivating and recruiting young researchers by adopting new systems: ICYS and 3D system.

<u>Ripple effect on the host institution</u>

(1) Building a system in which the structural reforms undertaken at MANA can be easily transferred to NIMS: imposing the MANA’s role in NIMS’s five-year plan.
(2) Dramatic improvements in NIMS's ability to provide support in English by implementing programs to improve the English proficiency of NIMS administrative staff and producing major documents and internal announcements in both Japanese and English.
(3) Provision of young excellent researchers to NIMS as permanent researchers.

(4) Provision of our knowledge of running an international research center to other centers of NIMS and outside institutions in Japan.

<Support by Host Institution>

NIMS supports MANA extensively by providing staff, research funds and research space and delegating operational authority to the Director-General. Since MANA's founding, NIMS has allocated approximately ¥1 billion annually for research project expenses and more than ¥400 million annually for project promotion expenses from its operations subsidies.

<Position of the Center within the Host Institution's Mid-Term Plan>

In NIMS's third five-year plan, launched in April 2011, MANA's development of innovative new materials based on nanoarchitectonics was recognized as one of NIMS's priority R&D fields, and MANA was positioned as the Nanoscale Materials Division, one of NIMS's three research divisions. NIMS is also increasing the number of MANA's permanent researchers and administrative staff. Sixteen new permanent staff were added between April 2011 and March 2014, bringing the total number of permanent staff at MANA to 89 (as of March 31, 2014).

B. Progress Plan

1. Mid- to Long-term Research Objectives and Strategies Based on the Center's Research Results to Date

<Outline>

In preparation of MANA's extension application, we conducted a detailed analysis of our research achievements to date. The analysis clearly highlighted the importance of cross-linking theoretical and experimental research and fusing nanotechnology (nanoarchitectonics) with the life sciences. In the extension period, MANA will vigorously promote these two types of fusion.

Also, when we analyzed the progress made on the three grand challenges that MANA has declared, we found that several promising preliminary outcomes had been obtained. Therefore, we decided to continue pursuing these in the extension period. In addition, we add another grand challenge related to the fusion of nanotechnology (nanoarchitectonics) with life science mentioned above.

<Theory-Experiment "Cross-linkage" (Fusion)>

In the extension period, MANA will organize a fifth field, Nano-Theory field, in addition to the existing four research fields (Nano-Materials, Nano-Systems, Nano-Power and Nano-Life fields). The new Nano-Theory field will be a large group of about 50 theoreticians. This means that about one-fourth of MANA researchers will be theoreticians.

Despite the fact that many interesting nanoscale phenomena are accompanied by excited states, dynamic processes and many-body effects, contemporary first principles calculations are not conducive to handling these. To overcome this obstacle, we will introduce bold yet appropriate approximation methods to spur a new trend in theoretical research. This will encourage the fusion of theoretical research with experimentation. Not only will the Nano-Theory field fuse theory and experimentation, it will act to promote interdisciplinary research among MANA's four other experimentation-oriented research fields.

< MANA's Unique Nano-Life Research >

MANA established the Nano-Life field with the aim of creating a new field that fuses MANA's world-leading nanotechnology with the life sciences. One important feature of MANA is this environment in which high caliber nanotechnology (nanoarchitectonics) and life science researchers work side-by-side and gain a thorough understanding of each other's disciplines. This has recently started producing remarkable results. In the extension period, we will take advantage of this environment to renew the Nano-Life field. We aim to create new, never-before-seen things and systems by studying the functions of cells (which are the building blocks of life), sensory organs and the brain, the most complex biological structure, and incorporating the knowledge gained into our best nanoarchitectonics technologies. Conversely, we will also promote the active utilization of nano-architectonics technologies in Nano-Life research.

<MANA's Grand Challenges>

MANA has declared three grand challenges and will continues pursuing the three grand challenges in the extension period. In addition, we add another grand challenge related to the fusion of nanotechnology (nanoarchitectonics) with life science:

★ Nanoarchitectonic supreme bio-sensing.

To tackle this challenge, we will make full use of MANA's original nanoarchitectonic techniques and nanoscale measurement methods such as multiple-probe scanning probe microscopes and ultra-sensitive/ultra-parallel molecular sensors.

2. Management System of the Research Organization

<Research Organizational Management System>

In April 2016, one year before the end of the 10-year project period, NIMS will launch its next Seven-Year Plan and MANA will implement the following key structural reforms: appointing a new Deputy Director, shuffle of PI lineup, constructive dissolution of MANA satellites, establishing Nano-Theory field, strengthening Nano-Life field, investment in MANA Grand Challenges, encouraging innovative and challenging research.

<Initiatives and Plans that will Impel System Reforms>

Reforming NIMS: The administrative experience cultivated at MANA and thorough clerical and technical support systems will be transplanted into NIMS.

Internationalizing NIMS and Other Japanese Research Institutions and Universities: We will strive to export MANA's research environment to other research institutions and universities aside from NIMS.

Promoting Global Research Exchange: MANA has grown into a world-class research center that attracts researchers from around the globe, and our name recognition has increased. We will expand our network beyond the leading countries of the West to include every country and region in the world.

3. Center's Position within the Host Institution, and Measures Taken by Host Institution to Provide Resources to the Center

<Position of the Center within the Organization of the Host Institution>

NIMS's next seven-year plan will begin in April 2016, one year before the conclusion of the originally scheduled WPI Project period (10 years). As such, this plan will make the necessary revisions to MANA's organization and research fields before then in preparation for the extended operation of the Center beginning in April 2017. In subsequent seven-year plans, MANA will continue to handle one of NIMS's Priority R&D Fields and will remain a core part of the Institution's research.

<Host Institution's Implementation Plan for Sustaining and Advancing the Center>

Regardless of whether the WPI program grant is extended or not, NIMS promises to provide MANA with the following research resources so that it can continue its basic activities.

i) Provision of approximately 90 tenure positions to MANA, including Principle Investigators, other scientists and administrative staff.

ii) Annual allocation of research project expenses and center activity expenses from NIMS's operations subsidies totaling about ¥1 billion/year to MANA.

After the WPI program concludes, in addition to i) and ii) above, we intend to take the following measures.

iii) We will replace the post-docs and other fixed- term employees hired using the WPI grant with those hired using external funding.

iv) MANA's original programs such as young researcher development programs, symposia and outreach activities will be transferred to NIMS.

v) In order to continue the administrative and technical research support that is especially advanced at MANA, we will create a replacement framework and boost research support functions by reforming NIMS's systems.

World Premier International Research Center Initiative (WPI)
Progress Report of the WPI Center
(For Extension Application Screening)

Host Institution	**National Institute for Materials Science (NIMS)**	Host Institution Head	**Sukekatsu Ushioda**
Research Center	**International Center for Materials Nanoarchitectonics (MANA)**	Center Director	**Masakazu Aono**

** Write your report within 30 pages. (The attached forms are in addition to this page count.) Keep the length of your report within the specified number of pages.*

Common Instructions:
** Please prepare this report based on the current (31 March 2014) situation of your WPI center.*
** Use yen (¥) when writing monetary amounts in the report. If an exchange rate is used to calculate the yen amount, give the rate.*

1. Overall Image of Your Center (write within 2 pages including this page)

Describe the Center's current identity and overall image. For centers that have had a change in their directors, describe that transition and the effects of the change.

- *On the sheets in Appendix 1, list the Principle Investigators, and enter the number of center personnel, a chart of the center's management system, a campus map showing the center's locations on the campus, and project funding.*

1-1. Preface

In the 6.5 years since MANA was launched, it has grown into a world-class research hub for the fields it handles and has accomplished remarkable research achievements (a detailed description is provided in Chapter 2). MANA's excellence is apparent from several indicators. For example, A) the number of papers in the world's top 1% by the number of citations has reached 80, B) MANA has achieved a very high field-weighted citation impact (FWCI) – a new indicator devised by Elsevier to fairly compare the quality of papers published by interdisciplinary research institutions – of 2.5 (both statistics are based on papers published between 2008 and 2013), and C) the average impact factor (IF) of journals in which MANA researchers have published papers is very high 5.24 (based on papers published in 2012). These figures far exceed those of many other world-class research institutes.

MANA's development to this point is due in large part to the support received from the WPI Program, and we would like to take this opportunity to express our sincere gratitude for this subsidy.

1-2. Background of MANA

MANA was established 6.5 years ago in NIMS, Japan's primary research institution for materials science. At that time, nanotechnology (and its foundation, nanoscience) was progressing rapidly and fast becoming indispensable in the field of materials science. Amid this backdrop, we designed MANA with the intention of creating a world-class research center that could boldly promote the development of new materials through the effective use of nanotechnology. In designing the Center, we were keenly aware that the true power of nanotechnology could not be harnessed without acknowledging that nanotechnology was fundamentally different from microtechnology and that the usual view of nanotechnology as an extension of microtechnology was incorrect. In order to crystallize this notion, we proposed the concept of "nanoarchitectonics". Nanoarchitectonics is a new paradigm of nanotechnology that emphasizes the following four viewpoints:

- Create reliable nanomaterials or nanosystems from unreliable nanoscale structures (nanoparts) that are assembled or organized unreliably.
- Note that main players are not individual nanoparts but their mutual interactions that cause an emergent functionality as a whole.
- Do not overlook an emergent functionality caused by the assembling of a huge number of nanoparts.
- Create a new theory field where conventional first principles computations are combined with novel bold approximation.

This concept of nanoarchitectonics has made MANA's research distinctive, and in turn, this has made MANA unique among the world's nanotechnology research institutions. We are also happy that the concept of nanoarchitectonics is starting to gain acceptance around the globe.

1-3. Vision, mission, and organization of MANA

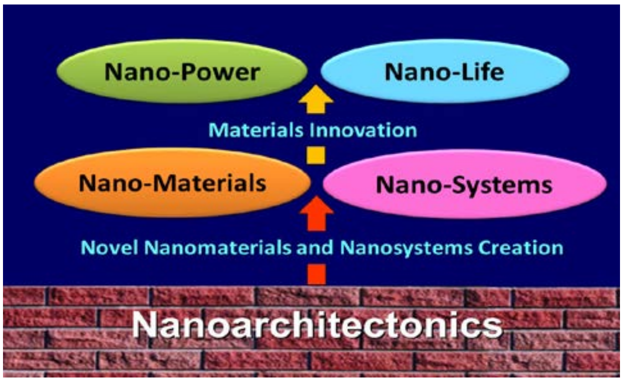
MANA's vision is:

Oriented towards a better global future,
we pioneer a new paradigm of nanotechnology for materials development.

To achieve this vision, MANA has declared the following four-fold mission:

1. Ground-breaking new materials development based on nanoarchitectonics
2. Interdisciplinary research fusion
3. Fostering next-generation young scientists
4. Global cooperation

To pursue a wide range of research, from the basics to application, based on the concept of nanoarchitectonics and use nanoarchitectonics to promote interdisciplinary research, MANA organized four research fields, i.e. Nano-Materials, Nano-Systems, Nano-Power and Nano-Life fields.



Four Research Fields of MANA

1-4. Present status of MANA

Based on the concept of nanoarchitectonics, MANA has produced numerous ground-breaking research outcomes that have gained worldwide attention and can be said to have grown into a world-class research center.

The present status of MANA can be summarized in the following five points:

- MANA has realized world-class research activities;
- With a foreign researcher ratio of 51%, MANA has become truly international;
- MANA is actively engaged in research that combines nanotechnology with other fields;
- MANA has fulfilled its responsibility to promote reforms in the host institution NIMS;
- MANA has produced outstanding young researchers who are now active around the world.

2. Research Activities (within 15 pages)

2-1. Research results to date

Describe issues of a global level that the Center has challenged, and give the results. Select 20 representative results achieved during the period from 2007 through March 2014. Number them [1] to [20] and provide a description of each. Place an asterisk (*) in front of those results that could only have been achieved by a WPI center.

- *In Appendix 2, list the papers underscoring each research achievement (up to 40 papers) and provide a description of each of their significance.*

< Overview >

MANA was established for the purpose of generating innovation in the development of new materials by carving out a new paradigm for nanotechnology based on the concept of nanoarchitectonics, and it has achieved this objective. Research at MANA has yielded concepts, such as soft-chemical nanoarchitectonics, interface nanoarchitectonics, neuromorphic nanoarchitectonics, topological nanoarchitectonics and nanoarchitectonics in vivo, in a bottom-up manner, and research has been pursued based on these concepts.

The following is a brief explanation of twenty selected MANA research achievements (pp. 4-13). As the table below shows, these achievements can be grouped into three major categories−Creation of New Research Fields, Fusion of Interdisciplinary Research Fields and Other Remarkable Research Results−and each of these can be further divided into three subcategories.

Classification of Selected 20 Research Results [1]-[20]

Creation of New Research Fields	Research Results
★ Nanosheet-based New Horizon for Novel Materials Creation	[1], [2]
★ Atomic Switch and Related Prospective Devices and Systems	[3], [4]
★ Molecular-scale Site-designated Chemical Nanoarchitectonics	[5], [6]
Fusion of Interdisciplinary Research Fields	
★ Nanoarchitectonics-inspired Nano-life Science	[7], [8]
★ Nano-life Science-inspired Nanoarchitectonics	[9], [10]
★ Theory-Experiment 'Cross-linkage' for Exploring Novel Nanoscale Materials and Systems	[11], [12]
Other Remarkable Research Results	
★ Innovative Nanoscale Devices and Systems	[13], [14], [15]
★ Innovative Nanoscale Characterization Methodologies	[16], [17]
★ Nanoarchitectonics Related to Sustainable Energy and Environment	[18], [19], [20]

The category "Creation of New Research Fields" refers to original research conducted at MANA that possesses generality and is gradually spreading worldwide. This includes various new materials fabricated with nanosheet technology, atomic switches and the wide array of devices derived therefrom and nanoarchitectonic chemistry research, which aims to realize monomolecular devices.

The category "Fusion of Interdisciplinary Research Fields" refers to nano-life research that borrow from MANA's advanced nanoarchitectonics, and conversely, nanoarchitectonics research that borrows from nano-life research, as well as research aimed at fusing theory and experimentation.

The category "Other Remarkable Research Results" includes a wide variety of outstanding research that does not fit in the other two categories.

< Selected 20 Research Results >

(See Appendix 2 for the Papers 1-40 referenced.)

Creation of New Research Fields

★ Nanosheet-based New Horizon for Novel Materials Creation

[1] Production of high-quality functional nanosheets via massive swelling and exfoliation of layered crystals — Representative researcher: T. Sasaki

We have developed a variety of oxide and hydroxide nanosheets via inducing enormous swelling of layered crystals in aqueous amine solutions. The highly swollen "aquacrystals" can be gently disintegrated into high-quality unilamellar nanosheets in high yield, which is difficult to attain by other delamination procedures. This process has been applied to various layered crystals synthesized in a designed composition and structure to produce a range of nanosheets exhibiting unique and useful properties. The nanosheets thus obtained have been effectively utilized as building blocks for "2D Nanosheet Nanoarchitectonics" to tailor functional nanostructured materials and nanodevices.

We observed the amazing phenomena of platy microcrystals of layered metal oxides undergoing huge swelling in amine solutions (see Fig. 1). The interlayer galleries evenly expanded up to 100 times beyond original spacing via permeation of the aqueous solution. The understanding on this reactivity provides important clues to controlling the exfoliation process into high-quality nano- sheets.

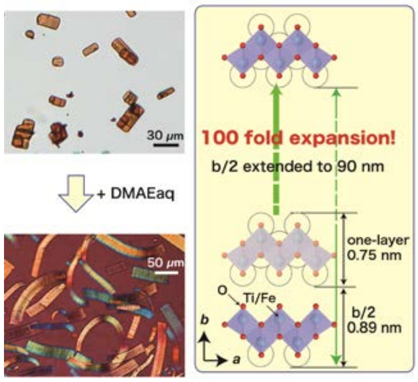


Fig. 1. Platy microcrystals of a layered titanate before and after the treatment with aqueous 2-dimethylaminoethanol (DMAE) (left). Structural illustration of the swelling (right).

See Papers 1 [*Nature Commun.* **4** (2013) 1632], 2 [*J. Am. Chem. Soc.* **136** (2014) 5491], and 3 [*Adv. Mater.* **22** (2010) 5082] in Appendix 2.

[2] Super-high-*k* oxide nanosheets: New 2D materials and devices beyond graphene — Representative researchers: M. Osada & T. Sasaki

We have discovered high-k oxide nanosheets, an important material platform for ultra-scale electronics and post-graphene technology. Newly developed nanosheets (Ti_2NbO_7, $(Ca,Sr)_2Nb_3O_{10}$) exhibited the highest permittivity (ε_r = 210~320) ever realized in all known dielectrics in the ultrathin region (< 10 nm). Our results offer a route to new 2D devices beyond graphene.

2D materials are now considered to be excellent candidates for future electronic applications. High-*k* oxide nanosheets are of major technological importance for establishing the thinnest and highest-*k* nanodielectrics (Fig. 2) that cannot be achieved in graphene and other materials. Notably, nanosheet-based capacitors exceeded textbook limits, opening a route to new capacitors and energy storage devices. A layer-by-layer engineering using high-*k* oxide nanosheets enabled us to design new 2D devices such as nanosheet FETs, artificial ferroelectrics, etc. Graphene is only the tip of the iceberg, and we are now opening up a new era of "post- graphene technology".

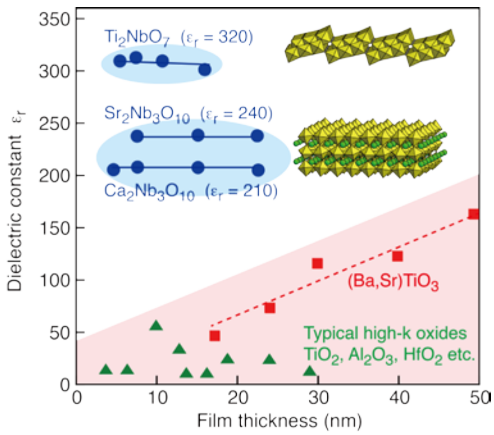


Fig. 2. Dielectric properties of high-*k* oxide nanosheets and various oxide dielectrics.

See Papers 4 [*Adv. Funct. Mater.* **22** (2011) 3482], 5 [*Adv. Mater.* **24** (2012) 210], and Opt. 1 [*Adv. Mater.* **24** (2012) 210] in Appendix 2.

★ Atomic Switch and Related Prospective Devices and Systems

[3] Atomic switch: Novel on/off switching characteristics and unique synapse-like behaviors

Representative researchers: T. Hasegawa, K. Terabe, M. Aono

We have developed a novel switching device, which is better than conventional semiconductor transistors in that it is a non-volatile switch, smaller in size, lower in energy consumption, etc. It already reached a technological level for the commercialization in collaboration with NEC Corp. The unique operating mechanisms of the atomic switch, i.e., movement of metal atoms/ions associated with their redox processes due to an applied potential, have enabled the development of various novel devices, such as 'non-volatile three-terminal atom transistor', 'on-demand function-selectable atomic switch', and 'synapse-like atomic switch junction'.

The synapse-like atomic switch junction, illustrated in Fig. 3 (a), emulates two types of plasticity of the synapse in our brain, i.e., short-term plasticity (STP) and long-term potentiation (LTP). Namely, the junction is not switched on even after many voltage pulses when the frequency is low (Fig. 3 (b)), but it is switched on after several voltage pulses when the frequency is large enough (Fig. 3 (c)). The results encourage us to develop conceptually new artificial neuromorphic computational systems that do not require any pre-programming.

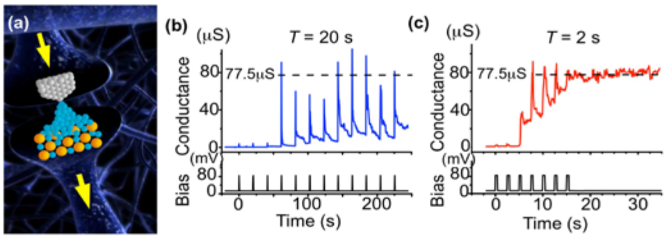


Fig. 3. Atomic switch works as an inorganic synapse (a). Ag_2S-based single atomic switch shows both STP-mode (b) and LTP-mode (c) depending on the learning frequency.

See Papers 6 [*Nature Mater.* **10** (2011) 591], 7 [*ACS Nano* **6** (2012) 9515], and Opt. 2 [*Nature Mater.* **11** (2012) 530] in Appendix 2.

[4] Networks of atomic switches for neuromorphic computation

Representative researchers: J. Gimzewski, A. Stieg, M. Aono

We have developed unique neuromorphic devices, known as atomic switch networks (ASN), comprised of highly interconnected (~10^9/cm^2) atomic switch interfaces which retain the synaptic properties of their component elements and generate a class of emergent behaviors known to underlie biological cognition. The utility of ASN devices in reservoir computing, a biologically inspired framework known to demonstrate unparalleled efficiency in real-time performance of complex tasks, has been demonstrated through performance of various benchmark machine-learning tasks including the parity-n test, NARMA-10 test and the T-maze. ASN devices hold great promise as a scalable hardware platform for signal processing and computation capable of overcoming modern operational limits in the RC paradigm.

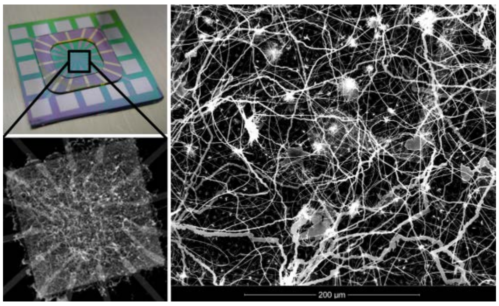


Fig. 4. The ASN device (upper left) is comprised of atomic switch junctions located at the crossing points of self-organized nanowire network. A look inside the ASN (lower left) reveals a highly interconnected neuromorphic architecture (right).

The mammalian brain exceeds modern computers in performing complex tasks such as associative memory, pattern recognition, or prediction as a result of the radically divergent physical structures and operating mechanisms. Drawing inspiration from the cortical neuropil, millions of atomic switches have been incorporated into a densely interconnected network of conductive nanowires, as shown in Fig. 4, through the nanoarchitectonics concept of self-organization. By combining concepts of computational neuroscience and machine learning with those of self-organization in complex nanoscale materials, these results lay a foundation for the creation of next-generation cognitive technologies.

See Papers 8 [*PloS ONE* **7** (2012) e42772], 9 [*Adv. Mater.* **24** (2012) 286], and 10 [*Nanotechnology* **24** (2013) 384004] in Appendix 2.

★ Molecular-scale Site-designated Chemical Nanoarchitectonics

[5] Electrical wiring of single molecules via conductive molecular chains

Representative researchers: Y. Okawa, M. Aono

Though single-molecule electronics has been widely investigated for a long time, the fabrication of practical single-molecule circuits remains challenging because of the lack of viable methods for wiring each molecule. To solve this problem, we have developed a novel method for single molecular wiring. Using a nanoscale-controlled chain polymerization on a molecular layer, we have succeeded in connecting single conductive polymer chains to single functional molecules via covalent bonds. We are investigating the electrical transport properties of the fabricated single molecule devices. These studies will be an important step in advancing the development of single-molecule electronic circuitry.

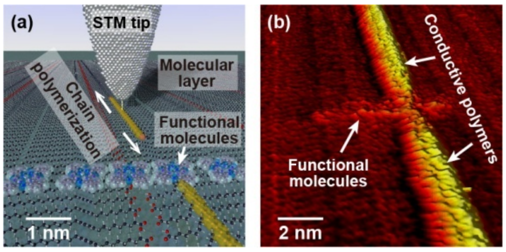


Fig. 5. Schematic illustration (a) and STM image (b) of chemical soldering. Chain polymerization is initiated with the STM tip. Two conductive polymer chains are connected to a single functional molecule (phthalocyanine).

Figure 5 (a) illustrates the wiring procedure, which we call "chemical soldering". Stimulation with a tip of scanning tunneling microscope (STM) on a molecular layer of diacetylene compound can initiate chain polymerization of diacetylene molecules. When the chain propagation encounters an adsorbed single functional molecule, the reactive front edge of the chain forms a covalent bond with the molecule. We have demonstrated that two polydiacetylene chains are connected to a single phthalocyanine molecule (Fig. 5 (b)). We have investigated the microscopic characteristics of the connection using both experimental and theoretical methods.

See Papers 11 [*J. Am. Chem. Soc*. **133** (2011) 8227] and 12 [*Nanoscale* **4** (2012) 3013] in Appendix 2.

[6] Controlling bound and unbound states of molecules (C_{60}) reversibly at designated sites

Representative researchers: T. Nakayama, M. Nakaya, M. Aono

Toward a realization of ultrahigh-density data storage using single-molecule manipulation with a scanning tunneling microscope (STM), a long-standing problem was how to achieve reversible and repeatable control of a molecular bit to represent 0 and 1. We solved this problem by controlling bound and unbound states of C_{60} molecules at room temperature and demonstrated bit operations at a bit density of 190 Tbits/in^2.

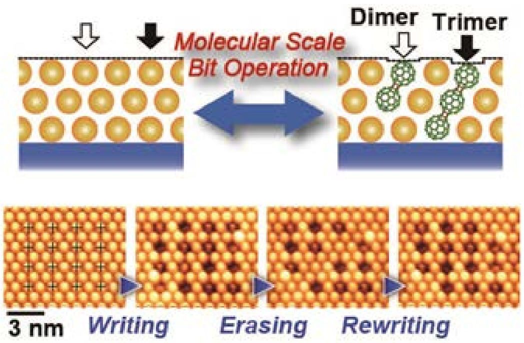


Fig. 6. (Upper) Schematic illustration of local and reversible control of bound and unbound states of C_{60} molecules. (Lower) A series of STM images showing single-molecule-level bit operation.

In a thin film of fullerene C_{60} molecules, single-molecule-level chemical reaction between C_{60} molecules was controlled using an STM tip. We found that negative and positive ionization of a designated C_{60} molecule perfectly trigger polymerization and depolymerization reactions of a designated C_{60} molecule with an adjacent molecule in the film, respectively. With this method, an ultra-dense data storage was demonstrated (see Fig. 6).

See Papers 13 [*Adv. Mater.* **22** (2010) 1622] and 14 [*ACS Nano* **5** (2011) 7830] in Appendix 2.

Fusion of Interdisciplinary Research Fields

★ Nanoarchitectonics-inspired Nano-life Science

[7] Nanoarchitectonic smart nanofibers for cancer and kidney disease therapy

Representative researchers: T. Aoyagi, M. Ebara

We have developed a smart anticancer nanofiber capable of simultaneously performing *thermotherapy and chemotherapy for treating malignant tumors. By tailoring the nanoarchitectures of polymer networks in the fiber, we demonstrated simultaneous heat generation and drug release in response to alternating magnetic field (AMF). Only a 5-10 min application of AMF can successfully induce cancer apoptosis both in vitro and in vivo studies.*

The nanofiber is composed of a chemically-crosslinkable temperature-responsive polymer with an anti-cancer drug and magnetic nano-particles, which serve as a trigger of drug release and a source of heat, respectively (Fig. 7(a)). Both in vitro and in vivo studies show that the majority of tumor cells died in only a 5-10 min application of AMF by double effects of heat and drug (Fig. 7(b)). We believe that the development of a manipulative material is considered to lead not only to improving the survival rate of cancer patients but also to providing minimally invasive treatment methods in combination with endoscopic surgery.

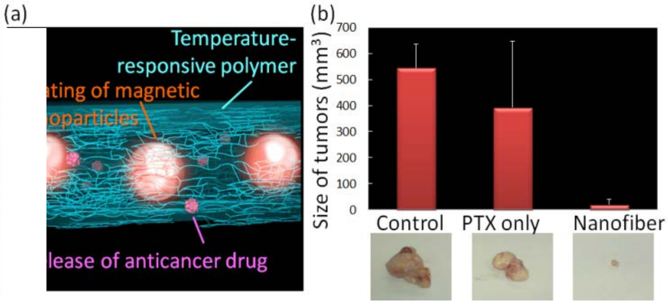


Fig. 7. Schematic illustration of smart nanofiber (a). in vivo studies show that size of tumors were successfully reduced by implantation of the smart nanofiber via double effects of heat and drug (b).

See Papers 15 [*Angew. Chem. Int. Ed.* **51** (2012) 10537] and 16 [*Adv. Func. Mater.* **23** (2013) 5753] in Appendix 2.

[8] Novel Nanoarchitectonic therapeutics – Complete recovery of Alzheimer's disease

Representative researcher: Y. Nagasaki

Reactive oxygen species (ROS) have been known to affect more than 90% of diseases. Conventional drugs had problems because of limited efficiencies along with severe adverse effects. Based on nanoarchitectonic strategy, we have developed novel anti-oxidative polymer therapeutics, which achieved complete recovery of cognition of Alzheimer's disease model mice.

One of the most important points of our nanoarchitectonics shown in Fig. 8 denotes that we have designed ROS-scavenging nanoparticles, which avoid internalization to healthy cells. This character suppresses disturbance to normal respiration in mitochondria and selectively scavenges excessively generated ROS in disease environments. With advancing age, the production of ROS increases remarkably and endogenous anti- oxidants fail to scavenge ROS completely. Such excess ROS continuously amplifies inflammation, thereby increasing the risk of potentially life-threatening disorders.

As shown in Fig. 8b, the cognition level of senescence accelerated mice (SAMP8) completely recovered by oral administration of our redox polymer based nanoparticle (RNP).

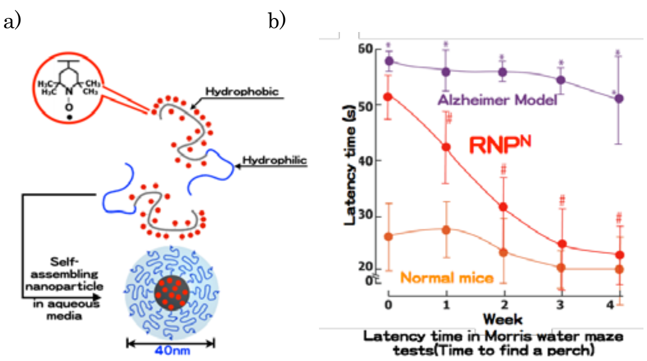


Fig. 8. a) Design of novel nanoarchitectonic therapeutics. b) Therapeuctic effect of RNP on cognitive dysfunction. RNP improved the latency period of SAMP8 mice in the Morris water-maze test. Latency time was determined by the time to find a rest place in water pool.

See Papers 17 [*Gastroenterology* **143** (2012) 1027] and 18 [*J. Am. Chem. Soc.* **132** (2010) 7982].

★ Nano-life Science-inspired Nanoarchitectonics

[9] Ultrasensitive and ultraparallel molecular sensing for artificial nose and other various applications

Representative researchers: G. Yoshikawa, M. Aono

We have developed a novel molecular sensor, which researchers had been trying to realize for 20 years all over the world. We named the new sensor "Membrane-type Surface stress Sensor (MSS)", *which is based on the comprehensive optimization of materials science, mechanics, crystallography, and electronics, investigated together with Dr. Heinrich Rohrer (Nobel Prize Winner in Physics 1986). In contrast to the %-order improvements in sensitivity by conventional approaches, the MSS achieved more than 100 times higher sensitivity in addition to better performance in all practical aspects. The MSS is expected to contribute to various fields; medicine, security, and environmental research.*

We fabricated MSS chips in collaboration with the MEMS team in EPFL, Switzerland, as shown in Fig. 9 (a). "Non-invasive breath analysis" is one of the potential applications of MSS. Figure 9 (b) shows that an array of MSS could distinguish the breath of cancer patients from that of healthy people in a double blind trial.

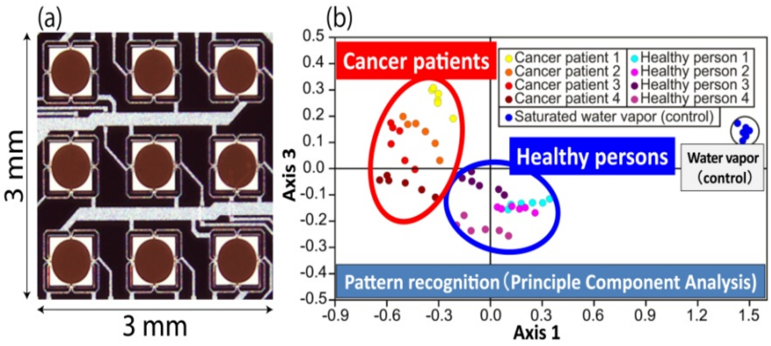


Fig. 9. Ultrasensitive/ultraparallel MSS works as an artificial diagnostic nose. (a) Photo image of an array of MSS. (b) Experimental results of breath analysis of cancer patients and healthy persons.

These results encourage us to develop a new type of a diagnostic module which can be integrated in mobile devices, such as a cell phone, to keep our health condition automatically.

See Papers 19 [*Nano Lett.* **11** (2011) 1044] and 20 [*Langmuir* **29** (2013) 7551] in Appendix 2.

[10] Progress in high-efficiency artificial photosynthesis Representative researcher: J. Ye

We have been conducting a series of pioneering works for challenging a high-efficiency artificial photosynthesis, which offers a potential solution for global warming and energy shortage issues. A new material Ag_3PO_4 with the world's highest quantum efficiency in photocatalytic water oxidation has been developed. Sophisticated control of surface/ interface structure has enabled efficient light harvesting, charge separation, and gas diffusion/conversion, making a big step towards realization of a high-efficiency artificial photosynthesis.

Here, we demonstrate an unique strategy for constructing a promising 3D artificial photo-synthetic system as a nano-life science-inspired nanoarchitectonics. Using cherry leaves as the template, we have successfully fabricated perovskite titanates with the 3D hierarchical architectures that mimic the structure of natural photosynthetic system in multi-scaled levels (Fig. 10). As a result of efficient mass flow/light harvesting network in such a special structure, the conversion efficiency of CO_2 into hydrocarbon fuels (CH_4) has been significantly improved.

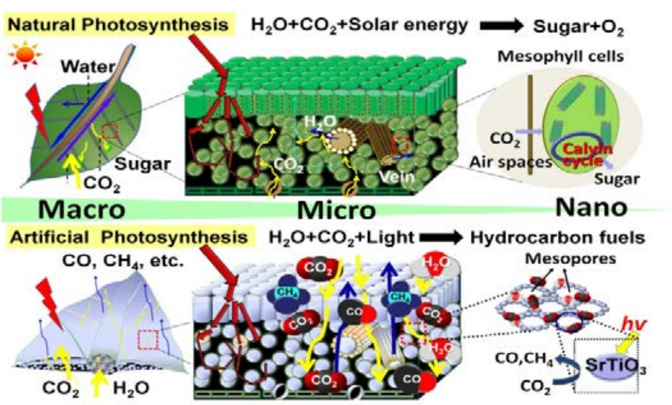


Fig. 10. Schematic illustration and comparison of the structure and key processes in (top) natural photo-synthetic system and (bottom) artificial photosynthetic system.

See Papers 21 [*Sci. Rep.* **3** (2013) 1667] and 22 [*Nature Mater.* **9** (2010) 559] in Appendix 2.

★ Theory-Experiment *Cross-linkage* for Exploring Novel Nanoscale Materials Systems

[11] Topological matter nanoarchitectonics for novel quantum devices

Representative researchers: X. Hu, T. Uchihashi

Because the uncertainty of quantum system becomes prominent, the functions of nano devices are hard to realize through design in a way similar to those in the macroscopic worlds. In order to develop a new design principle for advanced nanoquantum devices, we are exploiting the topology of various systems, which links bulk to surface and nano to macro as a quantum holography principle. A brand-new approach coined "topological nanoarchitectonics" is emerging.

At the interface between topological and trivial gapped states, a stable surface state should appear. In a topological superconductor (TS), zero-energy Majorana fermions (MFs) appear at the edge, which are equivalent to their antiparticles, whereas in a topological insulator (TI) the edge state can carry zero-resistance current.

We have designed nanoquantum devices for generating and manipulating MFs, exploiting the property that MFs appear only when 2D TSs enclose an odd-number of vortices (Fig. 11). We demonstrate that charge-neutral MFs can be moved by switching on and off point-like gate voltages. We show that the non-Abelian quantum statistics are generated by exchanging positions of MFs, useful for decoherence-free qubits and quantum computation.

In order to realize the TS state experimentally, we are working on an atomically thin superconductor on semiconductor surface with the Rashba effect and self-assembling of magnetic molecules. We demonstrate the surface superconductivity by direct transport measurements (Fig. 11) for the first time in the world. The desirable influence of the self-assembled magnetic molecules on the superconducting properties has also been clarified, rendering our system a promising platform hosting MFs.

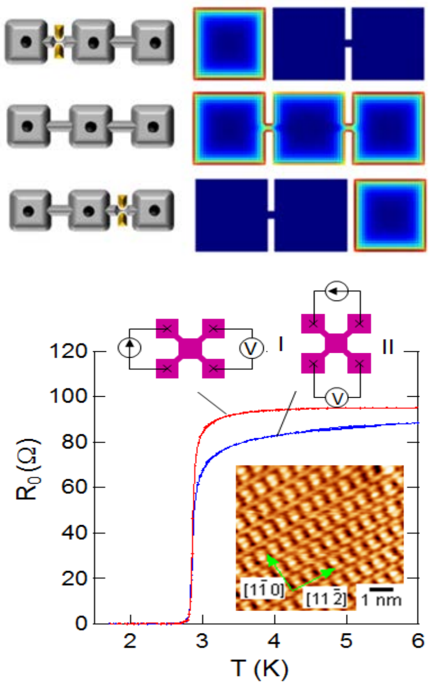


Fig. 11. (Upper) Basic blocks for manipulating MFs. Connections among TSs are pinched off by voltages at the junctions, which results in hopping of MFs. (Lower) Temperature dependence of zero bias resistance of the Si(111)-(√7×√3)-In reconstruction. Inset shows the STM image of sample surface.

We have also designed a novel TI where the edge state carries zero-resistance current optimally up to room temperature. In addition, spin polarization appears in the edge current and can be inverted by electric field, extremely ideal for spintronics.

See Papers 23 [*Europhys. Lett.* **99** (2012) 50004], 24 [*Phys. Rev. Lett.* **107** (2011) 207001], and Opt. 3 [*New J. Phys.* **15** (2013) 063031-1] in Appendix 2.

[12] Ultra-large-scale computation: Development and application of an advanced code

Representative researcher: D. R. Bowler, T. Miyazaki, N. Fukata

To enable first-principles electronic structure calculations using density functional theory (DFT) to be performed on systems which correspond to practical nanoscale devices and materials, we have developed a world-leading linear-scaling DFT code: CONQUEST. While it is very difficult to treat systems containing more than a few thousand atoms using standard DFT implementations, with CONQUEST we can treat systems with more than a million atoms. CONQUEST can perform robust and accurate electronic structure calculations, including structure relaxations or molecular dynamics, and is exceptionally efficient on massively parallel computers like the K computer. Our goal is to use CONQUEST to drive innovation in experimental research.

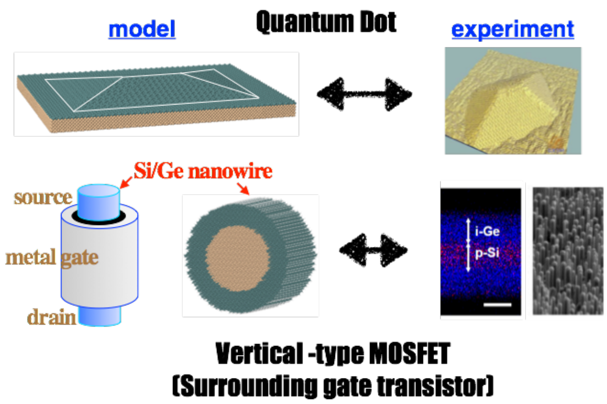


Fig. 12. (Top) Optimized structure of Ge nano-island on Si(001) substrate calculated using CONQUEST, and experimental structure. (Bottom) Atomic models of Si/Ge core-shell nanowire, along with TEM and SEM measurements and schematic of how nanowires can be used in transistors.

We have performed DFT calculations on three-dimensional Ge nano-islands grown on Si(001) substrates, to study the growth mechanism at the atomic scale, treating all the atoms (see Fig. 12 (top)). We have also recently started a collaborative theory-experiment project on Si/Ge core- shell nanowires to understand the atomic and electronic structure, including the interfaces, dopant stability and dopant states. With CONQUEST, we can investigate the effects of interfaces and boundaries on dopants, giving information that cannot be found with experiment or other first-principles techniques.

See Papers 25 [*J. Phys.: Condens. Matt.* **22** (2010)] and 26 [*Rep. Prog. Phys.* **75** (2012) 036503].

Other Remarkable Research Results

★ Innovative Nanoscale Devices and Systems

[13] Mesoscopic superconductivity quantum phenomena in superconductor/normal-metal Junctions

Representative researcher: H. Takayanagi

We have been working on mesoscopic superconductivity. In particular, we have treated superconductor (S) / normal-conductor (N) junctions and revealed various new quantum phenomena. In an S/N junction, electron Cooper pairs in S can penetrate into N (proximity effect). This effect results in many interesting quantum phenomena that can be applied in quantum information technology.

One of the most interesting superconducting meso-scopic device is the superconductor light emitting diode (LED), Fig. 13. The superconductor 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 electron Cooper pairs together with the possibility of the *on-demand* generation of entangled photon pairs. The enhancement of the electroluminescence in the active layer accompanying the superconducting transition in the electrode (Nb in Fig. 13) was demonstrated, and theoretical understanding was established.

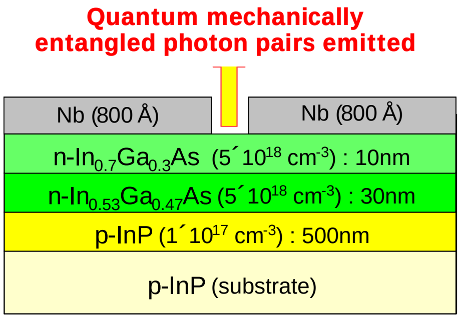


Fig. 13. Schematic cross sectional view of superconductor LED.

See Papers 27 [*Phys. Rev. Lett.* **107** (2011) 157403] and 28 [*Phys. Rev. Lett.* **103** (2009) 187001].

[14] Silicon-doped metal oxide thin film transistor for flat panel application

Representative researcher: K. Tsukagoshi

We realized a promising material for oxide thin film transistor (TFT) to produce a next generation power-saving flat display. Our Si-doped metal oxide TFT (SiM-OxTFT) behaves as a very stable and high-performance TFT with highly suppressed off-state current [Fig. 14].

As for pixel swithing TFT in the flat panel display, amorphous silicon or poly-silicon film has been customerily used. But because of serious large off-state current in the current TFTs, a new TFT is strongly desired to realize a low-power consumption system. Furthermore, higher mobility of TFT than the amorphous silicon is needed to present high resolution contents. Amorphous metal oxide thin-film transistor (a-OxTFT) is a possible candidate as the post silicon TFTs. Although the InGaZnO film is one of the candidates of the a-OxTFT, however, the InGaZnO is very unstable film in actual production. The electric property of the film is a very sensitive to oxygen absorption or desorption at the bonding sites adjacent to Zn atoms.

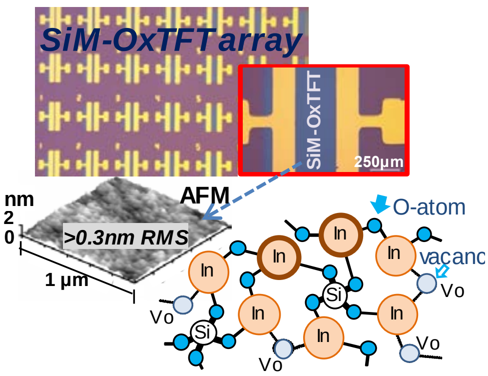


Fig.14 SEM images of SiM-OxTFT array. Schematic of vacancy (VO) suppression by incorporating SiO_2.

We discovered that the electric stability of the TFT is determined by the bond-dissociation energy of the dopant element in InOx film. By incorporating the dopant with higher bond-dissociation energy, the film supresses thermal active vacancy in the film. The basic property of the SiM-OxTFT has exceeded that of current commercial production TFTs.

See Papers 29 [*Appl. Phys. Lett.* **103** (2013) 172105] and 30 [*Appl. Phys. Lett.* **104** (2014) 102103].

[15] Nanogenerators and self-powered nanosystems

Representative researcher: Z. L. Wang

A control over humidity is necessary for improving the quality of life and enhancing industrial processes. As a result, humidity sensors based on various working principles have been extensively adopted in environmental monitoring. Ethanol, as a representative organic liquid/gas, is related with biomedicine, brewing, and other chemical processes, and its accurate analysis both in blood and breathing is of importance to monitoring and controlling drinking and driving under the influence of alcohol. We designed the triboelectric nanogenerator (TENG) as self-powered active sensors for detection of humidity or alcohol content.

These TENGs were made of polyamide 6, 6 (PA) film and PTFE film (PA TENG, PTFE TENG), respectively, which not only can detect liquid water and ethanol, but also can probe gaseous water and ethanol. The response of the PTFE TENG for the ethanol gas is investigated and displayed in Fig. 15a. Our study suggests that these TENG devices can be applied as self-powered active sensors for environmental monitoring and industrial manufacture with advantages of having low cost, simple fabrication, and good performance.

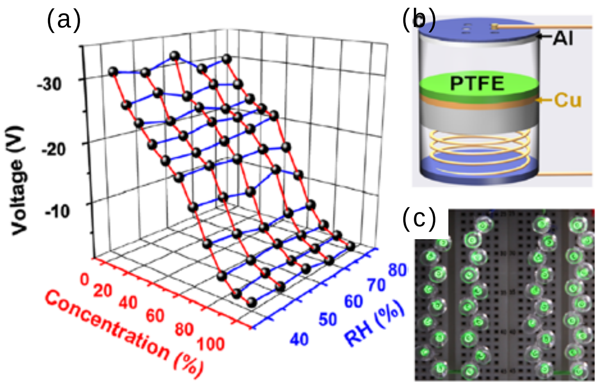


Fig. 15. (a) 3D graph of PTFE TENG sensor response to the changing external RH and ethanol concentration. (b) A schematic diagram of the fabricated device. (c) 40 LEDs lighted up by the TENG device before dripping ethanol.

See Paper 31 [*Nano Energy* **2** (2013) 693] in Appendix 2.

★ Innovative Nanoscale Characterization Methodologies

[16] Multiple-probe scanning probe microscopes (STM, AFM, KFM): Development and application

Representative researcher: T. Nakayama, M. Aono

Novel properties which will come from materials nanoarchitectonics must be characterized with innovative instruments and methodologies. Therefore, we developed multiple-probe scanning probe microscopes (MP-SPMs) and realized unique and indispensable nanoscale electrical measurements.

MP-SPMs have individually-driven 2 to 4 probes for identifying a nanostructure of interest and also for performing multiprobe electrical measurements of it. For example, the length of electron mean-free-path of a SWCNT on SiO_2 was measured to be about 500 nm at room temperature (see Fig. 16). MP-STM was converted into multiple-probe atomic force microscope (MP-AFM) using newly developed tuning fork sensor, and non-contact potential mapping via Kelvin force microscopy (KFM) was implemented in MP-AFM. These allow our MP-SPM system to handle nanostructures on insulating substrates.

See Papers 32 [*Adv. Mater.* **24** (2012) 1675] in Appendix 2.

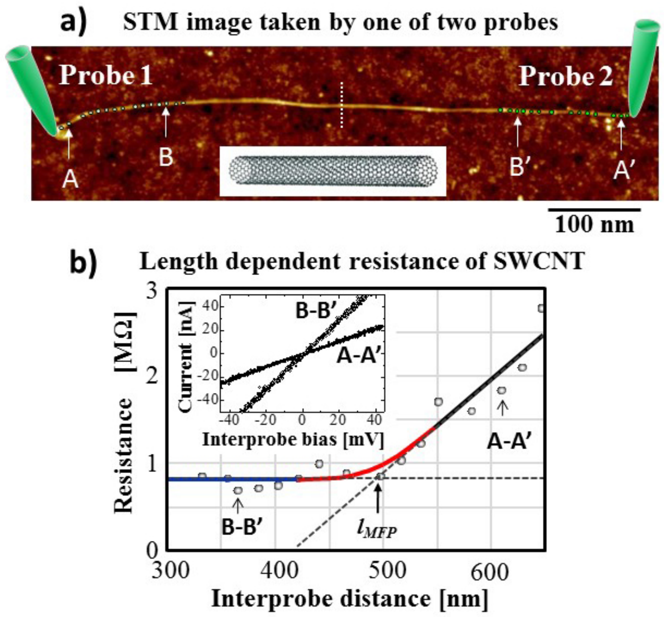


Fig. 16. (a) STM image of a SWCNT placed on a SiO_2/Si substrate. Two probes of the STM in contact with the SWCNT are schematically shown. (b) Length dependent resistance of a SWCNT. I-V curves measured between two probes are shown in the inset.

[17] Novel electrical, mechanical, thermal and optical properties of nanomaterials measured by *in situ* TEM Representative researcher: D. Golberg, Y. Bando

We have developed revolutionary methods of in situ transmission electron microscopy (TEM) which allow us to measure true mechanical, electrical, thermal and optical properties of nanomaterials, while in-tandem getting the deepest insights into their atomic structures. Designed TEM techniques combining the capabilities of a high-resolution TEM instrument and either an atomic force sensor, or a scanning tunneling microscopy probe, or a laser beam have become our powerful tools for our study of more than fifty nano-systems and morphologies, e.g. tubes, wires, sheets and particles. The key point of our experiments is that all measurements have been conducted on an individual nano- structure level under the highest spatial, temporal and energy resolution peculiar to TEM and thus can directly be linked to morphological, structural and chemical peculiarities of a given nanomaterial.

For example, we succeeded for the first time in the world to measure the tensile strength on individual singlewalled and multiwalled C and BN nanotubes (NTs), Fig. 17. The tubes were placed within a force-sensor microdevice inside a high-resolution TEM and their mechanics were then investigated in real-time by correlating the measured strength and Young's moduli, and types, and sites of NT structural defects under atomic resolution. The huge strength values of ~100 and ~33 GPa were determined for the defect-free C and BN NTs, respectively.

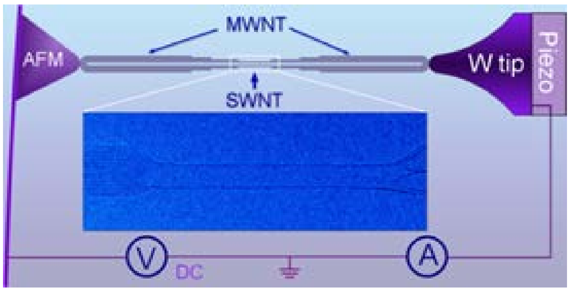


Fig. 17. Schematics of a singlewalled C (SWNT) unravelling from the multiwalled C (MWNT) nanotube using Joule heating followed by its direct tensile strength measurement under stretching in a

See Papers 33 [*Adv. Mater.* **22** (2012) 4071] and 34 [*Adv. Mater*. **22** (2010) 4895] in Appendix 2.

★ Nanoarchitectonics Related to Sustainable Energy and Environment

[18] Novel porous materials for next-generation high-performance batteries

Representative researcher: Y. Yamauchi

Platinum (Pt) have long been regarded as useful catalysts in fuel cells. However, the high cost of Pt catalysts, together with the limited reserves of Pt in nature, has been shown to be the major bottleneck for commercial applications. We have developed novel porous electrodes with highly electrocatalytic activity.

In view of the strong social demand for the reduced use of rare metals, there have been heightened calls for the development of a technology for securing high functionality with low use of Pt by producing porous structures with larger surface areas (Fig. 18). Our group has focused on fine controls of compositions and morphologies which are important factors for design of porous metals. We have developed a route to nanoporous metal films by a simple electrodeposition method in an aqueous surfactant solution. The Pt atomic crystallinity is coherently extending across several Pt nanoparticles, providing a large number of atomic steps and defect sites, which are very active sites in methanol oxidation reaction. As a result, the electrochemical performance is dramatically enhanced, compared to commercially available Pt catalysts.

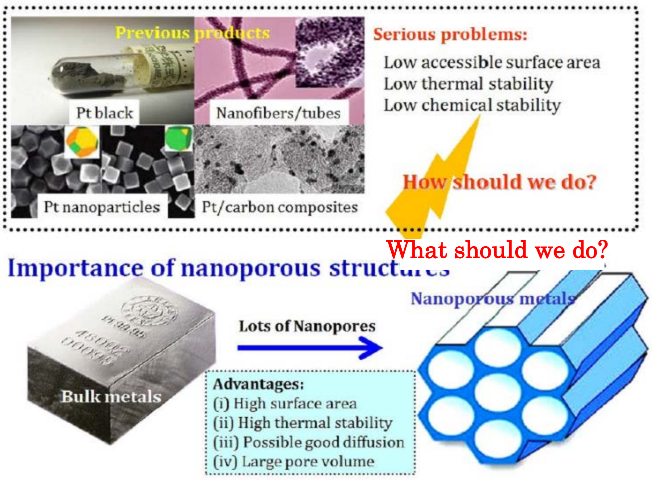


Fig. 18. Importance of nanoporous Pt beyond other commercially available Pt products.

See Papers 35 [*Angew. Chem. Int. Ed.* **52** (2013) 8050] and 36 [*Angew. Chem. Int. Ed.* **52** (2013)

13611] in Appendix 2.

[19] Nanoarchitectonic sensing/imaging of Cs in life environment

Representative researcher: K. Ariga

We have developed various molecular sensing systems in which designed molecules and materials recognize target substances with incredibly high specificity and sensitivity. Our sensing system can be used in any life environments to detect toxicity and important biological components. For example, detection of cancer-suspected substances in gas phase and faint chiral discrimination of bio-related drug molecules have been realized with reasonable sensing signals in electric, photonic, and magnetic modes.

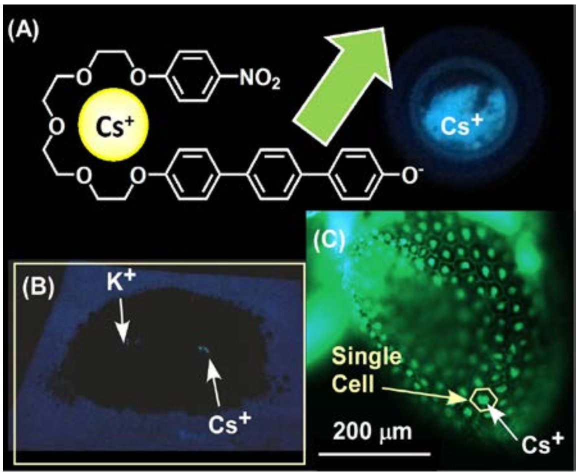


Fig. 19. (A) Caesium detection probe molecule and detection based on fluorescent emission on (B) ground and in (C) living plant cells.

Especially, micrometre-level 'naked-eye detection' of caesium (Cs) ions, a major source of contamination upon nuclear plant explosion, has been demonstrated. This research designed a substituted phenol compound with an electron-accepting 4-nitrophenyl ether group. The compound showed a distinctive green fluorescence in the presence of caesium ions (Fig. 19A) even on ground (Fig. 19B), while all other metal ions show dark blue fluorescence or nothing. The probe was sensitive to caesium concentrations of 1 part per million (Cs^+/K^+). The developed probe molecule is now commercialized and further applied to caesium ion detection in living cells (Fig. 19C).

See Papers 37 [*Nature Commun.* **4** (2013) 2188] and 38 [*Sci. Tech. Adv. Mater.* **14** (2013) 015002] in Appendix 2.

[20] Highly-efficient plasmonic systems for molecular sensing and energy conversion

Representative researcher: T. Nagao

Plasmonics and metamaterial are the new emerging paradigms for materials science which enable us to control the light in nano-space. Through this concept we can tailor remarkable functionality such as extraordinary signal enhancement of molecules, enhanced photocatalytic reaction, and smart solar power harvesting. Here we aim at manipulating infrared light waves for the applications in environmental monitoring as well as in solar and thermal energy conversion by developing new metallic nanostructures.

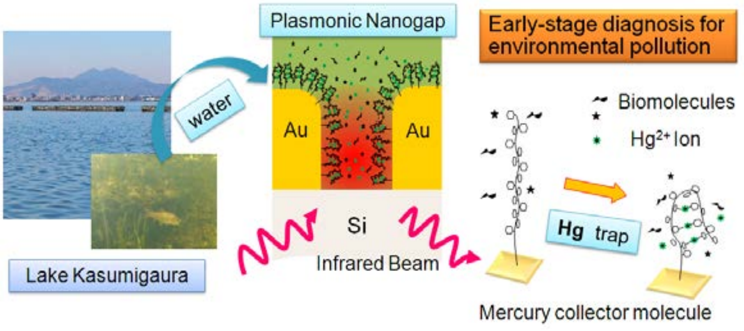


Fig. 20. Schematic illustration mercury detection from environmental water. The change in the molecular structure of the mercury collector is sensitively detected by the infrared absorption signal by the enhanced field of the nanogap plasmon.

Fig. 20 shows an example for the ppt-level single-step selective monitoring of the presence of mercury ions (Hg^{2+}) dissolved in environmental water by plasmon-enhanced vibrational spectroscopy. From natural water from Lake Kasumigaura (Ibaraki Prefecture, Japan), direct detection of Hg^{2+} with a concentration as low as 37 ppt was demonstrated, indicating the high potential of this simple method.

See Papers 39 [*Scientific Reports* **3** (2013) 1175] and 40 [*Adv. Opt. Mater.* **1** (2013) 814].

2-2. Research environment including facilities and equipment

Describe the degree to which the Center has prepared a research environment appropriate for a world premier international research center, including facilities, equipment and support systems, and describe the functionality of that environment.

World-Class Research Equipment

The research equipment available to researchers at MANA is, without a doubt, some of the best in the world. First, MANA has its own microfabrication facility, the MANA Foundry, which allows researchers to efficiently conduct their own microfabrication in-house. There are 13 staff to provide support for the MANA Foundry.

In its 40-plus years of existence, our host institution NIMS has built up an outstanding research infrastructure, and MANA researchers are free to use this equipment as well. This equipment includes world-class ultra-high-resolution electron microscopes, a dedicated beamline at a synchrotron radiation facility (SPring-8), one of the world's most advanced ultra-high magnetic field generators (10 T), an ultra-high-resolution nuclear magnetic resonance (NMR) spectrometer and an ultra-high pressure device (10-100 GPa).

MANA has a special electron microscope that enables the observation of the electrical, mechanical, thermal and optical properties under high-resolution structural observation. Multiple-probe scanning probe microscopes are also working, which can measure electrical conductance at the nanometer scale. MANA has also installed many other pieces of advanced equipment, including a photoelectron spectrometer, a Raman spectrometer and a femtosecond laser spectrometer.

Comfortable Research Space

In October 2008, the entire Nanomaterials and Biomaterials Research Building was allocated to MANA. The main researchers and equipment were all placed there, and it has served as the primary space for MANA's activities ever since. In March 2012, we completed the WPI-MANA Building, making the research environment at MANA even more convenient. The new building was designed to increase interaction among researchers from various fields, and it has significantly enhanced research activities at MANA by exchanging the way researchers conduct their research.

Improved Administrative and Technical Support

All of the staff in the Administrative Office are fluent in English and are equipped with wide-ranging administrative knowledge and experience. They provide researchers with seamless technical and administrative assistance, regardless of age or nationality, and we have nearly achieved the WPI Program mission of "creating an environment in which researchers can devote themselves to their research." The types of services provided are described in Section 4.3.

The Administration Office is staffed by six full-time technical support staff who provide wide-ranging support, including the maintenance of the more than 50 shared facilities, maintaining the laboratories, managing reagents, undertaking safety measures, purchasing, hauling and installing new equipment and assisting foreign researchers in applying for external funding.

2-3. Competitive and other funding

Describe the results of the Center's researchers to date in securing competitive and other research funding.

- *In Appendix 2, describe the transition in acquiring research project funding, and note any external funding that warrants special mention.*

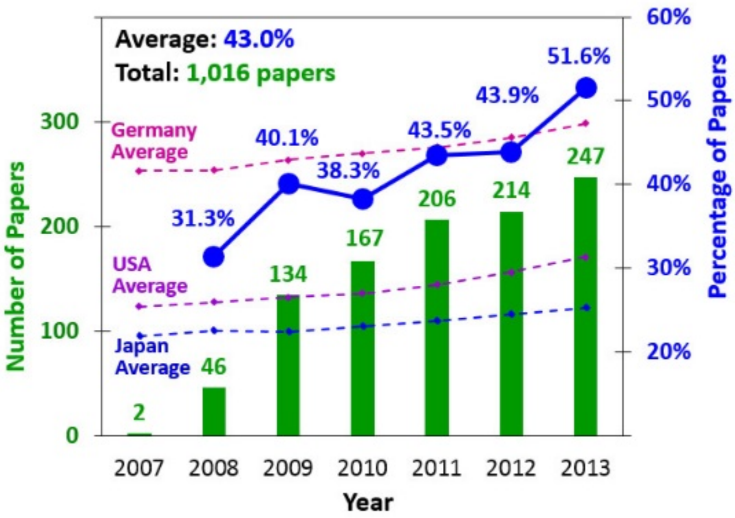
In the past 6.5 years, MANA researchers have secured 8.08 billion yen in research project funding, the breakdown of which is 1.21 billion yen in competitive external funding, 2.57 billion yen in commissioned research (including private funding) and 4.3 billion yen in operations subsidies.

Prime examples of the competitive external funding we have secured include numerous Grants-in-Aid for Scientific Research, one NEXT Program grant, seven CREST grants and nine PRESTO grants.

2-4. State of joint research

Describe the results of joint research conducted with other research organizations both in and outside Japan.

MANA researchers proactively conduct joint research with researchers from around Japan and throughout the world. In the past 6.5 years, MANA researchers have published 2,362 papers, of which 43% have been international joint works. The number of international joint works increases every year, and in 2013, they accounted for more than half of all papers published. Our percentage of international joint works is on par with the world leader Germany, and this shows the progress we have made in building a framework in which researchers from different coutries can cooperate on projects.



Internationally co-authored papers of MANA
Source of national averages: SciVal database, Elsevier B.V., (downloaded in June 2014)

MANA invites world-renowned researchers from outside research institutes to serve as PIs or APIs in those fields we deem important to the Center's mission. These researchers' labs are called MANA Satellite Labs, and they pursue joint research in close cooperation with our researchers (See Section 4-1-3). At present, MANA maintains satellites at UCLA and the Georgia Institute of Technology in the United States, CNRS (Toulouse) in France, the University of Montreal in Canada, UCL in England and the University of Tsukuba and the Tokyo University of Science in Japan. To date, research at the satellites has yielded 243 articles. The four overseas satellites are described in detail in Section 4-1-1.

We sign MOUs with foreign research institutes once we and a research group at the institute recognize the need to cooperate on a certain topic. Since MANA's inception, we have signed MOUs on research cooperation with 44 research institutions in 15 countries (Regional breakdown: Europe: 18, Asia: 15, North America: 6, South America: 2, Australia: 2, Middle East: 1). See Appendix 4-5 for details.

2-5. Appraisal by society and scientific organizations

Describe how society and/or scientific organizations in and outside Japan have recognized the Center's research achievements.

- *In Appendix 2, list the awards received and invitational lectures given by the Center's researchers.*

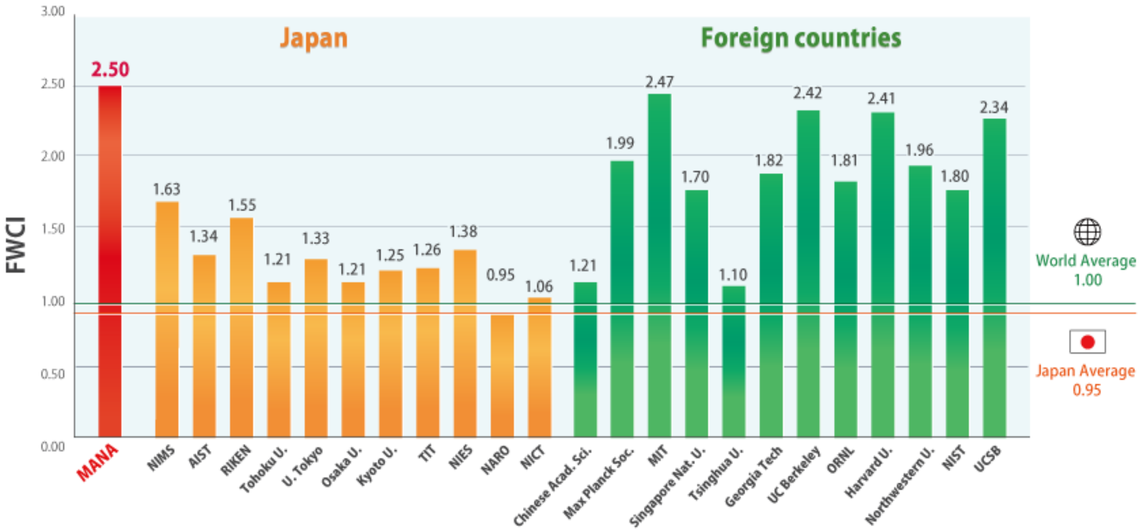
The quantity and quality of our publications clearly reflect our level of basic research activities. In the 6.5 years since MANA was established, our researchers have published 2,362 papers. Of those, 80 have achieved very high acclaim, entering the top 1% in the world by number of citations.

The high quality of MANA's research is witnessed by the large number of papers that our researchers have published in high impact journals. In 2013, MANA researchers published 479 papers, and the average impact factor of the journals in which they were published was an extremely high 4.89.

Elsevier recently devised a new indicator called Field-Weighted Citation Impact (FWCI), which adjusts citation counts depending on the level of focus in a given field, thus enabling the comparison of the quality of papers from research centers in different fields. With an extremely high FWCI of 2.5, MANA's performance is on par with elite universities in Europe and the United States.

In addition, five MANA researchers − Dr. Ariga (Materials Science), Dr. Bando (Materials Science), Dr. Golberg (Materials Science), Dr. Wang (Materials Science, Chemistry) and Dr. Yaghi (Chemistry) − were selected for Thomson Reuters' Highly Cited Researchers 2014.

As Appendix 2-3 shows, many MANA researchers have received awards and given numerous keynote speeches. A large number of researchers have also been asked to write review articles in top-tier international journals such as *Advanced Materials* and *Chemical Reviews*.



Field Weighted Citation Impact (FWCI) of MANA and other institutions in the world
Source: SciVal database, FWCIs were calculated for papers published from 2008 to 2013.

2-6. Feeding research outcomes back into society

2-6-1. Applications of research results

Describe the applications created from research results, their effect in spawning innovation, intellectual properties (IPs) obtained, and joint research activities conducted with corporations, etc.

One important mission of MANA's host institution NIMS is the research and development of practical materials, so MANA actively pursues applied research in addition to the basic research expected by the WPI Program. Several examples are as follows:

a) One of MANA's most important achievements has been the development of atomic switches, which have many potential applications. Compared to conventional CMOS transistor switches, atomic switches are smaller by an order of magnitude and consume less energy. Working in cooperation with NEC Co. Ltd., we used atomic switches as the switching circuits in a field programmable gate array (FPGA) and successfully boosted the performance thereof.

b) Since atomic switches can also be used as on/off power switches for currents larger than those that conventional transistor switches can handle, NIMS established the HONDA-NIMS Joint Research Center of Excellence for Advanced Functionality Materials at the request of Honda Co., Ltd. and the two parties have started conducting joint research.

c) Another notable research achievement at MANA is the development of nanosheet technology. To apply this technology, MANA and Murata Manufacturing Co. Ltd. have begun jointly developing high performance compact capacitors that take advantage of the extremely high permittivity of nanosheets.

d) One example of a more topical research application is a new reagent we developed to visualize radioactive cesium released into the atmosphere after the Fukushima Daiichi Nuclear Power Plant incident. It is currently being sold by Tokyo Chemical Industry Co. Ltd.

e) Another recent success is the dramatic improvement in the stability of In_2O_3-based materials (known as IGZO) which are widely used in smartphone displays. We have begun exploring the commercialization of this with a corporate partner whose name we cannot disclose.

Between October 2007 and December 2013, MANA researchers applied for 640 patents (435 in Japan and 205 overseas) and had 416 patents registered (318 in Japan and 98 overseas).

2-6-2. Achievements of Center's outreach activities

If the Center has conducted its own unique outreach activities, describe those worthy of special mention.

- *In Appendix 2, list and describe media coverage, press releases, and reporting.*

To disseminate the concept of nanoarchitectonics and raise MANA's profile, we have published special features in several renowned journals, including *Advanced Materials* (2012) and *Langmuir* (2013). The former featured a collection of 14 papers by MANA researchers, of which five have reached the top 1% in terms of citations. The latter featured papers by 48 researchers from around the world, 33 of which were submitted by researchers from outside MANA, and announced an open forum entitled "Nanoarchitectonics and the Interface".

Since FY2011, we have been disseminating MANA's outstanding research outcomes around the world in our online newsletter *MANA Research Highlights*. This newsletter is distributed to 2,000~3,000 media outlets and science journalists and to about 2,000 MANA mailing list members. Particularly outstanding research results are sent to approximately 4,000 researchers around the globe via *Science* e-mail alerts. These efforts have been an effective means of sharing MANA's outcomes with the global science community, and some of the highlighted papers have been the most downloaded articles.

Since MANA's inception, we have published the bilingual *Convergence* newsletter three times a year and are now on our 16th issue. Each issue includes a status report on the Center and interviews with Nobel Prize-class researchers. We currently distribute 1,650 copies to researchers in Japan and 1,800 copies to researchers overseas.

As a result of these efforts, a session on nanoarchitectonics will be included in the E-MRS Fall Meeting to be held in September 2014—more proof that the concept is permeating the global science community.

MANA has also actively pursued outreach activities geared to the general public. To generate an interest in science among young people, we have held events such as MANA Science Cafe, joint symposia, summer camps and summer school events for elementary and junior high school students featuring Nobel Prize winners Prof. H. Rohrer and Prof. H. Kroto. We also publish easy to understand videos of MANA research results on the internet.

3. Interdisciplinary Research Activities (within 3 pages)

3-1. State of Strategic (or “Top-down”) Undertakings toward Creating New Interdisciplinary Domains

To promote interdisciplinary research across MANA's four fields (Nano-Materials, Nano-Systems, Nano-Power and Nano-Life fields), MANA has established the following special funds.

A) Fusion Research Fund: Based on the belief that promoting joint research across fields especially among young researchers can lead to the creation of new research, we opened this fund to applications from our young researchers. Over the past two years, we have granted ¥10 million in research funds for six projects.

B) Theory-Experiment Fusion Research Program: We have been accepting applications for this funding program for two years in an effort to get theoretical researchers involved in MANA research projects and to encourage and support experimental research. Ten projects have been awarded a total of ¥20 million in research funds over the past three years.

C) Nano-Life Fusion Research Program: We established this fund to promote interdisciplinary research between Nano-Life researchers and researchers specializing in other nanotechnology fields. Over the past three years, two projects have been awarded ¥20 million in research funds.

D) Grand Challenge Research Program: Under this program, we solicited innovative, unconventional, interdisciplinary projects, including projects not limited to materials research. Seven projects have been awarded ¥6 million in research funds over the past two years.

For reference, MANA's Grand Challenge research targets are as follows.

★ Nanoarchitectonic artificial brain

★ Room-temperature superconductivity
★ Practical artificial photosynthesis

None of these research topics can be tackled without interdisciplinary research, and the act of setting these targets was intended to encourage research fusion at MANA. The results of these efforts are starting to take shape. Daily exposure to these bold research goals has boosted the motivation of researchers in every field, and they have started proposing numerous intriguing ideas at the Grand Challenge Meeting (a retreat-style meeting) and other venues.

3-2. State of “Bottom-up” Undertakings from the Center’s researchers toward Creating New Interdisciplinary Domains

MANA Seminars have become firmly established venues where MANA researchers and their outside colleagues can give presentations on the latest research topics and engage each other in discussions. Initially, these were administered in a top-down fashion, with the Center inviting guest lecturers, but recently, MANA researchers have started planning the seminars on their own accord. With researchers from a variety of fields in attendance, the discussions are lively, making the MANA Seminar a genuine "melting pot". As such, MANA Seminars play a vital role in promoting the fusion of different disciplines. In the 6.5 years since MANA opened, 395 MANA Seminars have been held.

MANA also holds the retreat-style Grand Challenge Meeting once or twice a year. The initial aim of the meeting was to encourage researchers working in different fields at MANA to brainstorm and discuss the kinds of research they aspire to, but the event led some young researchers to propose a Grand Challenge Meeting geared only to young researchers.

In this way, the interdisciplinary research promotion programs outlined in Section 3-1 have inspired MANA's researchers, making them aware of the importance of research fusion and creating a culture in which researchers promote interdisciplinary research on their own accord. A sample of the results of these initiatives is outlined in Section 3-3.

3-3. Results of research in fused research fields

Describe the Center’s record and results by interdisciplinary research activities.

- *In Appendix 3, list the main papers published (up to 20 papers) on the Center’s interdisciplinary research and provide a description of each of their significance.*

The following is a progress report on the three goals of the Grand Challenge, a program established by MANA to promote interdisciplinary research fusion, mentioned in Section 3-1.

★ Nanoarchitectonic artificial brain: As mentioned in Research Results [3] and [4] in Section 2-1, some very interesting research into nanoarchitectonic artificial brains is currently being pursued. The following is a simple summary of this research.

MANA researchers have successfully used atomic switches to create artificial synapses that mimic the characteristics of real synapses, structures that play important roles in brain function, but they have found that creating a random network of several hundreds of millions of these atomic switches yields extremely interesting properties. For example, when electrodes are placed at either end of the network and a direct current voltage is applied, the electrical conductivity increases and decreases randomly, which is opposite of the standard assumption that conductivity will increase in step with time. In other words, this system composed of inorganic materials behaves like a living organism. The mechanism behind this is unclear, but we have initiated a joint research project with an information theory researcher. This has the potential to open up a large new field of research and constitutes an extremely important fusion of nanoarchitectonics and neuroscience.

★ Room-temperature superconductivity: Our researchers thought it might be difficult to achieve using three-dimensional bulk crystals, so they are attempting to do so with a nanoscale controlled system. We cannot provide the details of this research here, but researchers are attempting to change several target insulators into superconductors by physically, not chemically, introducing electrons and holes. The preliminary results of this research are listed in Papers Opt.-4 and 5 in Appendix 2. Aside from this, we have achieved another highly interesting theoretical research outcome. Namely, we succeeded in theoretically designing a novel topological insulator where the edge state carries zero-resistance current optimally up to room temperature (See Paper Opt.-3 in Appendix 2). Researchers with outstanding experience in crystal physics and atomic layer deposition has since joined the project in an effort to realize this theoretical prediction, thus resulting in a cross-linkage that goes beyond simple cooperation between theoreticians and experimental researchers.

★ Practical artificial photosynthesis: As mentioned in Research Result [10] in Section 2.1, we are also promoting interdisciplinary research on practical artificial photosynthesis at the junction of catalysts. i.e., materials science, and plant photosynthesis. This is an ambitious project, and it has started producing some interesting results.

Other fusion research areas are as follows:

- A wide range of research on nanosheet technology; from the basics to applications
  <Fusion of Soft Chemistry, Materials Physics and Electronic Device Technology>
  (2-1. Research results [1] and [2])

MANA has actually created, useful new materials through its unique nanosheet technology, with which new materials that do not exist in nature can be systematically developed using soft-chemical procedures. Such achievements are attributed to the fusion of nanosheet technology, materials physics and electronic device technology.

- A wide range of research on the atomic switch; from the basics to applications
  <Fusion of Electrochemistry, Electronic Device Technology and Neuroscience>
  (2-1. Research results [3] and [4])

The atomic switch was originally invented through the integration of electrochemistry and electronic device technology. In collaboration with NEC Corporation, such “Beyond CMOS” devices, unique to MANA, have already progressed to the technological level necessary for practical use. More importantly, research has commenced as a result of the merging of the said technology with neuroscience, to develop base units for material-based brain-type computers.

- Development and application of ultra-sensitive/ultra-parallel molecular sensors
  <Fusion of Animal Olfactory Organs, Nanoarchitectonics and Medical Diagnosis>
  (2-1. Research result [9])

As a result of learning from animal olfactory organs, MANA has developed ultra-sensitive/ultra-parallel molecular sensors that are superior to animal olfactory organs. This unique technique, combined with medical diagnostics, has been used to realize a method for detecting cancer using human breath analysis.

- Development of efficient artificial photosynthetic systems
  <Fusion of Photocatalytic Chemistry, Plant Photosynthesis and Nanoarchitectonics>
  (2-1. Research result [10])

MANA is working toward realizing highly-efficient artificial photosynthetic systems, by integrating leading-edge photocatalytic chemistry research with plasmonic light antenna technology, as well as by utilizing structures of plant leaves that perform highly-efficient photosynthesis.

- Cancer and Alzheimer's disease treatments using nanoarchitectonics
  <Fusion of Medical Care and Nanoarchitectonics> (2-1. Research results [7] and [8])

Combining medicine with the excellent nanoarchitectonic technologies possessed by MANA enables the realization of fascinating medical treatment techniques. For instance, MANA has developed treatments for Alzheimer’s disease with the use of nanoarchitectonic particles, which deliver drugs to the brain efficiently. A smart nanofiber mesh has also been developed that, when applied directly to the affected part, enables the release of anticancer drugs by the application of an external stimulus (magnetic field).

- Exploration of decoherence-free quantum bits, room-temperature “superconducting” devices
  <Fusion of Theory and Experiment> (2-1. Research result [11])

Triggered by the theoretical study of topological insulators, a new world of solid-state physics is unfolding. MANA conducts development of novel nanoelectronic devices by fusing the research of MANA theorists, who are highly contributive to the field, and brilliant MANA experimentalists.

4. International Research Environment (within 4 pages)

4-1. International Circulation of Best Brains

4-1-1. Center's record of attracting and retaining top-world researchers from abroad

Describe the participation of top-world researchers as PIs and the residing of joint researchers at the Center.

- *In Appendix 4, give the number of overseas researchers among all the Center's researchers, and the yearly transition in their numbers.*

MANA has established satellites in the research institutes to which its external Principal Investigators are affiliated. At present, there are satellites at four overseas institutions: the University of California, Los Angeles (UCLA), the Georgia Institute of Technology, the Center for Materials Elaboration and Structural Studies (CEMES) at the French National Center for Scientific Research (CNRS) and the University of Montreal. These satellites play important roles in each of MANA's research fields and serve as training grounds for MANA's young researchers.

Dr. James Gimzewski from UCLA is a world-renowned nanotechnology researcher and recipient of the 1997 Feynman Prize. At MANA, he is conducting research on neuromorphic circuit networks in the Nano-System Field. Over the past six years, Dr. Gimzewski has visited MANA 22 times for a total of 262 days to conduct joint research on projects such as new neurocomputer circuits that use the learning abilities of atomic switches. His research was covered by NHK in the January 2010 program entitled *Proposal for the Future* and the February 2012 special report called *Nano Revolution: How Atoms Will Change Our Lives*. Dr. Gimzewski has also worked tirelessly to train young researchers, graduate students and administrative staff by hosting postdocs from MANA, holding the Japan-UK-USA Nanotechnology Summer School, and accepting MANA staff for internships at UCLA.

Dr. Zhong Lin Wang from the Georgia Institute of Technology is a highly active researcher whose publications, which have been cited more than 67,000 times, boast and H-index of 126. At MANA, he works in the Nano-Materials Field where he conducts research on bio-inspired photonic structures and nanogenerators that harvest mechanical energy. Dr. Wang is also the mentor to group leader Dr. Fukuta, who has visited the Georgia Institute of Technology 11 times for a total of 24 weeks. Together they conduct joint research on nano devices and have published their results in *ACS Nano*. Dr. Wang and Dr. Fukuda also promote personnel exchange, with one of Dr. Wang's postdocs working for Dr. Fukuta.

Dr. Christian Joachim from CNRS-CEMES is a world-renowned computational scientist who won the Feynman Prize in 1997 and 2005. At MANA, he works in the Nano-System Field where he studies the design, fabrication and atomic manipulation of nanocircuits as well as theories of surface electron interconnection. He actively engages in joint research with MANA researchers and has published 28 papers on the research conducted at MANA (including several papers published in top-tier journals such as *Nature Nanotechnology*). In addition, he has organized two workshops at CEMES: an October 2009 event aimed at promoting cooperation between computational scientists and experimental scientists and the November 2010 Japan-France Workshop on Nanomaterials.

Dr. Francoise Winnik from the University of Montreal is a world-renowned researcher in the fields of polymer chemistry, interfacial chemistry and nanoscience, and she serves as the Executive Editor of *Langmuir*, the journal of the American Chemical Society. At MANA, her research in the Nano-Life Field focuses primarily on the synthesis of new biocompatible polymers, but she also conducts wide-ranging, interdisciplinary research using the nanotubes and nanoparticles developed by MANA researchers in other fields. Dr. Winnik has labs at both MANA and the University of Montreal, and her teaching load at the university was reduced to zero to allow her to focus her energies entirely on research with MANA. Over the past three years, she has spent 495 days at MANA.

The number of famous scientists, young faculty members, students and other researchers who visit MANA from around the world increases every year—proof that MANA has become one of Japan's leading hubs for international research.

4-1-2. Employment of young researchers at the Center and their job placement after

leaving the Center

Describe the Center's employment of young researchers, including postdoctoral researchers, and the positions they acquire after leaving the Center.

- *In Appendix 4, enter the following:*

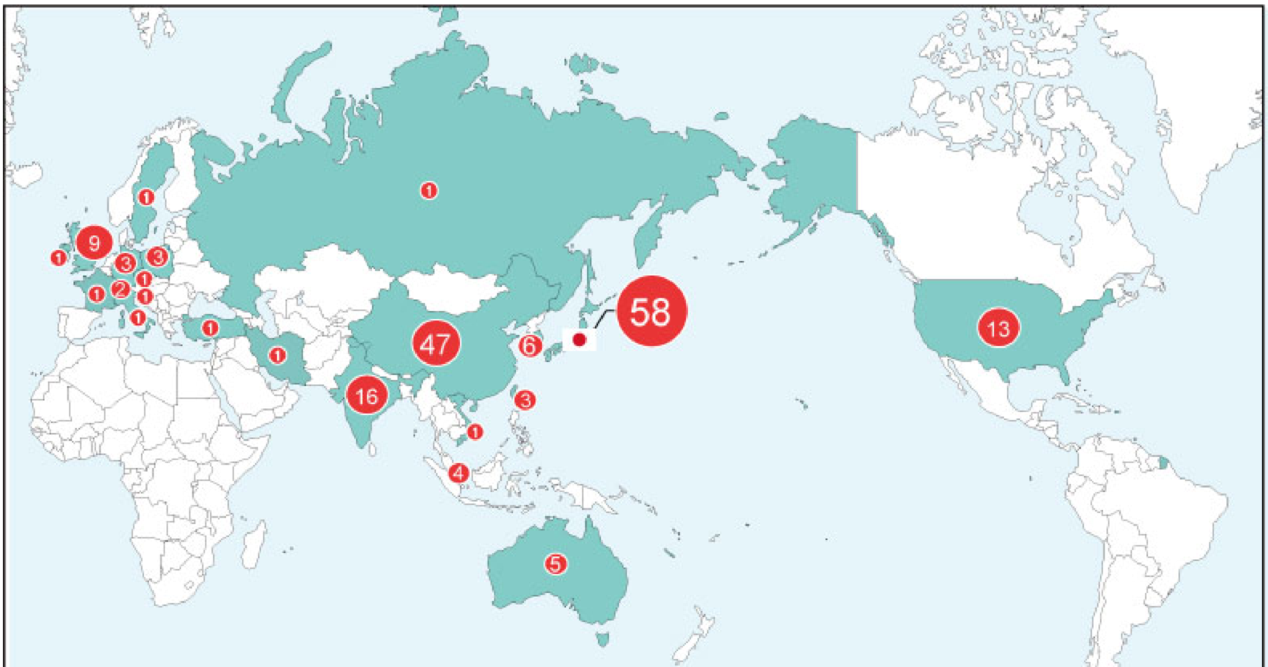
- The state of international recruitment for postdoctoral researchers, applications received, and selection made
- The percentage of postdoctoral researchers from abroad
- The positions that postdoctoral researchers acquire after leaving the Center

Young fixed-term researchers are postdocs and doctoral program students who represent nearly half of the MANA research personnel.

In addition to regular postdocs, there is also the higher position of ICYS-MANA Researcher, i.e., postdocs who conduct independent research without belonging to a specific group. ICYS, which was established as a tenure-track system for permanent researcher positions at NIMS, comprises several sub-systems, one of which is ICYS-MANA. ICYS Researchers are hired twice a year by way of international open recruiting. Over the past 6.5 years, 78 researchers have been hired from a total of 942 applicants (including 835 foreign applicants (89%)). Of these, more than half (40) have been hired under the ICYS-MANA system.

We also openly recruit regular postdocs and doctoral program students from around the world with announcements on our homepage. Postdocs are employed after document screenings and interviews by a three-person screening panel. Doctoral school students are selected after stringent document screenings and interviews by faculty members from the NIMS Joint Graduate Programs (See "6. Others" for details).

It is MANA's policy to not only attract young researchers from around the world and cultivate them into outstanding scientists, but to enhance their understanding of Japan and help them take the next step in their careers in many countries in the world. Over the past 6.5 years, eight postdocs from MANA have been appointed as NIMS permanent researchers, and 171 have leveled up to universities and research institutions in Japan and around the world. Looking at these former MANA postdocs, 32% have secured positions in Japan, and 68% have found jobs overseas, primarily in Asia but also in the United States, Europe and elsewhere in the world. In this way, MANA has become the hub for an ever-expanding network of nanotechnology researchers.



Destinations of MANA postdoc alumni (unit: number of people)

4-1-3. Overseas satellites and other cooperative organizations

- *In Appendix 4, describe the state of the Center's agreements concluded with overseas satellites and other cooperative organizations.*

One of MANA's missions is to become a hub and build a network connecting the world's nanotechnology centers. At present, MANA has memoranda of understanding (MOU) with 34 research institutes in 15 countries and promotes research and personnel exchange with these partners.

To make sure PIs in the satellites will independently undertake MANA research, NIMS and MANA established a funded joint research system. Under this system, joint research agreements are signed between NIMS and the satellite host institutions, and a portion of NIMS operations subsidies are allocated to fund joint research projects with the satellites. This enables effective cooperation between MANA and the satellites and has resulted in the satellites making major contributions to MANA.

4-2. Center's record of holding international symposia, workshops, research meetings, training meetings and others

- *In Appendix 4, describe the main international research meetings held by the Center.*

Until 2012, the MANA International Symposium focused primarily on annual reports of research findings of MANA, but in 2013 we transformed the symposium into a venue that attracts the world's best researchers with the aim of making it a more open and higher caliber event. In 2013 and 2014, we invited a total of 20 top researchers respectively, including Nobel Prize laureates, and presentations of the latest research findings were given on the main topics set by MANA. As a result, we attracted an all-time high 400-plus participants and received high marks for organizing a high caliber international conference.

Meanwhile, the number of requests from government agencies, universities and research institutes to hold research forums with MANA is on the rise. To date, MANA has held bilateral workshops with institutions in Canada, Australia, Switzerland, Spain and Taiwan as well as symposia with several Japanese and foreign universities (Osaka, Waseda, Northwestern, Montreal, Bristol, Rennes and National Taiwan University). In addition, MANA held a joint symposium with *Physical Chemistry Chemical Physics* (PCCP), the journal of the Royal Society of Chemistry. These events have helped us publicize MANA's activities widely and find joint research partners.

4-3. System for supporting the research activities of overseas researchers

Describe the Center's preparations to provide an environment conducive for overseas research to concentrate on their work, including for example living support in various languages or living support for their families.

All of the staff in MANA's Administrative Office are fluent in English, and they provide all researchers, regardless of age or nationality, with the same highly attentive, Japanese-style service. One foreign researcher who had previously worked at research centers in the United States and Europe even said MANA has the "best research environment" he has ever seen.

Eliminating the language barrier: Major handbooks, documents and the intranet are bilingual, and internal meetings and e-mail communication are conducted in English. We also provide information on external funding in English to encourage foreign researchers to apply for competitive funding and assist them in completing their application forms. These efforts aimed at eliminating the language barrier are gradually spreading throughout NIMS.

Orientation: MANA staff play a leading role in providing orientations in English to new NIMS researchers and offering lab tours every few months. By providing information necessary for research, including work regulations and information on benefits, purchasing, intellectual property, publication, research ethics, external funding, and safety and offering tours of research facilities, efforts are made to ensure that researchers can begin their research activities at NIMS as quickly as possible.

Livelihood support: NIMS outsources livelihood support for foreign researchers to the Japan International Science and Technology Exchange Center (JISTEC). Support includes assistance with various procedures including residence registration, school enrollment and transfer, opening bank accounts and moving. JISTEC also provides daily-life-related information, accompanies researchers and their family to the hospital, and offers support in the event of an accident.

Understanding Japan: MANA offers Japanese language and culture courses for its foreign researchers. Over the last six years, a total of 530 researchers have participated in Japanese language courses, and a total of 880 researchers have taken the culture course classes, which are held about once a month. Based on its experience, MANA also published an English language comic book called "The Challenging Daily Life" that discusses ways to handle issues that foreign researchers might encounter at a Japanese research institution.

Technical support: The six-person technical team in the Administrative Office is composed of experienced veterans who also have a strong command of English, and the foreign researchers have come to confide in them.

4-4. Others

Describe the Center's policy for sending Japanese researchers overseas to gain international experience, and give examples of how the Center is working to create career paths for its researchers within a global environment of researcher mobility.

In terms of the recruitment and training of young researchers, the Independent Scientist and ICYS Researcher systems, in which researchers conduct independent research without belonging to a specific group, have posted good results. In particular, the 3D System (double-mentor, double-discipline, double-affiliation 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 perspectives in these researchers.

Dr. Samuel Sanchez of a Max Planck Institute is one example of a researcher who flourished under the 3D System. When Dr. Sanchez was an ICYS-MANA Researcher at MANA, he used the 3D System to conduct joint research with a German research institute and has since become a group leader at the Max Planck Institute, Germany's leading research center.

We believe that sending young Japanese researchers to conduct research at major foreign research institutions for long periods of time is an effective way to cultivate internationally-minded, interdisciplinary researchers, so we encourage them to go overseas. To date, we have sent three young Japanese researchers on one to two-year research abroad trips to the University of Cambridge (UK), RWTH Aachen University (Germany) and MINATEC (France).

At MANA, 109 of the 208 researchers are postdocs and doctoral program students, of which 87, or 80%, are foreign nationals. In this manner, MANA has achieved an environment in which young researchers from around the world can hone their skills through friendly rivalry. That being said, the Program Committee has pointed out that MANA should increase the number of Japanese postdocs since their numbers are few. Therefore, to attract outstanding Japanese researchers to MANA and cultivate Japan's future research leaders, we established the YAMATO-MANA Program (**Y**oung, **A**spiring **M**otherland **A**cademics **TO MANA**) as a Center-wide effort to seek out talent; in FY2013, we hired eight researchers under this program. (Note: Yamato is the ancient name of Japan.)

MANA is playing a key role in the development of NIMS into an international research center, and its efforts to create an environment where foreign researchers can succeed was listed as a best practice in the 2014 White Paper on Science and Technology.

5. Organizational Reforms (within 3 pages)

5-1. Decision–making system in the center

Describe the strong leadership that the director is giving the Center's operation and its effect, and the division of roles and authority between the Center and its host institution.

The Director-General has successfully recruited outstanding researchers from around the globe and created an atmosphere in which they can freely engage in research and hone their skills through friendly rivalry. This is evidenced by the numerous remarkable research achievements described in Chapter 2 and stems from the strong leadership that the Director-General exhibits in all aspects of Center administration, including setting research policy, streamlining systems, adopting new measures and distributing research resources. Notable examples of this success include the Independent Scientist and 3D (Triple Double) systems, which have been highly effective tools for cultivating young researchers, and the adoption of a funded joint research system to invigorate research at the satellites.

In addition, the Director-General has helped to firmly establish the concept of nanoarchitectonics worldwide. This is the result of unflagging efforts to disseminate research outcomes by holding numerous research forums, publishing special features on nanoarchitectonics in well-known journals and distributing an online newsletter.

The Director-General has responded quickly to Program Committee comments, thus improving the quality of activities at the Center. For example, the Grand Challenge, which aims to tackle vexing research problems, Theory-Experiment Fusion Research, and YAMATO-MANA, a program designed to cultivate young Japanese researchers, have all made great strides.

The host institution NIMS has granted the Director-General broad authority over Center operations and respects his intentions to the fullest extent. Meanwhile, NIMS provides the Center with maximum support, allocating research resources in the form of 90 permanent staff and providing funds from the operations subsidy budget to the maximum extent possible.

5-2. Arrangement of administrative support staff and effectiveness of support system

Describe the assignment of the Center's administrative support staff who have English language and other specialized skills, effort made in establishing the support system, and the system's effectiveness.

Since NIMS was founded, it has used programs such as the International Center for Young Scientists (ICYS) to accumulate knowledge on how to run an international research center. This has been carried over to MANA, and we are using the WPI Program to take our efforts to the next level. As a result, we have succeeded in developing a near perfect research environment in which we can provide swift administrative and technical support to all researchers regardless of nationality.

The MANA Administrative Office is composed of four teams, Planning, General Affairs, Technical Support and Outreach, and the keystone is the General Affairs Team, which handles secretarial duties. An experienced NIMS administrator who is familiar with clerical duties and providing support to foreign researchers has been assigned as team leader and oversees all team duties. Secretaries are not assigned to specific research groups, but are transferred from group to group to provide careful support, all while keeping an eye on workload balance and suitability.

5-3. System reforms advanced by WPI program and their ripple effects

Concisely itemize the system reforms made to the Center's research operation and administrative organization, and describe their background and results. Describe the ripple effects that these reforms have on the host institution. (Describe the ripple effects on other institutions.)

<u>System reforms at MANA</u>

(1) We have focused energy on the promotion of interdisciplinary research by adopting new systems such as the Grand Challenge and Theory-Experiment Fusion Research.

(2) We have thoroughly internationalized MANA by promoting bilingual administration and providing research and livelihood support to foreign researchers.

(3) We have made advances in cultivating and recruiting young researchers by adopting systems from ICYS-MANA and devising the 3D System.

<u>Ripple effect on the host institution</u>

(1) While striving to make MANA one of NIMS's permanent research divisions and ensuring its future sustainability, we have built a system in which the structural reforms undertaken at MANA can be easily transferred to NIMS. In addition, the designation of one of its divisions as a World Premier International Research Center has boosted energy levels and morale throughout NIMS.

(2) By adopting MANA's policy of using English as the official language at NIMS, implementing

programs to improve the English proficiency of NIMS administrative staff and producing major documents and internal announcements in both Japanese and English, we have made dramatic improvements in NIMS's ability to provide support in English.

(3) Many of the young researchers who have made great strides within MANA's international melting pot have gone on to become permanent researchers at NIMS.

(4) We have taken full advantage of our experience and achievements with MANA in conceiving, planning and establishing other research centers, such as the Elements Strategy Initiative Center for Magnetic Materials, the Global Research Center for Environment and Energy based on Nanomaterials Science and the Structural Materials Research Center (e.g., adopting young researcher cultivation and recruitment systems akin to ICYS-MANA).

(5) We have provided our knowledge of running an international research center to other institutions. For example, we have advised AIMR, I^2CNER, IIIS, JAXA, JST, the Japan Agency for Marine-Earth Science and Technology, and the Institute for Molecular Science. Additionally, we have compiled this operational know-how into books ("This is the International Center for Young Scientists", "The Challenging Daily Life").

5-4. Support by Host Institution

The following two items concern the support that the host institution provides the Center, including those items of support that it committed to at the time of the initial project proposal submittal or in its revised commitment following the project's interim evaluation. Describe the functional measures that the host institution has taken to sustain and advance the Center's project.

5-4-1. Record of host institution support and its effects

- *In Appendix 5, describe the concrete measures being taken by the host institution.*

To ensure the effective operation of MANA, the host institution NIMS supports the Center extensively to fulfill its obligations, from the time of application by providing staff, research funds and research space and delegating operational authority to the Director-General. Since MANA's founding, NIMS has allocated approximately ¥1 billion annually for research project expenses and over ¥400 million annually for project promotion expenses (e.g., shared research facility, challenging exploratory research, satellite research, travel for official trips and invitations, symposium, outreach activity etc.) from its operations subsidies.

The support program enables MANA to implement original research initiatives, that include the Grand Challenge, Theory-Experiment Fusion, and nano-life fusion research, and to create an atmosphere to conduct innovative research across disciplines. The MANA Foundry and shared laboratories are equipped with the latest test systems and equipment. Veteran staff oversee the systems and equipment upkeep and also serve as experiment advisers. The NIMS supercomputer plays a crucial role in our theoretical research; approximately 20% of CPU time is used by MANA.

As mentioned in 4-1-3, joint research agreements between NIMS and satellite host institutions (a portion of NIMS operations subsidies are allocated to fund joint research projects with satellites) facilitate cooperative activities between NIMS and satellites.

5-4-2. Position of the Center within the host institution's mid-term plan

- *To Appendix 5, attach the cover sheets of the host institution's "Mid-term objectives" and/or "Mid-term plan" and parts of these documents related to the WPI Center.*

In its third five-year plan, launched in April 2011, NIMS was already taking steps to make MANA a permanent research center. Our development of innovative new materials based on nanoarchitectonics was recognized as one of NIMS's priority R&D fields, and MANA was positioned as the Nanoscale Materials Division, one of NIMS's three research divisions.

As it strives to make MANA a permanent unit of the organization, NIMS is also increasing the number of MANA's permanent researchers and administrative staff. Sixteen new permanent staff were added between April 2011 and March 2014, bringing the total number of permanent staff at MANA to 89 (as of

March 31, 2014). NIMS will appoint several new researchers every year to update the Center's potential to achieve successful research outcomes.

5-5. Others

Describe efforts advanced to foster young researchers (e.g., start-up funding, autonomous research environment) and to enlist female researchers.

- *In Appendix 5, give the transition in the number of female researchers.*

<u>Independent Scientists</u>

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

MANA appoints promising young researchers as Independent Scientists and trains them to become future research leaders in the Center with the 3D (Triple Double) System. Since Independent Scientists do not belong to any one research group, they can freely conduct research with other researchers in Japan and around the globe. These researchers are assigned two mentors—one from NIMS and a renowned scholar at a foreign research center ("Double Mentor"). The affiliation to two research institutions ("Double Affiliation") encourages researchers to engage in two specializations ("Double Discipline").

MANA provides excellent support to its Independent Scientists. In terms of research resources, MANA grants them a research allowance of ¥3 million a year, appoints one postdoc researcher to work under them, and covers their travel expenses when they need to meet with their mentors. They are also provided with individual offices and shared secretarial services to reduce the administrative burden.

Our system has proven itself to be highly effective in producing international and interdisciplinary young researchers. In April 2011, three Independent Scientists were promoted to Group Leader positions based on their achievements.

<u>Female researchers</u>

In FY2013, NIMS established a new permanent gender-specific researcher position for which only women can apply, and the female researcher hired under this system has been assigned to MANA. Two other female researchers were also hired as permanent researchers under this system in FY2013. (Note: Three male researchers were also hired in FY2013.)

The Director-General has instructed MANA researchers to make an effort to hire outstanding female researchers, and now, approximately 28% of the younger researchers (postdocs and graduate students) that MANA can hire at its own discretion are female researchers.

6. Others

- *In addition to the above 1-5 evaluation items, only if there is anything else that deserves mention regarding the center project's progress, please note it.*

<u>Performance-based salary system</u>

With the aim of encouraging researchers to produce research output to the maximum extent possible within a competitive environment, NIMS adopted individual performance evaluations and performance-linked benefits for its researchers soon after becoming an independent administrative institution. Since we do not believe that performance evaluations based on individual goal-setting are suitable for researchers engaged in original, challenging research, the NIMS system does not use management by objectives. To encourage researchers to freely pursue high level research, NIMS conducts performance evaluations on the output of said research and pays researchers who have produced excellent results generous bonuses regardless of their title or age.

By chance, this performance evaluation and benefit system has led to our research, which is conducted based on the objectives of the WPI Program (e.g., advanced world-class research and interdisciplinary research), receiving high evaluations. This is evidenced by the generous benefits that many MANA researchers receive by producing excellent results. This system is one reason why our researchers dedicate themselves to highly original research that leads to outstanding publications and patents.

Postdocs who produce outstanding achievements after coming to MANA undergo a special screening and receive an increase in salary for approximately 20% of them.

Cooperation with universities

Since NIMS is not a university, MANA strives to accept university and graduate school students in a variety of ways.

NIMS operates Joint Graduate Schools, having signed agreements with the University of Tsukuba, Hokkaido University, Waseda University and Kyushu University. Graduate students on this program come to NIMS to participate in research projects while receiving supervision from NIMS researchers. There are currently 24 MANA researchers serving as professors for the NIMS Joint Graduate School. Graduate students are appointed as NIMS Junior Researchers and receive salaries for their research activities. There are currently 36 Junior Researchers at MANA, of which 28 are foreigners.

NIMS also runs International Joint Graduate Schools in partnership with renowned foreign graduate schools. Doctoral students on these programs come to NIMS for anywhere from several months to one year, and NIMS researchers supervise their research. To date, MANA has accepted 44 students through this program. There is also an internship program in which students from Japanese and foreign universities are accepted for up to three months and are given opportunities to participate in nanoarchitectonics research. To date, MANA has accepted 275 students, of whom 219 were foreigners.

Advisors and the Evaluation Committee

There are currently three external intellectuals serving as Center Advisors. They provide advice on overall Center management and invaluable suggestions on individual research projects. They also cooperate in our outreach activities by serving as lecturers in science seminars geared toward elementary and junior high school students. The late Dr. Rohrer, a MANA advisor, used to attend the MANA International Symposium every year and offer invaluable advice on each of the lectures. It should be noted that his supervision of Independent Scientists also led to some revolutionary results, as reported in 2-1 [9] (page 7).

The MANA Evaluation Committee is composed of seven external eminent scientists and is chaired by Prof. Cheetham from the University of Cambridge. To date, the committee has met three times, once each in 2008, 2010 and 2012, to evaluate the Center's administration and research activities. The committee provides advice from a different perspective than the WPI Program Committee, and we respond to its recommendations by formulating action plans.

MANA Alumni

We have established the MANA/ICYS Alumni Association for researchers who used to work at MANA and ICYS with the aim providing a network that connects MANA/ICYS alumni throughout the world and promotes exchanges among alumni and current MANA researchers. On March 3 and 4, 2014, approximately 20 alumni were invited to attend the MANA/ICYS Reunion Workshop.

Each alumnus reported on his or her current research, and a discussion was held on how the alumni network can be used for stimulating exchanges. Several excellent ideas were raised, one of which was publishing a special feature jointly edited by MANA researchers and alumni and implementing a "homecoming program" in which alumni return to MANA for joint research; we plan to incorporate these initiatives into future MANA endeavors.

7. Center's Response to Results of FY2013 Follow-up (including Site Visit Results)

** Describe the Center's Response to Results of FY2013 Follow-up. Note: If you have already provided this information, please indicate where in the report.*

1) MANA should take the attitude “Make invisible ENEMY (competitors) visible” in highly competitive fields of research.

We pride ourselves on the outstanding, world-leading achievements MANA has made by effectively applying the concept of nanoarchitectonics, which we proposed to bring about a paradigm shift in nanotechnology. We have clearly defined benchmarks for each research field and undertake challenging research with a strong desire to compete with the world's leading researchers and research institutions and win. One example of this is the indicator we established to publish 10 articles every year that ranks in the top 1% in the world by number of citations.

2) MANA needs a platform to facilitate communication between theorists and experimentalists.

In April 2014, NIMS built the new Theoretical Research Building next to the WPI-MANA Building. About 35 theoretical researchers from NIMS will be assigned to the new facility, which will provide a venue where theorists and experimentalists can interact more closely. We will also establish the new Theoretician-Experimentalist Pairing Program to accelerate interdisciplinary research that fuses theory and experimentation.

3) MANA can and should play a substantial role in the exploration and development of basic materials to detect and remove radioactive species caused by nuclear disasters. This is a very urgent but brand-new issue to be addressed by materials science and technology. We are pleased that MANA is showing an interest in this direction while demonstrating a capability.

We take pride in the contribution MANA has made to society by developing a material that visualizes Cesium and adsorbents for radioactive elements, both of which have helped detect and remove radioactive materials emitted at the nuclear power plant incident. In particular, our fluorescent probe for detecting trace amounts of cesium particulates, developed to improve the decontamination process, has been commercialized as “Cesium Green.”

4) Challenging and long-term research, such as the development of room temperature superconductors, will need more open discussion, brainstorming and collaboration with diverse scientists from outside of MANA and NIMS. As such, we would like to recommend the holding of collaborative and brainstorming workshops.

We have held the Grand Challenge Meeting, an overnight retreat for young researchers, several times to brainstorm risky, challenging research that requires a long-term view, such as the development of room temperature superconductors. Thanks to these sessions, our young researchers have embarked on bold, exploratory joint research projects. Going forward, we will hold workshops on themes that effects MANA's strengths in order to broaden our communication with external scientists. For example, we have already organized an international workshop on topological insulators.

5) MANA should continue to work on evolving the Nano-Life research into projects built coherently around a solid core of fundamental science. There should be a path for taking what is known from fundamental interface chemistry and physics and developing a step-by-step connection to biological interfaces. There should be leaps of knowledge in MANA projects, not just incremental steps along well-traveled paths.

We aim to create new, never-before-seen outcomes and systems by studying the functions of cells, the building blocks of life, and the brain, the most complex biological structure, and incorporating the knowledge gained into our best nanoarchitectonics technologies. Conversely, we will also promote the active utilization of nanoarchitectonics technologies in Nano-Life research. In other words, we will define the interface between the two critical areas of fundamental science and nanoarchitectonics as Nano-Life research. Concrete examples of research include the following: a) building and assessing neuromorphic network circuits composed of MANA-developed synaptic atomic switches in an effort to move one step closer to realizing an artificial brain; b) using ultrasensitive/ultraparallel molecular sensors, which borrow from our knowledge of animal olfactory organs, for the early diagnosis of cancer from exhaled breath; c) developing a smart polymer fiber mesh that can attached to cancerous areas and release cancer-fighting drugs when an electromagnetic field is applying from outside the body; and d) developing redox polymer based nanoarchitectonic particles as effective Alzheimer's drug delivery vehicles to brains.

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1. FY 2013 List of Principal Investigators

NOTE:
・Underline names of investigators who belong to an overseas research institution.
・In case of researchers not listed in the latest report, attach "Biographical Sketch of a New Principal Investigator".

<Results at the end of FY2013>

Principal Investigators Total: 22

Name (Age)	Affiliation (Position title, department, organization)	Academic degree, specialty	Working hours (Total working hours: 100%) Work on center project: Research activities	Work on center project: Other activities	Others: Research activities	Others: Other activities	Starting date of project participation	Status of project participation (Describe in concrete terms)	Contributions by PIs from overseas research institutions
Director-General AONO, Masakazu* (69)	Director-General, International Center for Materials Nanoarchitectonics (MANA)	Ph.D. University of Tokyo, 1972 NanoSciene and nanotechnology	60%	15%	15%	10%	10/1/2007	a) usually stays at the center	－
BANDO, Yoshio*(66)	Chief Operating Officer, International Center for Materials Nanoarchitectonics (MANA)	Ph.D. Osaka University, 1975 Nanomaterials and transmission electron microscope	70%	30%	0%	0%	10/1/2007	a) usually stays at the center	－
SASAKI, Takayoshi*(58)	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. (Science) University of Tokyo, 1986 Nanosheet and soft chemistry	100%	0%	0%	0%	10/1/2007	a) usually stays at the center	－
ARIGA, Katsuhiko*(51)	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. Tokyo Inst. Tech., 1990 Supramolecular chemistry and surface science	100%	0%	0%	0%	10/1/2007	a) usually stays at the center	－

CHIKYOW, Toyohiro (54)	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. Waseda University, 1989 Semiconductor and electric materials	70%	10%	10%	10%	4/1/2011	a) usually stays at the center	－
GOLBERG, Dmitri* (53)	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. Moscow Institute for Ferrous Metallurgy, 1990 Nanotubes and nanowires	100%	0%	0%	0%	10/1/2007	a) usually stays at the center	－
<u>WANG, Zhong Lin *(52)</u>	Professor, School of Materials Science and Engineering, Georgia Institute of Technology	Ph.D. Arizona State University, 1987 Nano chemistry and nanodevices	15%	5%	60%	20%	10/1/2007	b) stays at the center twice a year, usually at GIT satellite	To conduct research themes of MANA and to accept a young researcher from MANA (1 month)
<u>GIMZEWSKI, James K. *(62)</u>	Dinstinguished Professor, Chemistry & Biochem. Dept., UCLA Director, Nano/Pico Characterization Lab, UCLA California NanoSystems Inst.	Ph.D. (Physical Chemistry) Univ. of Strathclyde, 1977 Nanoscience and nanobio	23%	3%	67%	7%	10/1/2007	b) stays at the center several times a year, usually at UCLA satellite	To conduct research themes of MANA
HASEGAWA, Tsuyoshi (51)	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. (Science) Tokyo Inst. Tech., 1996 Nano-devices	100%	0%	0%	0%	10/1/2007	a) usually stays at the center	－
HU, Xiao (52)	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. (Physics) University of Tokyo, 1990 Condensed matter physics	100%	0%	0%	0%	10/1/2007	a) usually stays at the center	－

JOACHIM Christian*(56)	Centre National de la Recherche Scientifique (CNRS) Lab: CEMES (UPR8011) Toulouse (France)	Ph.D. in Applied Mathematic Ph.D. in Quantum physics, computer science and nanoscience	18%	3%	72%	7%	10/1/2007	b) stays at the center several times a year, usually at CNRS satellite	To conduct research themes of MANA
NAKAYAMA, Tomonobu (52)	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. in physics University of Tokyo,1999 Scanning probe microscopy	100%	0%	0%	0%	10/1/2008	a) usually stays at the center	–
TAKAYANAGI, Hideaki*(62)	Professor, Tokyo University of Science, Research Institute for Science and Technology	Ph.D. (science) University of Tokyo, 1987 Mesoscopic superconductivity and quantum information physics	50%	10%	20%	20%	10/1/2007	b) stays at the center for six days a month	–
TSUKAGOSHI, Kazuhito (46)	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. Osaka University,1995 Nano electronics	90%	0%	10%	0%	1/1/2009	a) usually stays at the center	–
YE, Jinhua* (51)	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. University of Tokyo, 1990 Photocatalyst, eco-materials	30%	0%	50%	20%	10/1/2007	a) usually stays at the center	–
TAKADA, Kazunori* (52)	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. Osaka University, 1986 Solid-state chemistry	30%	0%	70%	0%	1/1/2010	a) usually stays at the center	–
UOSAKI, Kohei* (67)	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. Flinders Univ., 1977 Surface physical chemistry	80%	20%	0%	0%	7/1/2008	a) usually stays at the center	–

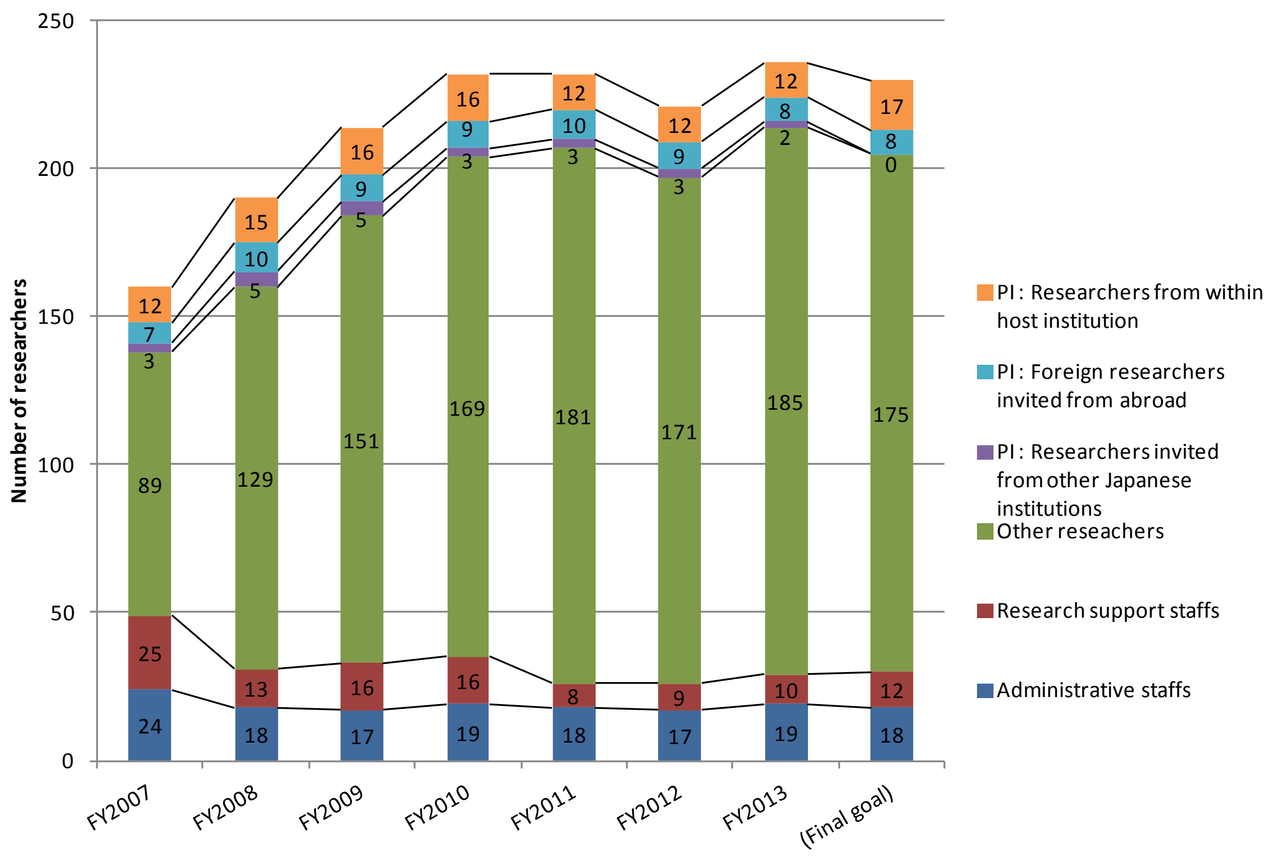
Appendix 1

YAGHI, Omar* (49)	The James and Neeltje Tretter Professor of Chemistry, UC Berkley	Ph.D. University of Illinois, 1990 Nanostructure of organic materials	30%	0%	60%	10%	3/10/2008	b) usually stays at UCB c) holds a videoconference from UCB once a week.	To conduct research themes of MANA and to supervise a research group of MANA
AOYAGI, Takao* (54)	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. Tokyo Inst. Tech., 1993 Biomaterials	70%	0%	20%	10%	9/1/2010	a) usually stays at the center	–
CHEN, Guoping (48)	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. Kyoto University, 1997 Biomaterials and tissue engineering	100%	0%	0%	0%	4/1/2011	a) usually stays at the center	–
NAGASAKI, Yukio*(54)	Professor, Department of Materials Science and Master's Master's School of Medical Sciences, University of Tsukuba	Ph.D. Tokyo University of Science, 1986 Biomaterials and polymer chemistry	20%	0%	70%	10%	10/1/2007	b) usually stays at the University of Tsukuba satellite	–
Françoise M. Winnik* (62)	Faculty of Pharmacy and Department of Chemistry, University of Montreal, Canada	Ph.D. (Chemistry) Univ. of Toronto, 1979 Polymer chemistry and photochemistry	40%	10%	40%	10%	4/1/2011	b) stays at the center for five months a year	To conduct research themes of MANA

World Premier International Research Center Initiative (WPI)

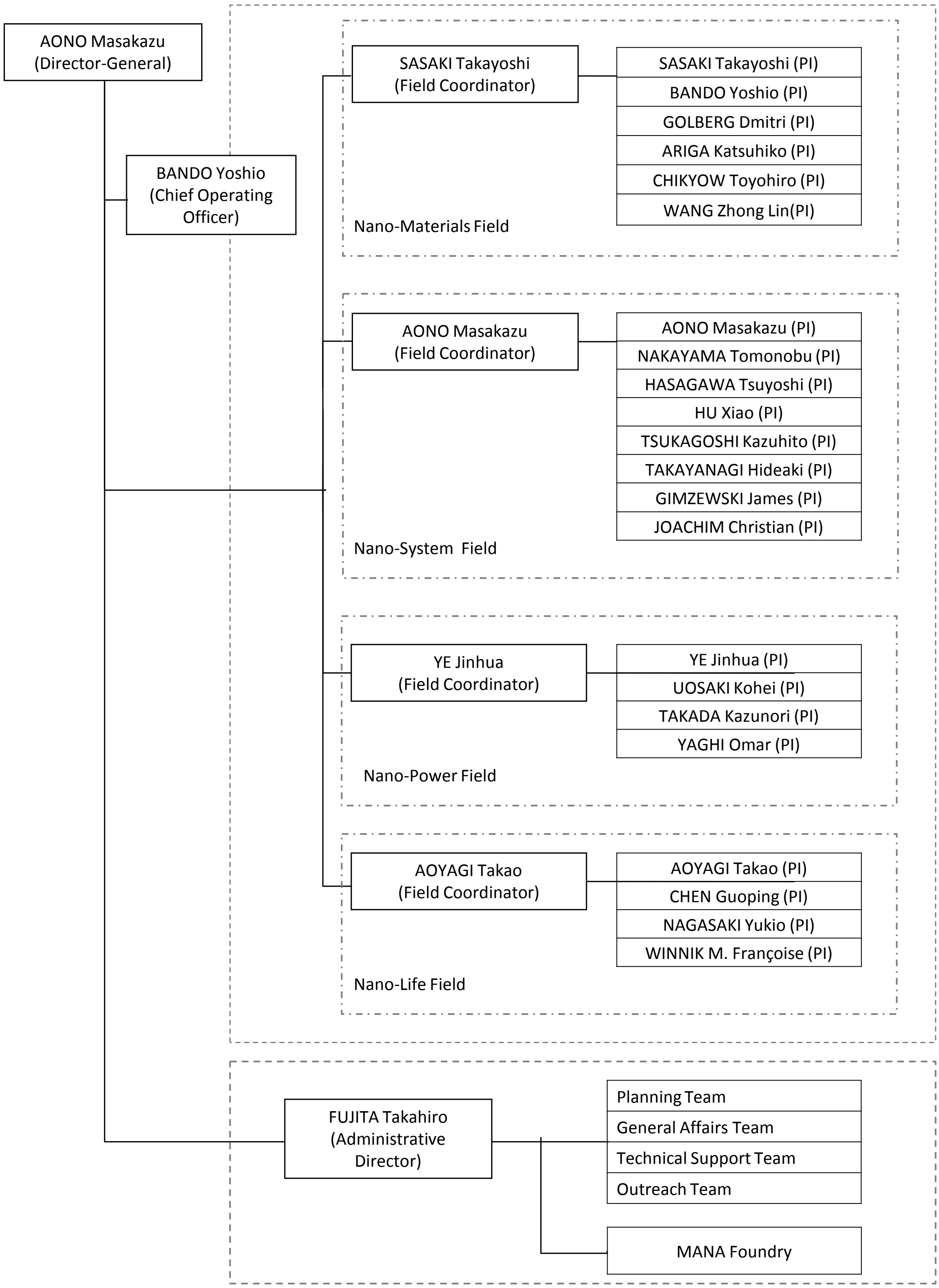
2. Annual transition in the number of Center personnel

*Make a graph of the annual transition in the number of center personnel since the start of project.



World Premier International Research Center Initiative (WPI)

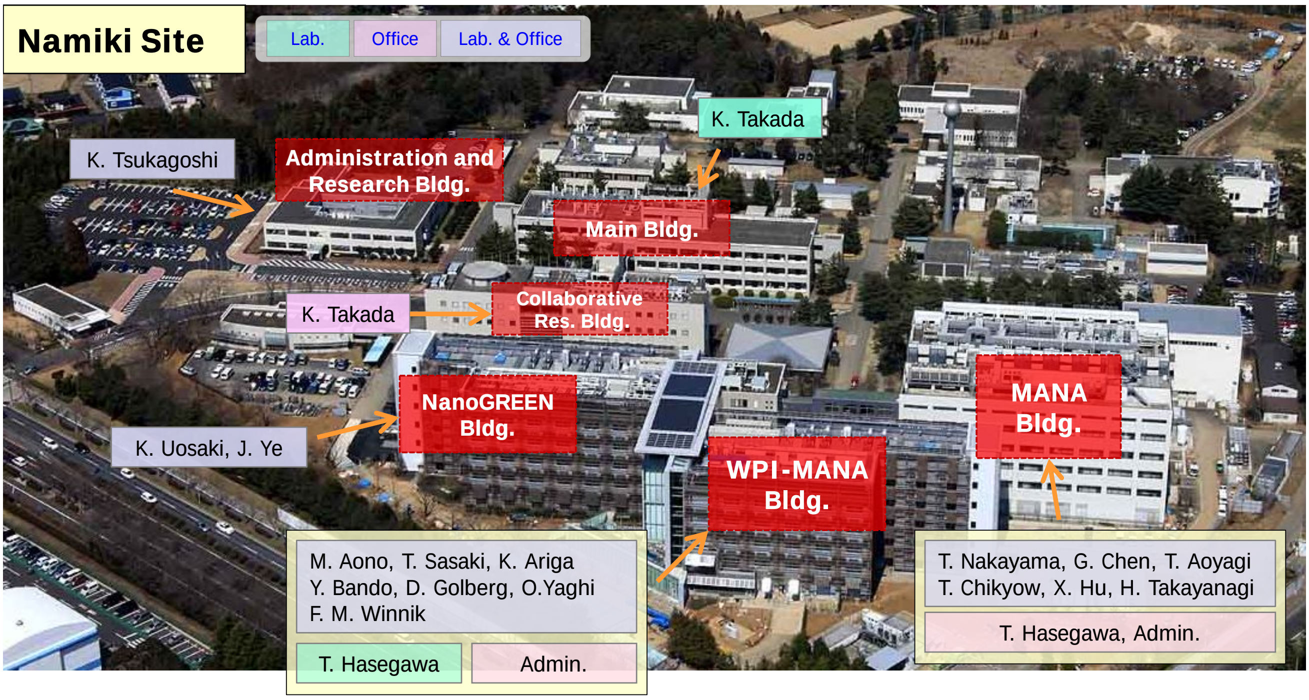
3. Diagram of management system



World Premier International Research Center Initiative (WPI)

4. Campus map

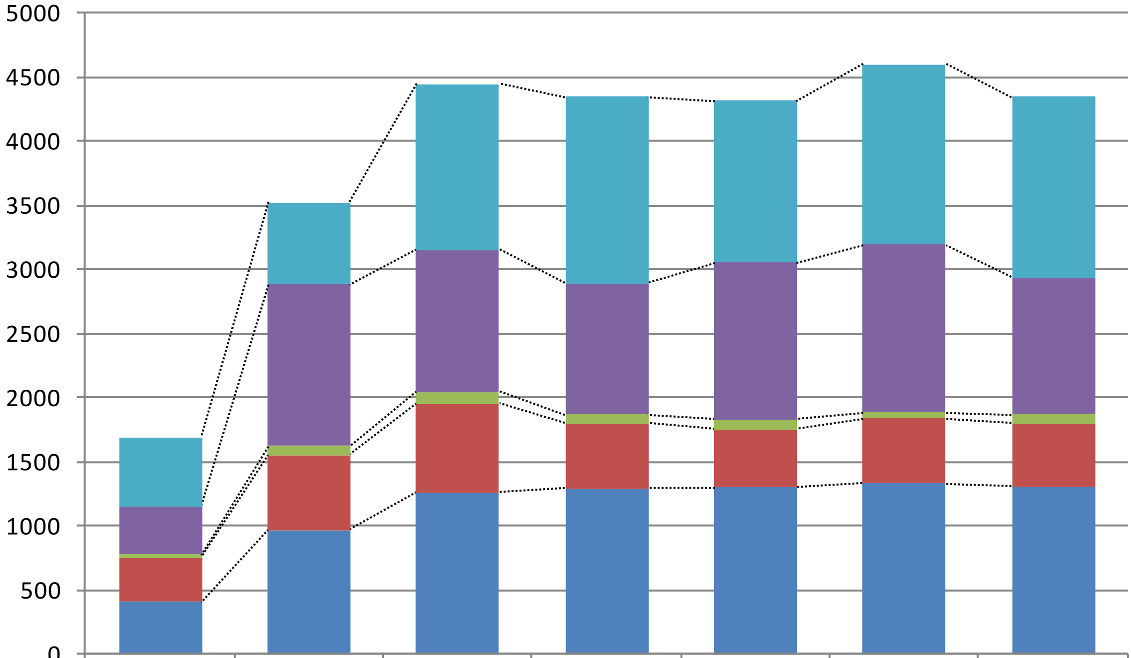
World Premier International Research Center (WPI) Initiative



World Premier International Research Center Initiative (WPI)

5. Annual transition in the amounts of project funding

*Make a graph of the transition in the number of overall project funding.



	FY2007	FY2008	FY2009	FY2010	FY2011	FY2012	FY2013
Reseach projects	537	639	1290	1455	1259	1406	1404
Equipment	380	1258	1112	1018	1226	1302	1066
Travel	18	75	92	72	70	47	75
Project activities	350	584	689	506	460	513	487
Personnel	408	970	1266	1295	1300	1330	1312

6. FY2013 Project Expenditures (the exchange rate used: 1USD=100JPY)

Overall project funding

Cost Items	Details	Costs (10,000 dollars)
Personnel	Center director and Administrative director	32
	Principal investigators (no. of persons): 14	157
	Other researchers (no. of persons): 185	990
	Research support staffs (no. of persons): 7	45
	Administrative staffs (no. of persons): 29	88
	Total	1312
Project activities	Gratuities and honoraria paid to invited principal investigators (no. of persons): 48	18
	Cost of dispatching scientists (no. of persons): 3	12
	Research startup cost (no. of persons): 27	52
	Cost of satellite organizations (no. of satellite organizations): 6	82
	Cost of international symposiums (no. of symposiums): 4	9
	Rental fees for facilities	0
	Cost of consumables	25
	Cost of utilities	244
	Other costs	45
	Total	487
Travel	Domestic travel costs	2
	Overseas travel costs	7
	Travel and accommodations cost for invited scientists (no. of domestic scientists): 108 (no. of overseas scientists): 108	59
	Travel cost for scientists on secondment (no. of domestic scientists): 4 (no. of overseas scientists): 23	7
	Total	75
Equipment	Depreciation of buildings	409
	Depreciation of equipment	657
	Total	1066
Other research projects	Projects supported by other government subsidies, etc.	647
	Commissioned research projects, etc.	398
	Grants-in-Aid for Scientific Research, etc.	359
	Total	1404
Total		4344

Ten thousand dollars

WPI grant	1,334
Costs of establishing and maintaining facilities	0
Cost of equipment procured	604
Name of equipment: SEM for super fine material evaluation Number of units: 1 Costs paid:	66
Name of equipment: Chromatographic mass spectrometry system for catalysts Number of units: 1 Costs paid:	54
Name of equipment: Thin film thermal conductivity measurement apparatus Number of units: 1 Costs paid:	36
Name of equipment: Thin film battery materials fabrication apparatus Number of units: 1 Costs paid:	29
Name of equipment: Organometallic chemical pressure deposition apparatus Number of units: 1 Costs paid:	23
Name of equipment: Hall resistance measurment apparatus Number of units: 1 Costs paid:	19
Name of equipment: Energy dispersive X-ray analyzer for low voltage SEM Number of units: 1 Costs paid:	17
Others	360

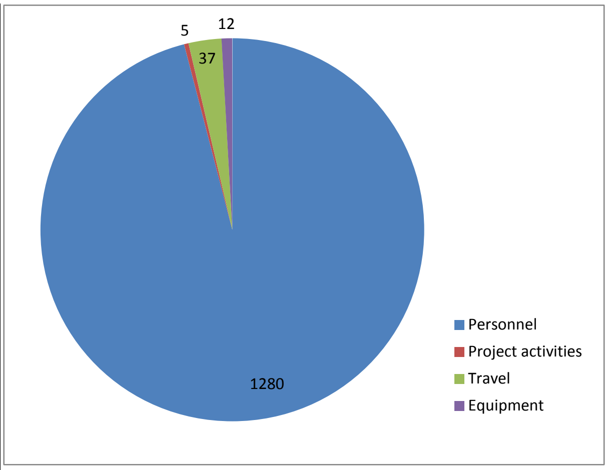
ii) Costs of Satellites and Partner institutions

Cost Items	Details	Costs (10,000 dollars)
Personnel	Principal investigators (no. of persons): 1	
	Other researchers (no. of persons): 15	
	Research support staffs (no. of persons): 2	
	Administrative staffs (no. of persons): 5	
	Total	63
Project activities		7
Travel		2
Equipment		0
Other research projects		10
Total		82

7. FY2013 WPI Grant Expenditures (the exchange rate used: 1USD=100JPY)

i) Overall expenditures

Cost Items	Details	Costs (10,000 dollars)
Personnel	Center director and Administrative director	32
	Principal investigators (no. of person): 14	157
	Other researchers (no. of person): 185	958
	Research support staffs (no. of person): 7	45
	Administrative staffs (no. of person): 29	88
	Total	1280
Project activities	Gratuities and honoraria paid to invited principal investigators (no. of person): 0	0
	Cost of dispatching scientists (no. of person): 0	0
	Research startup cost (no. of person): 0	0
	Cost of satellite organizations (no. of satellite organization): 0	0
	Cost of international symposiums (no. of symposiums): 1	5
	Rental fees for facilities	0
	Cost of consumables	0
	Cost of utilities	0
	Other costs	0
	Total	5
Travel	Domestic travel costs	1
	Overseas travel costs	9
	Travel and accommodations cost for invited scientists (no. of domestic scientists): 12 (no. of overseas scientists): 43	27
	Travel cost for scientists on secondment (no. of domestic scientists): 0 (no. of overseas scientists): 0	0
	Total	37
Equipment	Cost of equipment procured	12
	Total	12
Total		1334



ii) Costs of Satellites and Partner institutions

Cost Items	Details	Costs (10,000 dollars)
Personnel	Principal investigators (no. of person)	
	Other researchers (no. of person)	
	Research support staffs (no. of person)	
	Administrative staffs (no. of person)	
	Total	0
Project activities		
Travel		
Equipment		
Total		0

World Premier International Research Center Initiative (WPI)

1. List of papers underscoring each research achievement

* List papers underscoring each research achievement listed in the item 2-1 “Research results to date” (up to 40 papers) and provide a description of the significance of each (within 10 lines).
* For each, write the author name(s); year of publication; journal name, volume, page(s), and article title. Any listing order may be used as long as format is the same. If a paper has many authors, underline those affiliated with the Center.
* If a paper has many authors (say, more than 10), all of their names do not need to be listed.
* Place an asterisk (*) in front of those results that could only have been achieved by a WPI center.

I) 40 Papers Related to the Selected 20 Research Results Described in the Text

Note 1: The following 40 papers are selected from 2,362 papers that MANA has published in 2007-2013, so that all the 40 papers are related to those results that could only have been achieved by a WPI center. Therefore, an asterisk (*) is placed in front of all the 40 papers.

Note 2: The 40 papers are classified into 20 Research results [1]-[20] described in the text.

Research result [1]

*1. F. Geng, R. Ma, A. Nakamura, K. Akatsuka, Y. Ebina, Y. Yamauchi, N. Miyamoto, Y. Tateyama, and T. Sasaki, “Unusually stable ~100-fold reversible and instantaneous swelling of inorganic layered materials”, *Nature Commun.* **4** (2013) 1632.

A massive monolithic swelling of layered materials has been achieved in aqueous solution of 2-dimethylaminoethanol (DMAE), which was up to 100-fold with the gallery spacing increased from 0.9 nm to 90 nm. With quantitative analysis, it was determined that the largely expanded space was primarily occupied with H_2O along with minor trace of the DMAE. The swollen phase was unusually stable with no obvious observation of peeling or translational shifts during the swelling process, maintaining a nearly perfect three-dimensional lattice structure of >3000 layers. First-principle simulations of the molecules in the gallery yielded a long-range directional structuring of the H_2O molecules that may help to stabilize the highly swollen structure. The crystals could also instantaneously shrink back to their original sizes.

*2. F. Geng, R. Ma, Y. Ebina, Y. Yamauchi, N. Miyamoto and T. Sasaki, “Gigantic swelling of inorganic layered materials: A bridge to molecularly thin two-dimensional nanosheets”, *J. Am. Chem. Soc.* **136** (2014) 5491.

The macroscopic swelling could be realized in a wide variety of amines, ranging from primary amine, tertiary amine, to quaternary ammonium hydroxide, with little dependence on ion identity. The ammonium ion intercalation was mostly determined by the acid-base equilibrium and the accompany H_2O inflow was governed by osmotic pressure balance between the gallery and the solution environment, both of which are substantially molarity dependent. Therefore, in most cases, the ammonium ion intercalation saturated at a value of 37% relative to the exchange capacity, and the maximum swelling degree was ~100-fold with gallery expansion of ~90 nm. Although the swelling process was unselective, the nature of the intercalated ion was critical to the stability of the resulting swollen structure; that is, ions of higher polarity and smaller size helped stabilize the highly expanded structure, while ions of low polarity and larger size readily led to exfoliation.

*3. R. Ma, T. Sasaki, “Nanosheets of oxides and hydroxides: Ultimate 2D charge-bearing functional crystallites”, *Adv. Mater.* **22** (2010) 5082. (Invited review article).

This is an invited review article focusing on the recent progress on oxide and hydroxide nanosheets as an intriguing class of graphene-like 2D materials. A wide variety of monodisperse nanosheets have been produced by exfoliating layered precursory compounds via osmotic swelling. The nanosheets were found to show new and enhanced physicochemical properties associated with the exceptionally unique structure. Thus the nanosheets are very useful as functional building blocks. Various solution-based processes can be applied to organize them into precisely controlled nanostructures such as nanofilms, hollow nanospheres, nanotubes, nanocomposites and so on. Through this approach, a range of functional materials and nanodevices have been developed; photocatalytic coating films, high-k nanofilms, electrode matereials.

Research result [2]

*4. M. Osada, G. Takanashi, B. W. Li, K. Akatsuka, Y. Ebina, K. Ono, H. Funakubo, K. Takada, T. Sasaki, “Controlled polarizability of one-nanometer-thick oxide nanosheets for tailored, high-κ nano-dielectrics”, *Adv. Funct. Mater.* **22** (2011) 3482.

The ever-increasing requirements on smaller, higher-performance electronic devices result in efforts to incorporate new materials into microelectronics, in order to overcome the physical limits of current materials. In this context, the latest Semiconductor Roadmap predicts the implementation of high-κ ultrathin films (< 10 nm) in future applications. In this paper, we reported a rational approach to produce high performance nanodielectrics using 1-nm-thick oxide nanosheets. In titano-niobate nanosheets ($TiNbO_5$, Ti_2NbO_7, Ti_5NbO_{14}), the octahedral distortion inherent to site engineering by Nb incorporation resulted in a giant molecular polarizability, and their multilayer nanofilms exhibited high dielectric constant (160–320), the largest value being seen so far in high-κ nanofilms with the thickness down to 10 nm. Furthermore, these nanosheets offered simultaneous improvements in temperature dependence, lower loss and leakage current. Our work provides a new recipe for designing nanodielectrics desirable for practical high-κ devices.

*5. M. Osada, T. Sasaki, “Two-dimensional dielectric nanosheets: Novel nanoelectronics from nanocrystal building blocks”, *Adv. Mater.* **24** (2012) 210.

Two-dimensional (2D) nanosheets, which possess atomic or molecular thickness and infinite planar lengths, are attractive for the use in next-generation nanoelectronics. Despite significant advances in graphene-like 2D materials, it remains a challenge to explore high-□dielectric counterparts of graphene, which are essential for many devices such as memories, capacitors, and gate devices. In this paper, we review the progress made in 2D dielectric oxide nanosheets, highlighting emerging functionalities in electronic applications. Ti- and perovskite-based nanosheets exhibit the highest permittivity (ε_r = 210~320) ever realized in all known dielectrics in the ultrathin region (< 10 nm). A layer-by-layer engineering using these oxide nanosheets promises unique possibilities in the design of thin-film device architectures, such as capacitors, transistors, artificial ferroelectrics and spin-electronics. Graphene is only the tip of the iceberg, and we are now starting to discover new possibilities afforded by 2D oxides.

Research result [3]

*6. T. Ohno, T. Hasegawa, T. Tsuruoka, K. Terabe, J. K. Gimzewski, M. Aono, “Short-term plasticity and long-term potentiation mimicked in single inorganic synapses”, *Nature Mater.* **10** (2011) 591.

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. In neuromorphic engineering, emulation of known neural behavior has proven to be difficult to implement in software because of the highly complex interconnected nature of thought processes. In this study, we have succeeded in emulating the synaptic behavior using a single Ag_2S-based atomic switch. The synaptic functions of both STP and LTP characteristics through the use of input pulse repetition time were demonstrated. The results have attracted much attention because it achieves dynamic memorization in a single device without the need of external preprogramming, indicating a potential for the further creation of artificial neural systems that emulate characteristics of human memory.

*7. R. Yang , K. Terabe , G. Liu , T. Tsuruoka , T. Hasegawa, J. K. Gimzewski , M. Aono, “On-demand nanodevice with electrical and neuromorphic multifunction realized by local ion migration", *ACS Nano* **6 (11)** (2012) 9515.

In this paper, electrical and neuromorphic multifunctions were demonstrated using a WO_{3-x}-based gapless-type atomic switch, in which migration of oxygen ions are controlled. The device showed a wide range of time scales of memorization, resistance switching, and rectification varying from volatile to permanent in a single device. The device, showing on-demand electrical and neuromorphic multifunction, has a unique paradigm shifting potential for the fabrication of configurable circuits, analog memories, digital neural fused networks, and more in one device architecture.

Research result [4]

*8. A. V. Avizienis, H. O. Sillin, C. Martin-Olmos, H.-H. Shieh, M. Aono, J. K. Gimzewski, "Neuromorphic atomic switch networks", *PLoS ONE* **7** (2012) e42772.

Conventional fabrication techniques are unable to efficiently generate electronic devices with the highly complex interconnectivity found in biological neuronal networks. In this paper, we demonstrated the physical realization of a self-assembled neuromorphic device comprised of over a billion interconnected atomic switch elements that exhibit synapse-like operational characteristics embedded in a complex network of silver nanowires. Observations of these atomic switch networks (ASN) were in agreement with recent theoretical predictions, while emergent behaviors akin to brain function are observed, namely spatially distributed memory, recurrent dynamics and the activation of feedforward subnetworks. These devices display the functional characteristics required for implementing unconventional, biologically and neurally inspired computational methodologies in a synthetic experimental system.

*9. A. Z. Stieg, A. V. Avizienis, H.O. Sillin, C. Martin-Olmos, M. Aono, J. K. Gimzewski, "Emergent criticality in complex Turing B-type atomic switch networks", *Adv. Mater.* **24** (2012) 286.

The operation of atomic switches as individual synapse-like devices has demonstrated the ability to process information with both short-term and long-term memorization in a single two terminal junction. In this paper, atomic switches were self-assembled within a highly interconnected network of silver nanowires similar in structure to Turing's "B-Type unorganized machine". These atomic switch networks (ASN) exhibited emergent criticality similar in nature to previously reported electrical activity of neuronal assemblies. Rapid fluctuations in electrical conductance display power law scaling of temporal correlation lengths that were attributed to dynamic reorganization of the interconnected electroionic network. These collective properties indicate a potential utility for real-time, multi-input processing of distributed sensory data through reservoir computing. We proposed these highly coupled, nonlinear electronic networks as an implementable hardware-based platform toward the creation of physically intelligent machines.

*10. H. O. Sillin, H.-H. Shieh, R. Aguilera, A. V. Avizienis, M. Aono, A. Z. Stieg, J. K. Gimzewski, "A theoretical and experimental study of neuromorphic atomic switch networks for reservoir computing", *Nanotechnology* **24** (2013) 384004.

Atomic switch networks (ASN) have been shown to generate network level dynamics that resemble those observed in biological neural networks. In this paper, we developed and validated a numerical model based on the synapse-like properties of individual atomic switches and the random nature of the network wiring. The reported results highlighted the possibility to functionalize the network plasticity, differences between an atomic switch in isolation and its behaviors in a network, as well as the effects of changing network connectivity on the observed nonlinear dynamics. To demonstrate their utility for computation, we subjected the simulated network to training within the framework of Reservoir Computing (RC) and showed initial evidence of the ASN acting as a reservoir which may be optimized for specific tasks. This work represented initial steps in a unified approach of experimentation and theory to make ASNs a uniquely scalable platform for neuromorphic computing.

Research result [5]

*11. Y. Okawa, S. K. Mandal, C. Hu, Y. Tateyama, S. Goedecker, S. Tsukamoto, T. Hasegawa, J. K. Gimzewski, M. Aono, “Chemical Wiring and Soldering toward All-Molecule Electronic Circuitry”, *J. Am. Chem. Soc.* **133** (2011) 8227.

This paper presents a novel method for connecting functional molecules with conductive nanowires. Stimulation with a tip of scanning tunneling microscope (STM) on a molecular layer of diacetylene compound can initiate chain polymerization of diacetylene molecules. Since the front edge of chain polymerization necessarily has a reactive chemical species, the created polymer nanowire forms chemical bonding with an encountered molecular element. We name this spontaneous reaction ‘chemical soldering’. First-principles theoretical calculations are used to investigate the structures and electronic properties of the connection. It is demonstrated that two conductive polymer nanowires are connected to a single phthalocyanine molecule. A resonant tunneling diode formed by this method is discussed.

*12. Y. Okawa, M. Akai-Kasaya, Y. Kuwahara, S. K. Mandal, M. Aono, “Controlled chain polymerisation and chemical soldering for single-molecule electronics”, *Nanoscale* **4** (2012) 3013.

The method of initiating chain polymerization using the tip of a scanning tunneling microscope is very useful for fabricating single conductive polymer chains at designated positions and thereby wiring single-molecules. In this feature article, developments in the controlled chain polymerization of diacetylene compounds and the electronic and structural properties of polydiacetylene chains are summarized. The “chemical soldering” technique, which enables the covalent connection of single polydiacetylene chains to single functional molecules, is also discussed. In addition to the review parts, this feature article also reports original data. For example, the connection of single conductive polydiacetylene chains to isolated single phthalocyanine molecules is demonstrated.

Research result [6]

*13. M. Nakaya, S. Tsukamoto, Y. Kuwahara, M. Aono, T. Nakayama, “Molecular-scale control of unbound and bound C_{60} for topochemical ultradense data storage in an ultrathin C_{60} film”, *Adv. Mater.* **22** (2010) 1622.

We found that the unbound and bound states of C_{60} molecules can be controlled reversibly at the single-molecule level in an ultrathin film of C_{60} using a tip of the scanning tunneling microscope (STM) at room temperature (RT). The reversible switching was almost perfectly controlled by changing the polarity of an electric field that was locally applied to any designated position on the film by the STM tip. From experimental and theoretical studies, we concluded that the excellent controllability is achieved owing to negative and positive ionizations of C_{60} molecules which cause electron donation into and electron removal from a bonding state between the molecules, respectively: Negative and positive ionization efficiently lower activation energies necessary for the formation of a bound state of C_{60} molecules and for the dissociation of the bound state, respectively. Also, this chemical reaction method enabled topochemical data storage with a bit size of a single C_{60} molecule (about 1 nm) and with a data density of 190 Tbit/in^2.

*14. M. Nakaya, M. Aono, T. Nakayama, “Molecular-scale size tuning of covalently bound assembly of C_{60} molecules”, *ACS Nano* **5** (2011) 7830.

Reference [6]-1 showed that, when a negative sample bias voltage is applied to a tunneling junction between the C_{60} film and the tip of a scanning tunneling microscope (STM), a C_{60} molecule beneath the tip covalently bonds to an adjacent molecule in the underneath layer. We further found that such a chemical reaction is not necessarily limited to the top and second layers of the C_{60} film and that the resulting C_{60} oligomer can be tuned to form a dimer, trimer, tetramer, or pentamer; the number of interconnected C_{60} molecules increases one by one upon increasing the magnitude of the local electric field under the STM tip. The created oligomers are linear chains of C_{60} molecules starting from the top layer and aligned toward the interface layer in the multilayer C_{60} films. The electrostatic negative ionization of C_{60} molecules and its spatial distribution in the multilayer C_{60} film are critical factors in achieving size-tuning in oligomerization.

Research result [7]

*15. Y.-J. Kim, M. Ebara, T. Aoyagi, "A smart nanofiber web that captures and release cells", *Angew. Chem. Int. Ed.* **51** (2012) 10537.

This paper describes a novel approach for encapsulating and releasing cells using a smart nanofiber web without using any cross-linking/degradation processes. The smart web was fabricated by an electrospinning method with a newly synthesized photo-cross-linkable temperature-responsive polymer. We demonstrated the ability to capture, encapsulate, and release cells by dynamically transforming the fibrous structure of the nanofibers into hydrogel-like structures by wrapping, swelling, and deswelling processes in response to alternations of external temperature. This novel nanofiber enables the facile encapsulation and on-demand release of cells in response to external signals.

*16. Y.-J. Kim, M. Ebara, T. Aoyagi, "A smart hyperthermia nanofiber with switchable drug release for inducing cancer apoptosis", *Adv. Func. Mater.* **23** (2013) 5753.

A smart hyperthermia nanofiber is described with simultaneous heat generation and drug release in response to 'on-off ' switching of alternating magnetic field (AMF) for induction of skin cancer apoptosis. The nanofiber is composed of a chemically-crosslinkable temperature-responsive polymer with an anticancer drug (doxorubicin; DOX) and magnetic nanoparticles (MNPs), which serve as a trigger of drug release and a source of heat, respectively. The 70% of human melanoma cells died in only 5 min application of AMF in the presence of the MNPs and DOX incorporated nanofibers by double effects of heat and drug. Taken together these advantages on both the nano- and macroscopic scale of nanofibers demonstrate that the dynamically and reversibly tunable structures have the potential to be utilized as a manipulative hyperthermia material as well as a switchable drug release platform by simple switching an AMF 'on' and 'off '.

Research result [8]

*17. L.-B. Vong, T. Tomita, T. Yoshitomi, H. Matsui, Y. Nagasaki, "An orally administered redox nanoparticle that accumulates in the colonic mucosa and reduces colitis in mice", *Gastroenterology* **143**, (2012) 1027.

Ulcerative colitis (UC) is a chronic inflammatory disease of the colon area. Current treatments include anti-inflammatory and immunosuppressive drugs; however, these medications are not always effective because of non-specific distribution, drug metabolism, and side effects. In this study, we have developed a novel nitroxide radical-containing nanoparticle (RNP), which scavenges reactive oxygen species (ROS). A size of approximately several tens of nanometers is important for long-term retention in colon. Here we found that the concentration of RNP in the colonic mucosa is almost 50 times higher than that of conventional low-molecular-weight drugs. Interestingly, an even higher accumulation of nanoparticles was observed in the colonic mucosa of dextran sodium sulfate (DSS)-induced colitis mice. Additionally, nanoparticles did not enter the bloodstream through the intestinal wall, despite its long-term retention in the colonic mucosa. Based on these characteristics, oral nanotherapy of RNP^{O} showed an extremely high therapeutic and safe effect on UC.

*18. K. Yoshimoto, M. Nishio, H. Sugasawa, Y. Nagasaki, "Direct observation of adsorption-induced inactivation of antibody fragments surrounded by mixed-PEG layer on a gold surface", *J. Am. Chem. Soc.* **132** (2010) 7982.

To examine the adsorption behavior of antibody fragments (Fab′) directly immobilized on a gold surface through S-Au linkage, analyses by surface plasmon resonance (SPR), fluorometry, and atomic force microscopy (AFM) with an excellent blocking technique by the consecutive treatments of long polyethylene glycol (PEG) and short-PEG, abbreviated as mixed-PEG layer formation, were performed. AFM studies provided direct information on the time-dependent decrease in the height of the immobilized Fab′ on the gold surface. In contrast, the coimmobilization of densely packed mixed-PEG tethered chains around the Fab′ on the gold surface suppressed the decrease in the height of Fab′, presumably indicating that the conformational and/or orientation change of Fab′ was suppressed by the coimmobilized mixed-PEG layer.

The new findings obtained in this study are expected to be useful for the improvement of the antibody fragment method and, thus, for the construction of high-performance immuno-surfaces.

Research result [9]

*19. G. Yoshikawa, T. Akiyama, S. Gautsch, P. Vettiger, H. Rohrer, "Nanomechanical membrane-type surface stress sensor", *Nano Letters* **11** (2011) 1044.

In this paper, we presented a membrane-type surface stress sensor (MSS), which is based on the piezoresistive read-out integrated in the sensor chip. The MSS originates from a conventional cantilever structure, while we found that the membrane-based structure can achieve much better performance. Evaluation of a prototype MSS used in the present experiments demonstrates a high sensitivity which is comparable with that of optical methods and a factor of more than 20 higher than that obtained with a standard piezoresistive cantilever. The finite element analyses indicate that changing dimensions of the membrane and beams can substantially increase the sensitivity further. Given the various conveniences and advantages of the integrated piezoresistive read-out, this platform is expected to open a new era of surface stress-based sensing.

*20. G. Yoshikawa, F. Loizeau, C. J. Lee, T. Akiyama, K. Shiba, S. Gautsch, T. Nakayama, P. Vettiger, N. F. de Rooij, M. Aono, "Double-side-coated nanomechanical membrane-type surface stress sensor (MSS) for one-chip- one-channel setup", *Langmuir* **29** (2013) 7551.

One of the major issues of nanomechanical sensors is the difficulty of coating receptor layers on their surfaces to which target molecules adsorb or react. To have measurable deflection, a single-side coating is commonly applied to cantilever-type geometry, and it requires specific methods or protocols, such as inkjet spotting or gold−thiol chemistry. In this paper, we demonstrated the feasibility of the double-side coating on a membrane-type surface stress sensor (MSS) and verify its working principle by both finite element analysis (FEA) and experiments. In addition, simple hand-operated dip coating is demonstrated as a proof of concept, achieving practical receptor layers without any complex instrumentation. The compatibility with double-side coating enables MSS to be applied to most standard assays in medical and biological fields.

Research result [10]

*21. H. Zhou, J. Guo, P. Li, Tongxiang Fan, Di Zhang, J. Ye, "Leaf-architectured 3D hierarchical artificial photosynthetic system of perovskite titanates towards CO_2 photoreduction into hydrocarbon fuels", *Scientific Reports* **3** (2013) 1667.

As a nano-life science-inspired nanoarchitectonics, here we report an unique strategy for constructing a promising 3D artificial photosynthetic system (APS) for efficient CO_2 photoreduction into hydrocarbon fuels. Natural leaf is a synergy of complex architectures and functional components to produce an amazing bio-machinery for photosynthesis. Mimicking the structural and functional elements in the natural photosynthesis should be promising to achieve an efficient artificial photosynthetic system. In this work, by using leaves of cherry tree as the template, we have successfully fabricated perovskite titanates (e.g. $SrTiO_3$, $CaTiO_3$) with a modified sol-gel method. After acid treatment and calcination at 600°C, organics could be removed completely, leaving crystalline perovskite titanates. The obtained material preserves the morphological features of leaf at multi-scaled levels. It was found that leaf-architectured $SrTiO_3$ exhibits about a 3.5~4 fold improvement in activities than the referenced $SrTiO_3$ synthesized without templates. A further mechanism study revealed that the enhanced conversion efficiency of CO_2 into hydrocarbon fuels can be attributed to the synergistic effect of efficient mass flow/light harvesting network relying on the morphological replacement of a concept prototype-leaf's 3D architecture.

*22. Z. Yi, J. Ye, N. Kikugawa, T. Kako, S. Ouyang, H. Stuart-Williams, H. Yang, J. Cao, W. Luo, Z. Li, Y. Liu, R. L. Withers, "An orthophosphate semiconductor with photooxidation properties under visible-light irradiation", *Nature Mater.* **9** (2010) 559.

The search for active semiconductor photocatalysts that directly split water under visible-light irradiation remains one of the most challenging tasks for solar-energy utilization. Over the past 30 years, the search for such materials has focused mainly on metal-ion substitution as in $In_{1-x}Ni_xTaO_4$ and (V-; Fe- or Mn-)TiO_2, non-metal-ion substitution as in $TiO_{2-x}N_x$ and $Sm_2Ti_2O_5S_2$ or solid-solution fabrication as in $(Ga_{1-x}Zn_x)(N_{1-x}O_x)$ and ZnS–$CuInS_2$–$AgInS_2$. Here we report a new photocatalyst Ag_3PO_4, which was developed by incorporating p block element into a simple AgO oxide with narrow band gap. The new photocatalyst showed extremely high quantum yield (~90% at 420 nm) towards water oxidation, which is one of the key process for artificial photosynthesis, under visible light irradiation. The obtained quantum yield marked the world's highest record, approaching that in natural photosynthesis. The new photocatalyst also showed amazing activity in decomposition of organic contaminants in aqueous solution. This study not only supplies a new strategy for developing highly efficient visible-light-driven photocatalysts, but also shows a great step towards the realization of an artificial photosynthetic system.

Research result [11]

*23. Q.-F. Liang, Z. Wang, X. Hu, "Manipulation of Majorana fermions by point-like gate voltage in the vortex state of a topological superconductor", *Europhys. Lett.* **99** (2012) 50004. [Editor's Choice].

A vortex in a topological superconductor induces two Majorana fermions (MFs), one in the core and the other at the sample edge. Here we demonstrate that edge MFs can be transported and braided by turning gate voltages on and off at the point-like constriction junctions between samples. The controllable high mobility of edge MFs is due to the topological property, namely an edge MF appears only when the sample perimeter includes odd number of vortices. As shown explicitly by solving the time-dependent Bogoliubov-de Gennes equation, disturbance to the quantum coherence of MFs during braiding is negligibly small in this scheme due to the point-like application of the gate voltage. The present work bridges for the first time the fundamental topological features of edge MFs and their adiabatic dynamics which is important for performing topological quantum computation.

*24. T. Uchihashi, P. Mishra, M. Aono, T. Nakayama, "Macroscopic superconducting current through a silicon surface reconstruction with indium adatoms: Si(111)-($\sqrt{7}\times\sqrt{3}$)-In", *Phys. Rev. Lett.* **107** (2011) 207001. [Highlighted as an Editor's Suggestion and a Viewpoint in Physics].

Macroscopic and robust supercurrents are observed by direct electron transport measurements on a silicon surface reconstruction with In adatoms [Si(111)-($\sqrt{7}\times\sqrt{3}$)-In]. The superconducting transition manifests itself as an emergence of the zero resistance state below 2.8 K. *I-V* characteristics exhibit sharp and hysteretic switching between superconducting and normal states with well-defined critical and retrapping currents. The two-dimensional (2D) critical current density $J_{2D,c}$ is estimated to be as high as 1.8 A/m at 1.8 K. The temperature dependence of $J_{2D,c}$ indicates that the surface atomic steps play the role of strongly coupled Josephson junctions.

Research result [12]

*25. D. R. Bowler, T. Miyazaki, "Calculation for millions of atoms with density functional theory: linear-scaling shows its potential", *J. Phys.: Condens. Matter* **22** (2010) 074207.

This paper demonstrates that density functional theory (DFT) calculations are possible on systems with over two million atoms. The weak scaling (scaling with fixed computational load per process) is perfect, showing the same time per process for systems with 4,096 atoms and systems with 2,000,000 atoms. The strong scaling (fixed system size with increasing number of nodes) is extremely high. Overall, the paper demonstrates the potential of linear scaling DFT methods.

*26. D. R. Bowler, T. Miyazaki, "O(N) methods in electronic structure calculations", *Rep. Prog. Phys.* **75** (2012) 036503.

A comprehensive overview of linear scaling approaches to electronic structure, covering DFT and quantum chemistry methods, and discussing technical implementation as well as algorithms and approaches. The existing applications are discussed, and five significant challenges to linear scaling are identified and discussed. This paper has become one of the standard references in the field.

Research results [13]

*27. H. Sasakura, S. Kuramitsu, Y. Hayashi, K. Tanaka, T. Akazaki, E. Hanamura, R. Inoue, H. Takayanagi, Y. Asano, H. Kumano, I. Suemune, “Nb/n-InGaAs/p-InP superconductor/ semiconductor-diode light emitting device” *Phys. Rev. Lett.* **107**(2011) 157403.

We experimentally demonstrate Cooper pairs’ drastic enhancement of the band-to-band radiative recombination rate in a semiconductor. Electron Cooper pairs injected from a superconducting electrode into an active layer by the proximity effect recombine with holes injected from a p-type electrode. The recombination of a Cooper pair with p-type carriers dramatically increases the photon generation probability of a light-emitting diode in the optical-fiber communication band. The measured radiative decay time rapidly decreases with decreasing temperature below the superconducting transition temperature of the niobium electrodes. Our results indicate the possibility to open up new interdisciplinary fields between superconductivity and optoelectronics.

*28. Y. Asano, I. Suemune, H. Takayanagi, and E. Hanamura, “Luminescence of a Cooper Pair”, *Phys. Rev. Lett*. **103** (2009) 187001.

This paper theoretically discusses the photon emission spectra of a superconducting p-n junction. On the basis of the second order perturbation theory for electron-photon interaction, we show that the recombination of a Cooper pair with two p-type carriers causes enhancement of the luminescence intensity. The calculated results of photon emission spectra explain characteristic features of observed signal in an recent experiment. Our results indicate high functionalities of superconducting light-emitting devices.

Research result [14]

*29. S. Aikawa, T. Nabatame, K. Tsukagoshi, “Doping control in In-X-O metal oxide semiconductors for thin-film transistor applications”, *Appl. Phys. Lett.* **103** (2013) 172105.

For next generation amorphous metal-oxide thin film transistor (a-OxTFT), we found that the stability of the transistor properties strongly depends on the bond-dissociation energy of dopant element in InOx film. By incorporating the dopant with higher bond-dissociation energy, the film becomes less sensitive to oxygen partial pressure used during film formation processs. Because the doped silicon in amorphous In_2O_3-based thin films is found to suppress the formation of unstable oxygen vacancies, silicon doped metal oxide TFTs (SiM-OxTFTs) behave as the stable high-performance a-OxTFT with highly suppressed off-state current.

*30. N. Mitoma, S. Aikawa, X. Gao, T. Kizu, M. Shimizu, M.-F. Lin, T. Nabatame, K. Tsukagoshi, “Stable amorphous In_2O_3-based thin-film transistors by incorporating SiO_2 to suppress oxygen vacancies”, *Appl. Phys. Lett*. **104** (2014) 102103.

Incorporating SiO_2 into amorphous In_2O_3-based thin films is found to suppress the formation of unstable oxygen vacancies. The SiO_2 in InOx film suppressed the de-population of donor-like traps and charge-carrier trapping at the semiconductor/insulator interface, which led to stable TFT operation. As the SiO_2 content increased, the activation energy in the current off region greatly increased and the density of state (DOS) at the band tail became small, resulting in making transistor properties more stable against electrical and thermal stresses. Particularly, the subthreshold swing and turn-on voltage of the transistor have been drastically improved. The results of the present study aid the mass production of highly stable amorphous InO-based thin-film transistors.

Research result [15]

*31. H. Zhang, Y. Yang, Y. Su, J. Chen, C. Hu, Z. Wu, Y. Liu, C. P. Wong, Y. Bando, Z. L. Wang, "Triboelectric nanogenerator as self-powered active sensors for detecting liquid/gaseous water/ ethanol", *Nano Energy* **2** (2013) 693.

Triboelectric nanogenreator has been demonstrated as an effective means for converting mechanical energy. Since the effectiveness of triboelectric charged surface being charged is strongly dependent on the surface adsorbed molecules, we show that the triboelectric nanogenerator, made of polyamide 6, 6 (PA) film or polytetrafluoroethylene (PTFE) film, can serve as a self-powered active sensor for detecting water or ethanol in gas or liquid phase. The performance of the active sensors has been understood in reference to the levels of wettability of solid polymer surfaces. This new approach for sensing could be advantageous of simple fabrication, low-cost and easy application.

Research result [16]

*32. T. Nakayama, O. Kubo, Y. Shingaya, S. Higuchi, T. Hasegawa, C.-S. Jiang, T. Okuda, Y. Kuwahara, K. Takami, M. Aono, "Development and application of multiple-probe scanning probe micro- scopes", *Advanced Materials* **24** (2012) 1675.

We reviewed multiple-probe scanning probe microscopes (MP-SPMs), in which two, three or four scanning tunneling microscope (STM) or atomic force microscope (AFM) probes are operated independently. Each probe in an MP-SPM is used not only for observing high-resolution STM or AFM images but also for forming an electrical contact enabling nanoscale local electrical conductivity measurement. We developed the world's first double-probe STM (DP-STM) and directly observed ballistic transport of electrons through one-dimensional metal nanowires and carbon nanotubes. Quadruple-probe STM (QP-STM) has also been developed and clarified the conductivity of two-dimensionally polymerized C_{60} films without the ambiguity of contact resistance between the probe and sample. Moreover, a quadruple-probe AFM (QP-AFM) with four tuning-fork-type self-detection force sensor has been developed to measure the conductivity of a nanostructure on an insulating substrate.

Research result [17]

*33. M.S. Wang, D. Golberg, Y. Bando, "Tensile tests on individual single-walled carbon nanotubes: Linking nanotube strength with its defects", *Adv. Mater.* **22** (2010) 4071.

In this work, we present the first reported set of tensile strength measurements on twelve individual carbon singlewalled nanotubes (SWNTs). We applied a technique that is able to produce an individual SWNT by a consecutive stepwise in situ electrical breakdown of multiwalled C nanotube (MWNT) shells inside a high resolution transmission electron microscope (HRTEM) equipped with a conducting atomic force microscope (AFM) unit. The tensile properties of thus produced tubes were then investigated by correlating the tensile strength and types, and sites of structural defects under direct tube lattice imaging (spatial HRTEM resolution was ~1.7 Å). The SWNTs of various structures/morphologies exhibited different fracture strength ranging from 25 GPa to ~100 GPa, the latter approaching the theoretical limit. The tubes with relatively higher strength possessed visibly perfect shell structures. By contrast, significant strength reduction in low-strength samples was attributed to clearly identifiable shell structural defects, e.g. atomic steps containing spatially separated 5/7 C-ring pairs.

*34. X.L. Wei, M.S. Wang, Y. Bando, D. Golberg, "Tensile tests on individual multi-walled boron nitride nanotubes", *Adv. Mater.* **22** (2010) 4895.

Herein we reported the first detailed measurements regarding the mechanical responses of individual multi-walled boron nitride nanotubes (BNNTs) under tensile loading or pulling-out of nested multi-walled BNNTs inside a high-resolution transmission electron microscope (HRTEM) equipped with an integrated atomic force microscope (AFM) system within the side-entry transmission electron microscope (TEM) holder. By measuring the applied forces and tube lengths until tubes broke, we obtained real stress-strain curves from which the ultimate tensile strengths and strains, and the Young's modulus of tubes were directly calculated. The tensile strength reached 33 GPa, and the Young's modulus might be up to 1.3 TPa. Also, under parallel HRTEM observations we unambiguously determined the breaking sites, broken shell number and tube diameters, and also the atomic structures of tubes. This enabled us to explore the effects of experimental conditions (such as mechanical system misalignment and the tube atomic structures) on the first time measured mechanical quantities.

Research result [18]

*35. C. Li, T. Sato, Y. Yamauchi, “Electrochemical synthesis of one-dimensional mesoporous Pt nanorods utilizing surfactant- micelle assembly in confined space”, *Angew. Chem. Int. Ed.* **52** (2013) 8050.

One-dimensional (1D) metallic nanostructures, particularly those composed of noble metals, have sparked great scientific interest for practical applications, owing to their uniquely anisotropic structure. In recent advances in energy conversion materials, one-dimensional (1D) materials have been widely demonstrated to be particularly effective as electrocatalysts for the methanol oxidation reaction (MOR) and oxygen reduction reaction (ORR) at low cost. We successfully designed self-supported 1D mesoporous Pt nanowires by all-wet electrochemical synthesis inside the confined space of PC membrane. The 1D motifs exhibited high activity and CO-tolerant performance in the electro-oxidation of methanol, and our MPNRs showed only 31 % loss of ESCA even after harsh accelerated durability test. Thus, the self-supported mesoporous structures are highly desired in high activity and stability for the large surface area with less aggregation and ripening of Pt nanoparticles. Such geometrically favorable factors will provide a new avenue in designing highly efficient electrocatalysts used in artificial energy conversion systems.

*36. H. Ataee-Esfahani, M. Imura, Y. Yamauchi, “All-metal mesoporous nanocolloids: Solution-phase synthesis of core-shell Pd@Pt nanoparticles with a designed concave surface”, *Angew. Chem. Int. Ed.* **52** (2013) 13611.

In recent years, many efforts have been made for the synthesis of shape- and size-controlled metal colloidal nanoparticles which can bring out novel physical and chemical properties. Bimetallic nanoparticles have often shown superior catalytic activities over their monometallic counterparts, due to the synergetic effect of the second metal. However, heterogeneous bimetallic nanoparticles, such as core-shell structures, are difficult to be prepared in comparison with monometallic nanoparticles. Our target in this study is the synthesis of ‘mesoporous metal nanoparticles’ with high indexed facets which can provide high catalytic active sites for catalytic reactions, especially in electro-oxidation reactions. Mesoporous metal nanoparticles with concave surface can provide not only high surface area but also abundant active sites for catalytic reactions. Our approach based on all-wet process in low concentrated surfactant solution is widely applicable to other metal and alloy systems and also will be utilized as a promising approach for industrial mass-production.

Research result [19]

*37. J. Labuta, S. Ishihara, T. Šikorský, Z. Futera, A. Shundo, L. Hanyková, J. V. Burda, K. Ariga, J. P. Hill, “NMR spectroscopic detection of chirality and enantiopurity in referenced systems without formation of diastereomers”, *Nature Commun.* **4** (2013) 2188.

In drug manufacturing, it is also important to determine their optical purity in each stage of synthesis. This research reports a novel technique for determining optical purity by utilizing nuclear magnetic resonance (NMR) and a new symmetrically-structured porphyrin resolving agent. The molecules do not form structural isomers (diastereomers) even when they bind with a chiral object of measurement. The mechanism of this technique is based on the breakdown of the structural symmetry of the porphyrin resolving agent by the bonding of chiral molecules. The developed symmetrical achiral porphyrin resolving agent offers high versatility as well as universality enabling measurement of the optical purity of diverse species of chiral molecules, such as chiral carboxylic acids, esters, protected amino acids, ketones, alcohols, and others.

*38. T. Mori, M. Akamatsu, K. Okamoto, M. Sumita, Y. Tateyama, H. Sakai, J. P Hill, M. Abe, K. Ariga, "Micrometer-level naked-eye detection of cesium particulates in the solid state", *Sci. Tech. Adv. Mater.* **14** (2013) 015002.

As a result of the accident at Nuclear Power Plant following the Great East Japan Earthquake of March 2011, a large amount of radioactive substances, cesium 137, leaked and contaminated a wide area. This research developed a fluorescent probe that detects cesium ion using supermolecular interaction. It is possible to visualize the distribution of cesium ion with submillimeter accuracy even on ground and in living plants. This detection mechanism adopted the deprotonation of phenols as a probe reaction. Interaction with an electron-accepting 4-nitrophenyl ether group can occur upon effective inclusion of Cs cation through a variable-length polyethylene glycol chain with the aim of selectively detection.

Research result [20]

*39. C. Hoang, M. Oyama, O. Saito, M. Aono, T. Nagao, "Monitoring the presence of ionic mercury in environmental water by plasmon-enhanced infrared spectroscopy," *Scientific Reports* **3** (2013) 1175.

In the past decade, vaporized mercury emission from coal-fired generators as well as small-scale Au mines has been increasing and causing ubiquitous pollution of atmosphere as well as environmental water across the border. The detection methods of mercury from air has been widely studied and commercialized, but the detection method for environmental water is still premature. We demonstrate the ppt-level single-step selective monitoring of the presence of mercury ions (Hg^{2+}) dissolved in environmental water by plasmon-enhanced vibrational spectroscopy. We combined a nanogap-optimized mid-infrared plasmonic structure with mercury-binding DNA aptamers to monitor in situ the spectral evolution of the vibrational signal of the DNA induced by the mercury binding. For example, with natural water from Lake Kasumigaura (Ibaraki Prefecture, Japan), direct detection of Hg^{2+} with a concentration as low as 37 ppt ($37\text{x}10^{-10}$ %) was readily demonstrated, indicating the high potential of this simple method for environmental and chemical sensing of metallic species in aqueous solution.

*40. J. Wi, S. Tominaka, T. Nagao, "Arrays of nanoscale gold dishes containing engineered sub-structures," *Adv. Opt. Mater.* **1** (2013) 814.

Increasing interest exists, but still it is difficult to monitor the states of the electromagnetic nearfield and chemical states of individual nano-materials when the probing area are smaller than that of the wavelength of the visible light commonly used for optical microscope. In this article, we demonstrated that by using the well-engineered Au nanostructures, it is possible to control the enhancement of SERS signal and thereby to read the direction of the light polarization around the nanometer-scale small objects. Furthermore, bi-metallic nanostructures, in which chemically active materials are positioned inside the plasmonic dishes, allow to monitor the progress of the chemical reaction occurring at the nanoscale space. These results illustrate unprecedented flexibility in integrating the physically synthesized plasmonic substructures which are expected to be highly useful in real time monitoring nanoscopic light-matter interactions and biochemical reactions.

II) Optional 5 Papers

*Opt. 1. M. Osada, T. Sasaki, "Two-dimensional dielectric nanosheets: Novel nanoelectronics from nanocrystal building blocks", *Adv. Mater.* **24** (2012) 210.

Two-dimensional (2D) nanosheets, which possess atomic or molecular thickness and infinite planar lengths, are attractive for the use in next-generation nanoelectronics. Despite significant advances in graphene-like 2D materials, it remains a challenge to explore high-*k* dielectric counterparts of graphene, which are essential for many devices such as memories, capacitors, and gate devices. In this paper, we review the progress made in 2D dielectric oxide nanosheets, highlighting emerging functionalities in electronic applications. Ti- and perovskite-based nanosheets exhibit the highest permittivity (ε_r = 210~320) ever realized in all known dielectrics in the ultrathin region (< 10 nm). A layer-by-layer engineering using these oxide nanosheets promises unique possibilities in the design of thin-film device architectures, such as capacitors, transistors, artificial ferroelectrics and spin-electronics. Graphene is only the tip of the iceberg, and we are now starting to discover new possibilities afforded by 2D oxides.

*Opt. 2. I. Valov, I. Sapezanskaia, A. Nayak, T. Tsuruoka, T. Bredow, T. Hasegawa, G. Staikov, M. Aono and R. Waser, "Atomically controlled electrochemical nucleation at superionic solid electrolyte surfaces", *Nature Materials* **11** (2012) 530.

In this research, we have succeeded in adopting electronic conductivity to super-ionic material with keeping the property of ionic conductor, which is needed for the solid electrochemical reaction. This enabled the first STM observation of a super-ionic material. Namely, charge transfer between the STM tip and the material to cause the chemical reaction, and STM observation of Redox reaction in which metal atoms precipitate become possible. The experiment revealed that precipitation of metal atoms due to the reduction process of solid electrochemical reaction requires a certain time (time lag) after bias application. It was also reveled that bias larger than a certain threshold value makes the time lag negligible small. As such, the atomic-scale observation revealed many phenomena; those are not detectable in macroscopic observations.

*Opt. 3. Q. Liang, L. Wu, X. Hu, "Electrically tunable topological state in [111] perovskite materials with an antiferromagnetic exchange field", *New J. Phys.* **15** (2013) 063031-1.

We propose a scheme of band engineering by means of staggered electric potential, anti- ferromagnetic exchange field and spin–orbital coupling for electrons on a honeycomb lattice. With fine control on the degrees of freedom of spin, sublattice and valley, one can achieve a topological state with simultaneous non-zero charge and spin Chern numbers. In terms of first principles calculations, we demonstrate that the scheme can be realized by material modification to perovskite G-type antiferromagnetic insulators, such as LaCrO3 grown along the [111] direction, where Dirac electrons are contributed from Au+3 ions which replace Cr ions on an atomic sheet of buckled honeycomb lattice. In a finite sample, this state provides a spin-polarized zero-resistance edge current optimally up to room temperature, robust to both non-magnetic and magnetic defects. The spin polarization is reversible by electric field while the whole system does not show net magnetization, which is extremely ideal for spintronics.

*Opt. 4. T. Tsuchiya, K. Terabe, M. Aono, "All-solid-state electric-double-layer transistor based on oxide ion migration in Gd-doped CeO_2 on $SrTiO_3$ single crystal", *Appl. Phys. Lett.* **103** (2013) 073110.

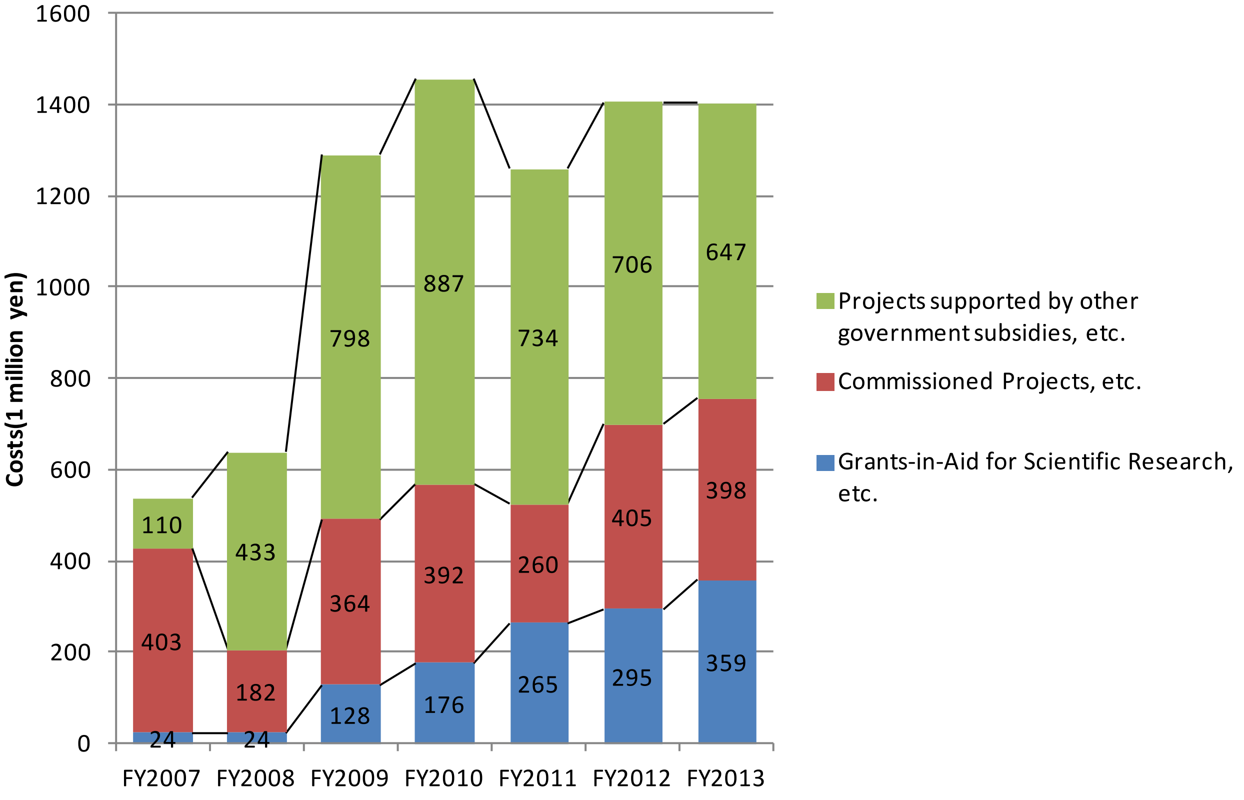
An all-solid-state electric-double-layer transistor (EDLT) with a Gd-doped CeO2 (GDC) oxide ionconductor/SrTiO3 (STO) insulator structure has been developed. At 473 K, the drain current of the EDLT was well controlled, from less than nA order to μA order, by electrostatic carrier doping at the GDC/STO interface due to oxide ion (O^{2-}) migration in the GDC, in contrast to an inactiveness at room temperature. The EDL capacitance at the interface, measured with an AC impedance spectroscopy, was 14 μF cm^{-2}, higher than that reported for a microporous-SiO_2 EDLT and comparable to that of an ionic-liquid-gated EDLT.

*Opt. 5. T. Yamaguchi, E. Watanabe, H. Osato, D. Tsuya, K. Deguchi, T. Watanabe, H. Takeya, Y. Takano, S. Kurihara, H. Kawarada, "Low-temperature transport properties of holes introduced by ionic liquid gating in hydrogen- terminated diamond surfaces", *J. Phys. Soc. Jpn* **82** (2013) 074718.

The surface conductivity of (111)- and (100)-oriented hydrogen-terminated diamonds was investigated at low temperatures for different carrier densities. The carrier density was controlled in a wide range in an electric doublelayer transistor configuration using ionic liquids. As the carrier density was increased, the temperature dependences of sheet resistance and mobility changed from semiconducting to metallic ones: the sheet resistance and mobility for the (111) surface were nearly independent of temperature for a sheet carrier density of ~4 x 10^{13} cm^{-2}, indicating metallic carrier transport. It was also found that the interface capacitance, determined from the gate voltage dependence of the Hall carrier density, depended significantly on the crystal orientation.

2. Annual transition in non-WPI project funding (grants)

*Make a graph of the annual transition in non-WPI project funding (grants).
*Describe external funding warranting special mention.



[External funding warranting special mention]

Basic Research Programs (CREST)
- T. Sasaki: Next-generation electronics using inorganic nanosheets (2008) [Budget: 167,863,800 yen]
- K. Ariga: Dynamic interfacial nanotechnology (2009) [Budget: 88,465,000 yen]
- T. Hasegawa: Three-terminal nonvolatile device 'atom transistor' (2009) [Budget: 117,390,000 yen]
- T. Nagao: Control of interfacial electromagnetic field and utilization of thermal energy in the heterolayer of ceramics (2013) [Budget: 201,500,000 yen]

Basic Research Programs (PRESTO)
- N. Fukata: Vertical three-dimensional semiconductor devices (2007) [Budget: 49,270,000 yen]
- Y. Tateyama: Reaction design for redox reactions on solid/solution interfaces (2007) [Budget: 44,265,000 yen]
- Y. Yamauchi: Next-generation magnetic record media (2008) [Budget: 106,600,000 yen]
- L. Sang: Multi-band engineering of III-Nitride for high efficiency photoelectricity energy conversion devices (2012) [Budget: 53,300,000 yen]
- N. Shirahata: Well-designed nanostructures of monolayers/semiconductors for environmentally-friendly optoelectronic applications (2013) [Budget: 52,000,000 yen]

Grants-in Aid for Scientific Research A
- K. Tsukagoshi: High-performance atomic film device (2009) [Budget: 47,060,000 yen]
- T. Nakayama: New functional scanning probes (2010) [Budget: 48,490,000 yen]
- A. Belik: Functional transition metal oxides (2010) [Budget: 47,970,000 yen]
- Y. Okawa: Measurement of functions of single molecular device wired by conductive macromolecular chain (2012) [Budget: 37,700,000 yen]

- T. Uchihashi: Development and control of superconductivity in super structure of semiconductor surface (2013) [Budget: 34,200,000 yen]

Grants-in Aid for Scientific Research for Young Scientists S

- T. Nagao: Metallic nano-materials and infrared plasmons (2008) [Budget: 88,900,000 yen]

Grants-in Aid for Scientific Research for Young Scientists A

- M. Ebara: Development of early detection method by on-site infection disease biomarker in low infrastructure regions (2013) [Budget: 18,500,000 yen]
- S. Moriyama: Observation of electron orbit and electromagnetic response of controlling element for a single relativistic particle (2013) [Budget: 19,600,000 yen]

Funding Program for Next Generation World-Leading Researchers (NEXT Program)

- N. Fukata: Next-generation high efficiency solar cells using functionalized silicon nanostructures (2010) [Budget: 113,100,000 yen]

Adaptable and Seamless Technology transfer Program through target-driven R&D (A-STEP)

- T. Chikyow: Fabrication of ZnO green LED with super low electric power consumption on Si base (2011) [Budget: 20,800,000 yen]
- T. Chikyow: Development of ferroelectric capacitor for next-generation power semiconductor enabling ultrahigh efficient energy conversion (2013) [Budget: 20,410,000 yen]

JST Revitalization Promotion Program

- G. Chen: Development of fabrication apparatus system for medical porous materials (2012) [Budget: 6,500,000 yen]

3. Major Awards, Invited Lectures, Plenary Addresses (etc.) (within 2 pages)

3-1. Major Awards

* List main internationally-acclaimed awards received announced in order from the most recent.
* For each, write the recipient's name, name of award, and year issued. In case of multiple recipients, underline those affiliated with the center.

1. Takako KONOIKE, *Young Scientist's Encouragement Award* (by the Physical Society of Japan), 2014
2. Yukio NAGASAKI, *Award of the Japanese Society for Biomaterials* (by the Japanese Society for Biomaterials), 2014
3. Zhong Lin WANG, *James C. McGroddy Prize in New Materials* (by the American Physical Society), 2014
4. Masakazu AONO, *Nanoscience Prize* (at ACSIN-12 conference), 2013
5. Katsuhiko ARIGA, *Fellow of the Royal Society of Chemistry* (by the Royal Society of Chemistry), 2013
6. Alexei BELIK, *Young Scientist's Prize* (by the Japanese Ministry of Education, Culture, Sports, Science and Technology, MEXT), 2013
7. Takayoshi SASAKI, *Science and Technology Prize* (by the Japanese Ministry of Education, Culture, Sports, Science and Technology, MEXT), 2013
8. Kazuhito TSUKAGOSHI, *JSPS Prize* (by the Japan Society for the Promotion of Science), 2013
9. Françoise M. WINNIK, *SPSJ International Award* (by the Society of Polymer Science, Japan, SPSJ), 2013
10. Yusuke YAMAUCHI, *PCCP Prize* (by the Chemical Society of Japan), 2013
11. Yusuke YAMAUCHI, *Young Scientist's Prize* (by the Japanese Ministry of Education, Culture, Sports, Science and Technology, MEXT), 2013
12. Genki YOSHIKAWA, *Tsukuba Encouragement Prize for Young Researchers* (by the Science and Technology Promotion Foundation of Ibaraki), 2013
13. Yoshio BANDO, Dmitri GOLBERG, *Thomson Reuters Research Front Award* (by Thomson Reuters), 2012
14. Takayoshi SASAKI, *CSJ Academic Prize* (by the Chemical Society of Japan), 2012
15. Satoshi TOMINAKA, *Funai Research Incentive Award* (by the FUNAI Foundation for Information Technology), 2012
16. Yusuke YAMAUCHI, *Tsukuba Encouragement Prize for Young Researchers* (by the Science and Technology Promotion Foundation of Ibaraki), 2012
17. Tadaaki NAGAO, *Fellow of the Institute of Physics* (by the Institute of Physics, UK), 2011
18. Tadaaki NAGAO, *Naito Taisyun Memorial Award* (by the Naito Taisyun Science and Technology Foundation), 2011
19. Jun NAKANISHI, *Young Scientist's Prize* (by the Japanese Ministry of Education, Culture, Sports, Science and Technology, MEXT), 2011
20. Katsunori WAKABAYASHI, *PSJ Young Scientist Award* (by the Physical Society of Japan), 2011
21. Zhong Lin WANG, *MRS Medal* (from Materials Research Society), 2011
22. Mark E. WELLAND, *Knighthood in the Queen's Birthday Honors list* (by Queen's Birthday Honors, UK), 2011
23. Françoise M. WINNIK, *CIC Macromolecular Science and Engineering Award* (by the Chemical Institute of Canada), 2011
24. Masakazu AONO, *Feynman Prize in Nanotechnology* (by the Foresight Institute, Palo Alto, USA), 2010
25. Katsuhiko ARIGA, *Nice Step Researcher* (by the Japan Science and Technology Agency), 2010
26. Tetsushi TAGUCHI, *Award of the Adhesion Society of Japan* (by the Adhesion Society of Japan), 2010
27. Kohei UOSAKI, *CSJ Award* (by the Chemical Society of Japan), 2010
28. Katsunori WAKABAYASHI, *Young Scientists's Award* (by the Japanese Ministry of Education, Culture, Sports, Science and Technology, MEXT), 2010
29. Daisuke FUJITA, *Ichimura Award* (by the New Technology Development Foundation, Japan), 2009
30. James K. GIMZEWSKI, *Fellow of the Royal Society, FRS* (by the Royal Society, London, UK), 2009
31. James K. GIMZEWSKI, *Institute of Electronic Technology, AWARD to honor 10 Millionth Record Inspection*, London, UK, 2009
32. Kazuhiro HONO, *Honda Frontier Award* (by the Honda Memorial Foundation), 2009

33. Naoki OHASHI, *Richard M. Fulrath Award* (by the American Ceramics Society), 2009
34. Kohei UOSAKI, *Fellow of the Electrochemical Society* (by the Electrochemical Society), 2009
35. Yoshio BANDO, *Fellow of the American Ceramic Society* (by the American Ceramic Society), 2008
36. Kenji KITAMURA, *Inoue Harushige Award* (by Japan Science and Technology Agency), 2008
37. Takayoshi SASAKI, Minoru OSADA, *Tsukuba Prize* (by the Science and Technology Promotion Foundation of Ibaraki), 2008
38. Kohei UOSAKI, *Fellow of the International Society of Electrochemistry* (by the International Society of Electrochemistry), 2008

3-2. Invited Lectures, Plenary Addresses (etc.) at International Conferences and International Research Meetings

* List up to 20 main presentations in order from most recent.

* For each, write the lecturer/presenter's name, presentation title, conference name and date(s)

1. Kazuhito TSUKAGOSHI, *Atomically thin semiconducting channels for future nano-electronics*, Trends in Nanotechnology Japan 2014, Jan 29 - Jan 31, 2014
2. Masakazu AONO, *Controlling single atoms and molecules at solid surfaces and interfaces*, 12th International Conference on Atomically Controlled Surfaces, Interfaces and Nanostructures, Nov 5 - Nov 8, 2013
3. Yukio NAGASAKI, *Nanotechnology in, vivo: redox polymer therapeutics*, 40th Annual Meeting & Exposition of the Controlled Release Society, Sep 19, 2013
4. Zhong Lin WANG, *Nanogenerators as New Energy Technology and Piezotronics for Functional Systems*, European Congress and Exhibition on Advanced Materials and Processes, Sep 9 – Sep 12, 2013
5. Françoise M. WINNIK, *Functions of self -assembled soft materials designed through materials nanoarchitectonics*, 175th Anniversary Symposium of the Finnish Society of Sciences and Letters, Sep 1-2, 2013
6. James K. GIMZEWSKI, *Atomic switch networks: dynamical systems for universal computation*, Discussion Workshop: New Horizons in Electrochemistry- at the Boundary to Physics and Materials Science, Aug 26-28, 2013
7. Naoki FUKATA, *Doping and characterization of impurity atoms in Si and Ge nanowires*, E-MRS, May 27 - May 31, 2013
8. Katsuhiko ARIGA, *Two-dimensional nanoarchitectonics: clay, graphene and nanofrake in assembly*, 245th American Chemical Society National Meeting & Exposition, Apr 7 - Apr 11, 2013
9. Tomonobu NAKAYAMA, *Multiple-probe scanning probe microscopes for nanosystems research*, The 6th International Conferece on Advanced Materails and Nano, Feb 11- Feb 15, 2013
10. Tadaaki NAGAO, *Plasmons in atomic-scale/nanoscale objects and their applications*, The 7th International Conference on Photonics and Applications, Nov 26 - Nov 29, 2012
11. Katsunori WAKABAYASHI, *Electronic transport and magnetic properties of graphene nanoribbons*, The International Union of Materials Research Societies – International Conference on Electronic Materials 2012, Sep 23 - Sep 28, 2012
12. Guoping CHEN, *Development of stepwise tissue development-mimicking matrices from stem cells*, 15th International Biotechnology Symposium (IBS) and Exhibition, Sep 16 - Sep 22, 2012
13. Kohei UOSAKI, *Formation and structural determination of 'confined molecular catalysts' on and within molecular layers formed on Si(111) surface with direct Si-C bond for photoelectrochemical hydrogen generation and CO2 reduction*, American Chemistry Society National Meeting &Exposition, Aug 19 - Aug 23, 2012
14. Xiao HU, *Majorana fermion in topological superconductor*, 11th International Conference on Condensed Matter Theory, Aug 12- Aug 15, 2012
15. Dmitri GOLBERG, *In situ TEM measurements of nanotube and nanosheet properties*, Microscopy and Microanalysis 2012, Jul 29 - Aug 2, 2012
16. Christian JOACHIM, *To be Nano or not to be Nano?*, International Conference of Young Researchers on Advanced Materials, Jul 1-6, 2012
17. Takao MORI, *Nanostructured borides and perspectives of high temperature thermoelectric materials*, Materials Research Society Spring Meeting 2012, Apr 9 - Apr 13, 2012
18. Tsuyoshi HASEGAWA, *Atom movement controlled three-termninal device, 'Atom Transistor'*, 24th International Microprocesses and Nanotechnology Conference, Oct 24 - Oct 27, 2011
19. Yoshio BANDO, *Novel synthesis and property of BN nanotubes and nanosheets*, Pacifichem 2010, Dec 15 - Dec 20, 2010
20. Takayoshi SASAKI, *Layer-by-layer assembly of transition metal oxide nanosheets into ultrathin functional films*, 12th International Ceramics Congress, Jun 6 - Jun 11, 2010

4. List of Achievements of Center's outreach activities

* Using the table below, show the achievements of the Center's outreach activities from FY2011 through FY2013 (number of activities, times held).

Activities	FY2011 (number of activities, times held)	FY2012 (number of activities, times held)	FY2013 (number of activities, times held)
PR brochure, pamphlet	4	5	5
Lectures, seminars for general public	7	7	5
Teaching, experiments, training for elementary and secondary school students	12	12	15
Science cafe	0	1	0
Open houses	2	2	2
Participating, exhibiting in events	3	2	3
Press releases	11	21	18
Research Highlights (e-mail newsletter)	2	4	7

5. List of Media Coverage of Projects Carried Out between FY 2011 – 2013
(within 2 pages)

* Select main items of press releases, media coverage, and reports (especially overseas)

1) Japan

No.	Date	Type media (e.g., newspaper, magazine, television)	Description
1	Apr. 10, 2011	Nihon Keizai Shimbun (Nikkei)	With an increasing number of non-Japanese returning to their home countries in response to the nuclear power plant accident triggered by the Great East Japan Earthquake, introduction of MANA as an example of a workplace that has succeeded in keeping its international employees.
2	June 27, 2011 July 8, 2011	Ibaraki Shimbun / Mainichi Shimbun / Nikkan Kogyou Shimbun / Nikkei / Nikkei Sangyo Shimbun Science News	In joint research with the University of California, Los Angeles (UCLA; USA), development of a new "synapse device" that autonomously reproduces the two distinctive features of the neural activity of the brain, "memory of necessary information" and "forgetting of unnecessary information," in a single device. (Tsuyoshi Hasegawa)
3	Dec. 20, 2011 Dec. 26, 2011 Jan. 16, 2012 Jan. 27, 2012	Chemical Daily / Nikkan Kogyo Shimbun, Nikkei / Nikkei Sangyo Shimbun, Asahi Shimbun, Science News	Successful formation of a very large number of nanopores (mesoporous) in a Prussian blue crystal structure. (Yusuke Yamauchi)
4	Jan. 1, 2012	NHK BS Premium	Introduction of research at MANA in the first broadcast, "Atom changes life," in the television series "Nano Revolution."
5	Jan. 16, 2012 Jan. 27, 2012	Nikkei Japan Metal Daily	Development of a growth technique that enables high speed formation of new silicon nanostructures which have a tapered structure and internal pn junctions. (Naoki Fukata)
6	May 9, 2012 May 10, 2012 Aug. 28, 2012	Nikkan Kogyo Shimbun Nikkei Sangyo Shimbun Mainichi Shimbun	Development of a new elastic "soft capsule" using an inorganic nanometer thickness flaky material (nano-sheets). (Katsuhiko Ariga)
7	Nov. 16, 2012 Nov. 23, 2012 Nov. 27, 2012	Nikkan Kogyo Shimbun Science News Nikkei Sangyo Shimbun	Development of an on-demand type device that switches functions in response to requests from the user. (Yang Rui, Kazuya Terabe, James Gimzewski, Masakazu Aono)
8	Dec. 21, 2012 Dec. 22, 2012	Asahi Shimbun Yomiuri Shimbun	Success in precise sub-millimeter visualization of the position of cesium. (Katsuhiko Ariga)
9	Jan. 23, 2013 Feb. 1, 2013	Nikkan Kogyo Shimbun Science News	Success in theoretical design of a photocatalyst that enables mass production of hydrogen. (Jinhua Ye)

10	Feb. 11, 2013 Mar. 5, 2013 Mar. 22, 2013 June 7, 2013	Asahi Shimbun Nikkan Kogyo Shimbun Science News Newton	Success in development of a gel material that releases drugs in response to human applied force. (Katsuhiko Ariga)
11	Mar. 28, 2013	Nikkan Kogyo Shimbun	Discovery of an extremely rare gigantic swelling phenomenon of layered crystals by water. (Takayoshi Sasaki)
12	June 15, 2013 June 17, 2013 June 19, 2013 June 27, 2013 June 28, 2013 July 16, 2013	Mainichi Shimbun / Nikkei / Tokyo Shimbun / Yomiuri Shimbun, Chemical Daily / Nikkan Kogyo Shimbun / Nikkei Sangyo Shimbun, Yajiuma TV (TV Asahi), Asahi Shimbun, Science News, Ohayo-Nippon Kanto-Koshin-Etsu (NHK General TV)	Development of a nanofiber mesh that makes it possible to realize thermotherapy and chemotherapy of cancer simultaneously. (Mitsuhiro Ebara)
13	Nov. 29, 2013	Nikkei Sangyo Shimbun	Development of a technology for growing layered perovskite compounds in a high quality crystalline state on diverse substrates. (Takayoshi Sasaki)
14	Jan. 17, 2014	Science News	Success in creation of a structure in which ultra-thin graphene is pasted on a 3-dimensional skeleton in a manner like papier mache by a method modeled on a blown candy technique. (Yoshio Bando, Dimitri Golberg)
15	Feb. 20, 2014 Feb. 22, 2014	Chemical Daily / Ibaraki Shimbun / Nikkan Kogyo Shimbun / Nikkei / Sankei Shimbun, Yomiuri Shimbun	Development of a portable blood purification system using a wristwatch-type cartridge as an alternative to dialysis. (Mitsuhiro Ebara)
16	Feb. 20, 2014	Chemical Daily	Development of the world's smallest high performance condenser device with performance approximately 2000 times higher than existing MLCC by using conductive and dielectric materials. (Takayoshi Sasaki, Minoru Osada)

2) Overseas

No.	Date	Type media (e.g., newspaper, magazine, television)	Description
1	Sep. 28, 2012	Science Vol. 337	Introduction of examples of operation of overseas laboratories bringing together outstanding researchers from countries around the world in the column “Satellite Labs Extend Science.” (Omar Yaghi)
2	Mar. 16, 2013	Canadian Broadcasting Corporation	Broadcast of the NHK international joint production program, "Nano Revolution." (James Gimzewski)

World Premier International Research Center Initiative (WPI)

List of papers of representative of interdisciplinary research activities

* List up to 20 papers that underscoring each interdisciplinary research activity and give brief accounts (within 10 lines).
* For each, write the author name(s); year of publication; journal name, volume, page(s), and article title. Any listing order may be used as long as format is the same. If a paper has many authors, underline those affiliated with the Center.
* If a paper has many authors (say, more than 10), all of their names do not need to be listed.

1. F. Geng, R. Ma, A. Nakamura, K. Akatsuka, Y. Ebina, Y. Yamauchi, N. Miyamoto, Y. Tateyama, and T. Sasaki, "Unusually stable ~100-fold reversible and instantaneous swelling of inorganic layered materials", *Nature Commun*. **4** (2013) 1632.

A massive monolithic swelling of layered materials has been achieved in aqueous solution of 2-dimethylaminoethanol (DMAE), which was up to 100-fold with the gallery spacing increased from 0.9 nm to 90 nm. With quantitative analysis, it was determined that the largely expanded space was primarily occupied with H_2O along with minor trace of the DMAE. The swollen phase was unusually stable with no obvious observation of peeling or translational shifts during the swelling process, maintaining a nearly perfect three-dimensional lattice structure of >3000 layers. First-principle simulations of the molecules in the gallery yielded a long-range directional structuring of the H_2O molecules that may help to stabilize the highly swollen structure. The crystals could also instantaneously shrink back to their original sizes.

2. F. Geng, R. Ma, Y. Ebina, Y. Yamauchi, N. Miyamoto and T. Sasaki, "Gigantic swelling of inorganic layered materials: A bridge to molecularly thin two-dimensional nanosheets", *J. Am. Chem. Soc.* **136** (2014) 5491.

The macroscopic swelling could be realized in a wide variety of amines, ranging from primary amine, tertiary amine, to quaternary ammonium hydroxide, with little dependence on ion identity. The ammonium ion intercalation was mostly determined by the acid-base equilibrium and the accompany H_2O inflow was governed by osmotic pressure balance between the gallery and the solution environment, both of which are substantially molarity dependent. Therefore, in most cases, the ammonium ion intercalation saturated at a value of 37% relative to the exchange capacity, and the maximum swelling degree was ~100-fold with gallery expansion of ~90 nm. Although the swelling process was unselective, the nature of the intercalated ion was critical to the stability of the resulting swollen structure; that is, ions of higher polarity and smaller size helped stabilize the highly expanded structure, while ions of low polarity and larger size readily led to exfoliation.

3. R. Ma, T. Sasaki, "Nanosheets of oxides and hydroxides: Ultimate 2D charge-bearing functional crystallites", *Adv. Mater*. **22** (2010) 5082. (Invited Review Article).

This is an invited review article focusing on the recent progress on oxide and hydroxide nanosheets as an intriguing class of graphene-like 2D materials. A wide variety of monodisperse nanosheets have been produced by exfoliating layered precursory compounds via osmotic swelling. The nanosheets were found to show new and enhanced physicochemical properties associated with the exceptionally unique structure. Thus the nanosheets are very useful as functional building blocks. Various solution-based processes can be applied to organize them into precisely controlled nanostructures such as nanofilms, hollow nanospheres, nanotubes, nanocomposites and so on. Through this approach, a range of functional materials and nanodevices have been developed; photocatalytic coating films, high-k nanofilms, electrode matereials.

4. M. Osada, G. Takanashi, B. W. Li, K. Akatsuka, Y. Ebina, K. Ono, H. Funakubo, K. Takada, T. Sasaki, "Controlled polarizability of one-nanometer-thick oxide nanosheets for tailored, high-κ nano-dielectrics", *Adv. Funct. Mater.* **22** (2011) 3482.

The ever-increasing requirements on smaller, higher-performance electronic devices result in efforts to incorporate new materials into microelectronics, in order to overcome the physical limits of current materials. In this context, the latest Semiconductor Roadmap predicts the implementation of high-κ ultrathin films (< 10 nm) in future applications. In this paper, we reported a rational approach to produce high performance nanodielectrics using 1-nm-thick oxide nanosheets. In titano-niobate nanosheets ($TiNbO_5$, Ti_2NbO_7, Ti_5NbO_{14}), the octahedral distortion inherent to site engineering by Nb incorporation resulted in a giant molecular polarizability, and their multilayer nanofilms exhibited high dielectric constant (160–320), the largest value being seen so far in high-κ nanofilms with the thickness down to 10 nm. Furthermore, these nanosheets offered simultaneous improvements in temperature dependence, lower loss and leakage current. Our work provides a new recipe for designing nanodielectrics desirable for practical high-κ devices.

5. M. Osada, T. Sasaki, "Two-dimensional dielectric nanosheets: Novel nanoelectronics from nano-crystal building blocks", *Adv. Mater.* **24** (2012) 210.

Two-dimensional (2D) nanosheets, which possess atomic or molecular thickness and infinite planar lengths, are attractive for the use in next-generation nanoelectronics. Despite significant advances in graphene-like 2D materials, it remains a challenge to explore high-□dielectric counterparts of graphene, which are essential for many devices such as memories, capacitors, and gate devices. In this paper, we review the progress made in 2D dielectric oxide nanosheets, highlighting emerging functionalities in electronic applications. Ti- and perovskite-based nanosheets exhibit the highest permittivity (ε_r = 210~320) ever realized in all known dielectrics in the ultrathin region (< 10 nm). A layer-by-layer engineering using these oxide nanosheets promises unique possibilities in the design of thin-film device architectures, such as capacitors, transistors, artificial ferroelectrics and spin-electronics. Graphene is only the tip of the iceberg, and we are now starting to discover new possibilities afforded by 2D oxides.

6. T. Ohno, T. Hasegawa, T. Tsuruoka, K. Terabe, J. K. Gimzewski, M. Aono, "Short-term plasticity and long-term potentiation mimicked in single inorganic synapses", *Nature Mater.* **10** (2011) 591.

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. In neuromorphic engineering, emulation of known neural behavior has proven to be difficult to implement in software because of the highly complex interconnected nature of thought processes. In this study, we have succeeded in emulating the synaptic behavior using a single Ag_2S-based atomic switch. The synaptic functions of both STP and LTP characteristics through the use of input pulse repetition time were demonstrated. The results have attracted much attention because it achieves dynamic memorization in a single device without the need of external preprogramming, indicating a potential for the further creation of artificial neural systems that emulate characteristics of human memory.

7. R. Yang , K. Terabe , G. Liu , T. Tsuruoka , T. Hasegawa, J. K. Gimzewski , M. Aono, "On-deman nanodevice with electrical and neuromorphic multifunction realized by local ion migration", *ACS Nano* **6 (11)** (2012) 9515.

In this paper, electrical and neuromorphic multifunctions were demonstrated using a WO_{3-x}-based gapless-type atomic switch, in which migration of oxygen ions are controlled. The device showed a wide range of time scales of memorization, resistance switching, and rectification varying from volatile to permanent in a single device. The device, showing on-demand electrical and neuromorphic multifunction, has a unique paradigm shifting potential for the fabrication of configurable circuits, analog memories, digital neural fused networks, and more in one device architecture.

8. A. V. Avizienis, H. O. Sillin, C. Martin-Olmos, H.-H. Shieh, M. Aono, J. K. Gimzewski, "Neuromorphic atomic switch networks", *PLoS ONE* **7** (2012) e42772.

Conventional fabrication techniques are unable to efficiently generate electronic devices with the highly complex interconnectivity found in biological neuronal networks. In this paper, we demonstrated the physical realization of a self-assembled neuromorphic device comprised of over a billion interconnected atomic switch elements that exhibit synapse-like operational characteristics embedded in a complex network of silver nanowires. Observations of these atomic switch networks (ASN) were in agreement with recent theoretical predictions, while emergent behaviors akin to brain function are observed, namely spatially distributed memory, recurrent dynamics and the activation of feedforward subnetworks. These devices display the functional characteristics required for implementing unconventional, biologically and neurally inspired computational methodologies in a synthetic experimental system.

9. A. Z. Stieg, A. V. Avizienis, H.O. Sillin, C. Martin-Olmos, M. Aono, J. K. Gimzewski, “Emergent criticality in complex Turing B-type atomic switch networks”, *Adv. Mater.* **24** (2012) 286.

The operation of atomic switches as individual synapse-like devices has demonstrated the ability to process information with both short-term and long-term memorization in a single two terminal junction. In this paper, atomic switches were self-assembled within a highly interconnected network of silver nanowires similar in structure to Turing’s “B-Type unorganized machine”. These atomic switch networks (ASN) exhibited emergent criticality similar in nature to previously reported electrical activity of neuronal assemblies. Rapid fluctuations in electrical conductance display power law scaling of temporal correlation lengths that were attributed to dynamic reorganization of the interconnected electroionic network. These collective properties indicate a potential utility for real-time, multi-input processing of distributed sensory data through reservoir computing. We proposed these highly coupled, nonlinear electronic networks as an implementable hardware-based platform toward the creation of physically intelligent machines.

10. H. O. Sillin, H.-H. Shieh, R. Aguilera, A. V. Avizienis, M. Aono, A. Z. Stieg, J. K. Gimzewski, “A theoretical and experimental study of neuromorphic atomic switch networks for reservoir computing”, *Nanotechnology* **24** (2013) 384004.

Atomic switch networks (ASN) have been shown to generate network level dynamics that resemble those observed in biological neural networks. In this paper, we developed and validated a numerical model based on the synapse-like properties of individual atomic switches and the random nature of the network wiring. The reported results highlighted the possibility to functionalize the network plasticity, differences between an atomic switch in isolation and its behaviors in a network, as well as the effects of changing network connectivity on the observed nonlinear dynamics. To demonstrate their utility for computation, we subjected the simulated network to training within the framework of Reservoir Computing (RC) and showed initial evidence of the ASN acting as a reservoir which may be optimized for specific tasks. This work represented initial steps in a unified approach of experimentation and theory to make ASNs a uniquely scalable platform for neuromorphic computing.

11. Y.-J. Kim, M. Ebara, T. Aoyagi, “A smart hyperthermia nanofiber with switchable drug release for inducing cancer apoptosis”, *Adv. Func. Mater.* **23** (2013) 5753.

A smart hyperthermia nanofiber is described with simultaneous heat generation and drug release in response to ‘on-off ’ switching of alternating magnetic field (AMF) for induction of skin cancer apoptosis. The nanofiber is composed of a chemically-crosslinkable temperature-responsive polymer with an anticancer drug (doxorubicin; DOX) and magnetic nanoparticles (MNPs), which serve as a trigger of drug release and a source of heat, respectively. The 70% of human melanoma cells died in only 5 min application of AMF in the presence of the MNPs and DOX incorporated nanofibers by double effects of heat and drug. Taken together these advantages on both the nano- and macroscopic scale of nanofibers demonstrate that the dynamically and reversibly tunable structures have the potential to be utilized as a manipulative hyperthermia material as well as a switchable drug release platform by simple switching an AMF ‘on’ and ‘off ’.

12. L.-B. Vong, T. Tomita, T. Yoshitomi, H. Matsui, Y. Nagasaki, “An orally administered redox nanoparticle that accumulates in the colonic mucosa and reduces colitis in mice”, *Gastroenterology* **143**, (2012) 1027.

Ulcerative colitis (UC) is a chronic inflammatory disease of the colon area. Current treatments include anti-inflammatory and immunosuppressive drugs; however, these medications are not always effective because of non-specific distribution, drug metabolism, and side effects. In this study, we have developed a novel nitroxide radical-containing nanoparticle (RNP), which scavenges reactive oxygen species (ROS). A size of approximately several tens of nanometers is important for long-term retention in colon. Here we found that the concentration of RNP in the colonic mucosa is almost 50 times higher than that of conventional low-molecular-weight drugs. Interestingly, an even higher accumulation of nanoparticles was observed in the colonic mucosa of dextran sodium sulfate (DSS)-induced colitis mice. Additionally, nanoparticles did not enter the bloodstream through the intestinal wall, despite its long-term retention in the colonic mucosa. Based on these characteristics, oral nanotherapy of RNP showed an extremely high therapeutic and safe effect on UC.

13. G. Yoshikawa, T. Akiyama, S. Gautsch, P. Vettiger, H. Rohrer, "Nanomechanical membrane-type surface stress sensor", *Nano Letters* **11** (2011) 1044.

In this paper, we presented a membrane-type surface stress sensor (MSS), which is based on the piezoresistive read-out integrated in the sensor chip. The MSS originates from a conventional cantilever structure, while we found that the membrane-based structure can achieve much better performance. Evaluation of a prototype MSS used in the present experiments demonstrates a high sensitivity which is comparable with that of optical methods and a factor of more than 20 higher than that obtained with a standard piezoresistive cantilever. The finite element analyses indicate that changing dimensions of the membrane and beams can substantially increase the sensitivity further. Given the various conveniences and advantages of the integrated piezoresistive read-out, this platform is expected to open a new era of surface stress-based sensing.

14. G. Yoshikawa, F. Loizeau, C. J. Lee, T. Akiyama, K. Shiba, S. Gautsch, T. Nakayama, P. Vettiger, N. F. de Rooij, M. Aono, "Double-side-coated nanomechanical membrane-type surface stress sensor (MSS) for one-chip- one-channel setup", *Langmuir* **29** (2013) 7551.

One of the major issues of nanomechanical sensors is the difficulty of coating receptor layers on their surfaces to which target molecules adsorb or react. To have measurable deflection, a single-side coating is commonly applied to cantilever-type geometry, and it requires specific methods or protocols, such as inkjet spotting or gold−thiol chemistry. In this paper, we demonstrated the feasibility of the double-side coating on a membrane-type surface stress sensor (MSS) and verify its working principle by both finite element analysis (FEA) and experiments. In addition, simple hand-operated dip coating is demonstrated as a proof of concept, achieving practical receptor layers without any complex instrumentation. The compatibility with double-side coating enables MSS to be applied to most standard assays in medical and biological fields.

15. H. Zhou, J. Guo, P. Li, Tongxiang Fan, Di Zhang, J. Ye, ”Leaf-architectured 3D hierarchical artificial photosynthetic system of perovskite titanates towards CO_2 photoreduction into hydrocarbon fuels”, *Scientific Reports* **3** (2013) 1667.

As a nano-life science-inspired nanoarchitectonics, here we report an unique strategy for constructing a promising 3D artificial photosynthetic system (APS) for efficient CO_2 photoreduction into hydrocarbon fuels. Natural leaf is a synergy of complex architectures and functional components to produce an amazing bio-machinery for photosynthesis. Mimicking the structural and functional elements in the natural photosynthesis should be promising to achieve an efficient artificial photosynthetic system. In this work, by using leaves of cherry tree as the template, we have successfully fabricated perovskite titanates (e.g., $SrTiO_3$, $CaTiO_3$) with a modified sol-gel method. After acid treatment and calcination at 600°C, organics could be removed completely, leaving crystalline perovskite titanates. The obtained material preserves the morphological features of leaf at multi-scaled levels. It was found that leaf-architectured $SrTiO_3$ exhibits about a 3.5~4 fold improvement in activities than the referenced $SrTiO_3$ synthesized without templates. A further mechanism study revealed that the enhanced conversion efficiency of CO_2 into hydrocarbon fuels can be attributed to the synergistic effect of efficient mass flow/light harvesting network relying on the morphological replacement of a concept prototype-leaf's 3D architecture.

16. Z. Yi, J. Ye, N. Kikugawa, T. Kako, S. Ouyang, H. Stuart-Williams, H. Yang, J. Cao, W. Luo, Z. Li, Y. Liu, R. L. Withers, "An orthophosphate semiconductor with photooxidation properties under visible-light irradiation", *Nature Mater.* **9** (2010) 559.

The search for active semiconductor photocatalysts that directly split water under visible-light irradiation remains one of the most challenging tasks for solar-energy utilization. Over the past 30 years, the search for such materials has focused mainly on metal-ion substitution as in $In_{1-x}Ni_xTaO_4$ and (V-, Fe- or Mn-)TiO_2, non-metal-ion substitution as in $TiO_{2-x}N_x$ and $Sm_2Ti_2O_5S_2$ or solid-solution fabrication as in $(Ga_{1-x}Zn_x)(N_{1-x}O_x)$ and ZnS–$CuInS_2$–$AgInS_2$. Here we report a new photocatalyst Ag_3PO_4, which was developed by incorporating p block element into a simple AgO oxide with narrow band gap. The new photocatalyst showed extremely high quantum yield (~90% at 420 nm) towards water oxidation, which is one of the key process for artificial photosynthesis, under visible light irradiation. The obtained quantum yield marked the world's highest record, approaching that in natural photosynthesis. The new photocatalyst also showed amazing activity in decomposition of organic contaminants in aqueous solution. This study not only supplies a new strategy for developing highly efficient visible-light-driven photocatalysts, but also shows a great step towards the realization of an artificial photosynthetic system.

17. Q.-F. Liang, Z. Wang, X. Hu, "Manipulation of Majorana fermions by point-like gate voltage in the vortex state of a topological superconductor", *Europhys. Lett.* **99** (2012) 50004. [Editor's Choice].

A vortex in a topological superconductor induces two Majorana fermions (MFs), one in the core and the other at the sample edge. Here we demonstrate that edge MFs can be transported and braided by turning gate voltages on and off at the point-like constriction junctions between samples. The controllable high mobility of edge MFs is due to the topological property, namely an edge MF appears only when the sample perimeter includes odd number of vortices. As shown explicitly by solving the time-dependent Bogoliubov-de Gennes equation, disturbance to the quantum coherence of MFs during braiding is negligibly small in this scheme due to the point-like application of the gate voltage. The present work bridges for the first time the fundamental topological features of edge MFs and their adiabatic dynamics which is important for performing topological quantum computation.

18. T. Uchihashi, P. Mishra, M. Aono, T. Nakayama, "Macroscopic superconducting current through a silicon surface reconstruction with indium adatoms: Si(111)-($\sqrt{7}\times\sqrt{3}$)-In", *Phys. Rev. Lett.* **107** (2011) 207001. [Highlighted as an Editor's Suggestion and a Viewpoint in Physics].

Macroscopic and robust supercurrents are observed by direct electron transport measurements on a silicon surface reconstruction with In adatoms [Si(111)-($\sqrt{7}\times\sqrt{3}$)-In]. The superconducting transition manifests itself as an emergence of the zero resistance state below 2.8 K. *I*-*V* characteristics exhibit sharp and hysteretic switching between superconducting and normal states with well-defined critical and retrapping currents. The two-dimensional (2D) critical current density $J_{2D,c}$ is estimated to be as high as 1.8 A/m at 1.8 K. The temperature dependence of $J_{2D,c}$ indicates that the surface atomic steps play the role of strongly coupled Josephson junctions.

19. Q. Liang, L. Wu, X. Hu, "Electrically tunable topological state in [111] perovskite materials with an antiferromagnetic exchange field", *New J. Phys.* **15** (2013) 063031-1.

We propose a scheme of band engineering by means of staggered electric potential, anti-ferromagnetic exchange field and spin–orbital coupling for electrons on a honeycomb lattice. With fine control on the degrees of freedom of spin, sublattice and valley, one can achieve a topological state with simultaneous non-zero charge and spin Chern numbers. In terms of first principles calculations, we demonstrate that the scheme can be realized by material modification to perovskite G-type antiferromagnetic insulators, such as LaCrO3 grown along the [111] direction, where Dirac electrons are contributed from Au+3 ions which replace Cr ions on an atomic sheet of buckled honeycomb lattice. In a finite sample, this state provides a spin-polarized zero-resistance edge current optimally up to room temperature, robust to both non-magnetic and magnetic defects. The spin polarization is reversible by electric field while the whole system does not show net magnetization, which is extremely ideal for spintronics.

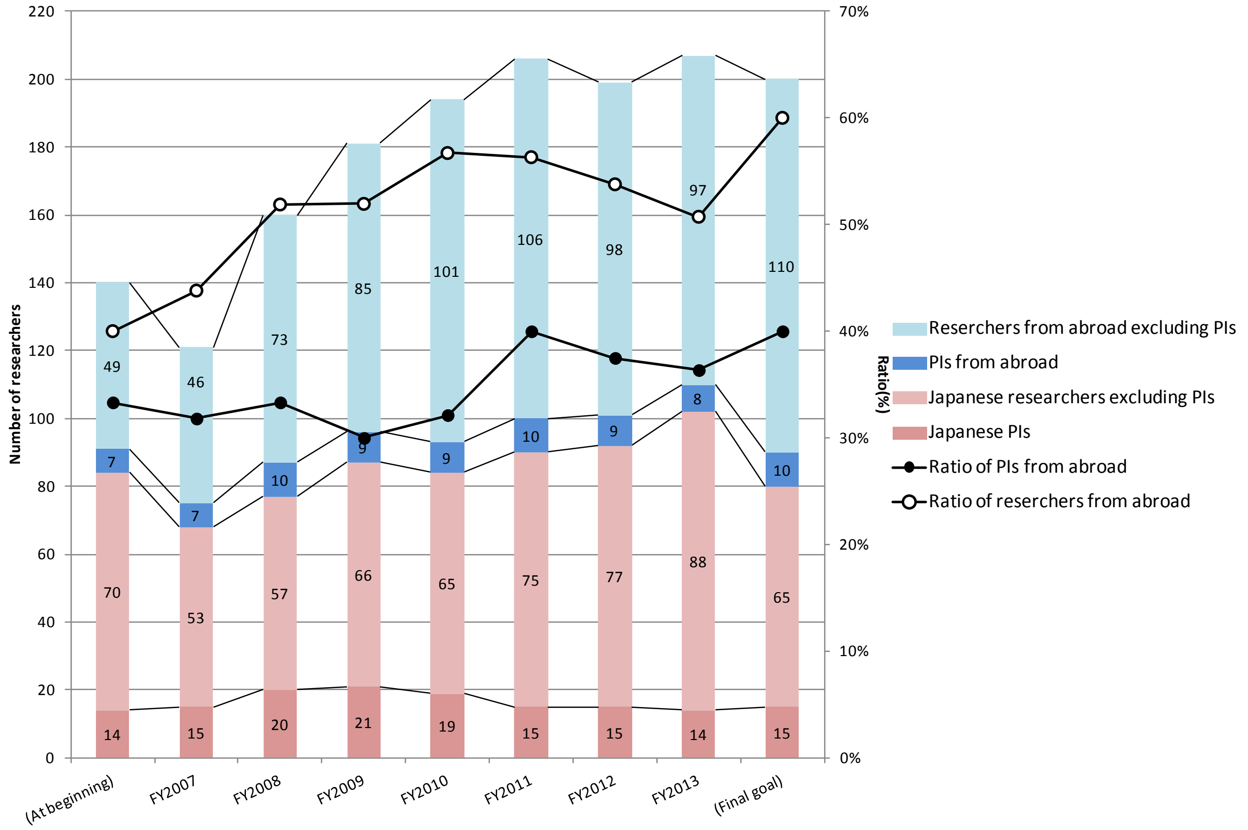
20. T. Tsuchiya, K. Terabe, M. Aono, “All-solid-state electric-double-layer transistor based on oxide ion migration in Gd-doped CeO_2 on $SrTiO_3$ single crystal”, *Appl. Phys. Lett.* **103** (2013) 073110.

An all-solid-state electric-double-layer transistor (EDLT) with a Gd-doped CeO_2 (GDC) oxide ionconductor/$SrTiO_3$ (STO) insulator structure has been developed. At 473 K, the drain current of the EDLT was well controlled, from less than nA order to μA order, by electrostatic carrier doping at the GDC/STO interface due to oxide ion (O^{2-}) migration in the GDC, in contrast to an inactiveness at room temperature. The EDL capacitance at the interface, measured with an AC impedance spectroscopy, was 14 μF cm^{-2}, higher than that reported for a microporous-SiO_2 EDLT and comparable to that of an ionic-liquid-gated EDLT.

World Premier International Research Center Initiative (WPI)

1. Number of overseas researchers and annual transition

*Make a graph of the transition in the number of overseas researchers since the application.



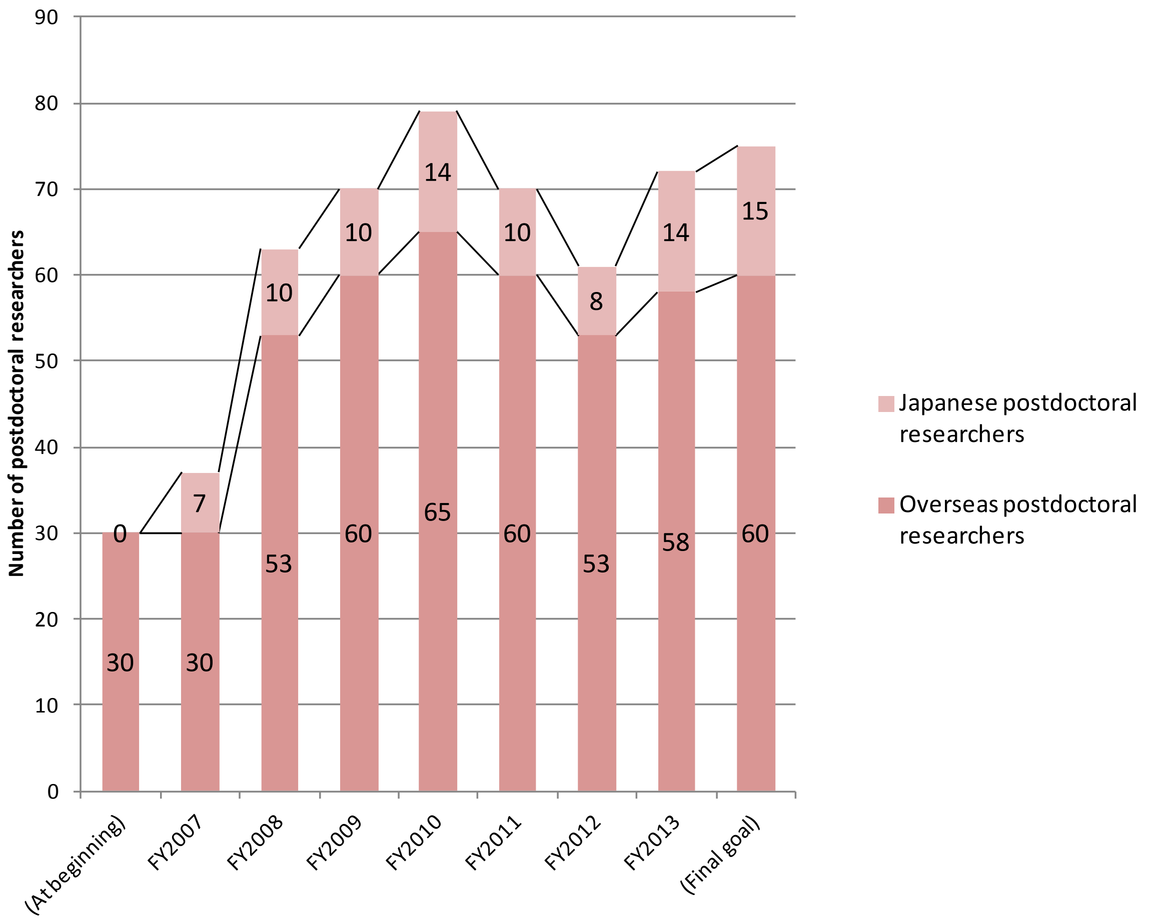
2. Postdoctoral positions through open international solicitations

* In the column of number of applications and number of selection, put the number and percentage of overseas researchers in the < > brackets.

FY	number of applications	number of selection
FY2007	167 < 141, 85%>	9 < 6, 67%>
FY2008	119 < 109, 92%>	10 < 7, 70%>
FY2009	84 < 73, 87%>	3 < 1, 34%>
FY2010	128 < 112, 88%>	3 < 3, 100%>
FY2011	94 < 86, 92%>	5 < 4, 80%>
FY2012	169 < 148, 88%>	5 < 4, 80%>
FY2013	181 < 166, 92%>	5 < 4, 80%>

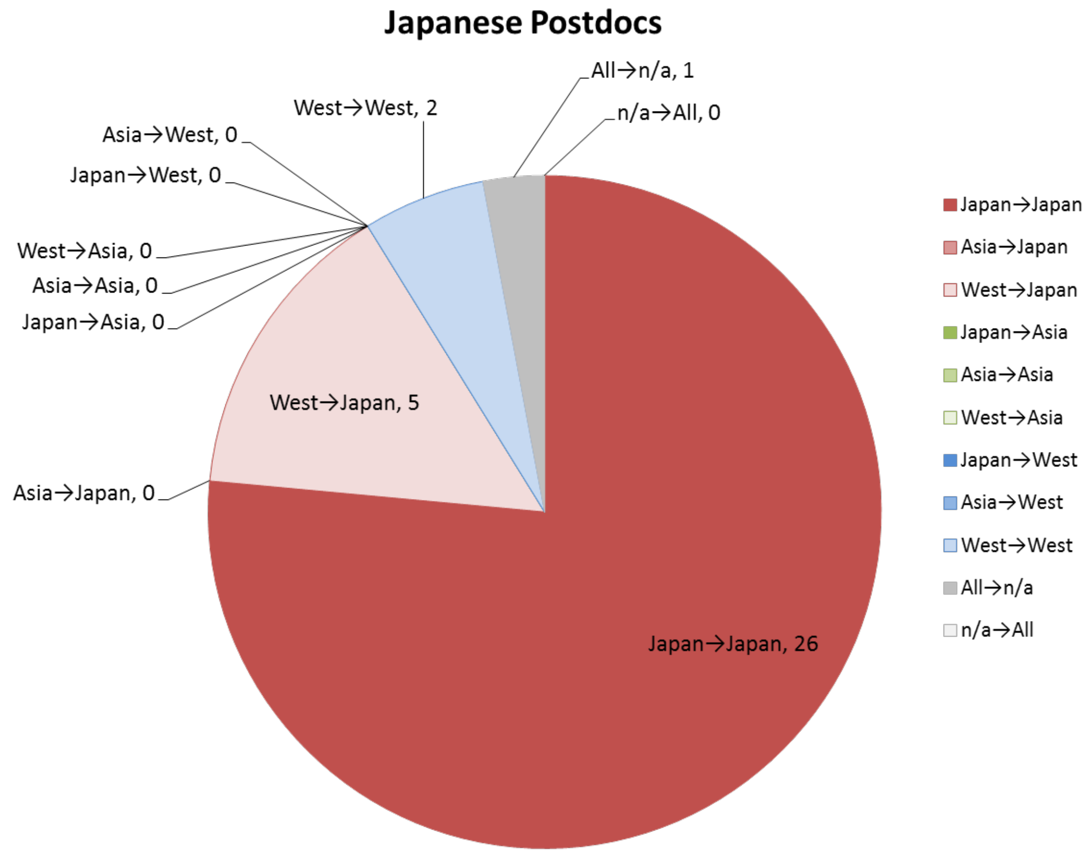
3. Number of overseas postdoctoral researchers and annual transition

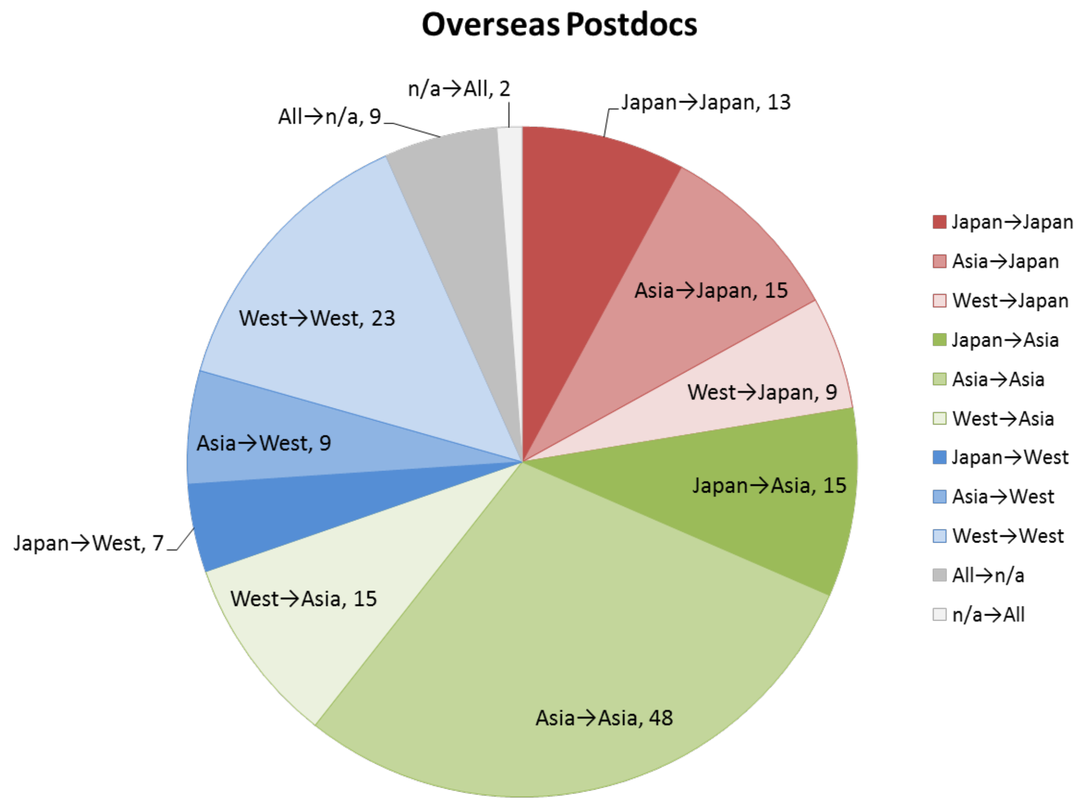
*Make a graph of the transition in the number of overseas postdoctoral researchers since the application.



4. Status of postdoc employment at institutions of postdoctoral researchers

- ○○→△△ indicates that a posdoc has come to the WPI Center from an institute in ○○ and moved to one in △△.
- n/a indicates unknown or resignation for personal reason.





5. List of the cooperative research agreements outside Japan

1.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Department of Chemistry, Kent State University, USA Memorandum of Understanding (MOU) for collaboration on "Design of novel nanoporous materials" Signed on 2008 January 10 Valid until 2013 January 10 (expired) For joint research activities between MANA and Kent State University, including research collaborations, exchange of personnel and organizing workshops.
2.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Chemical and Biological Engineering, Rensselaer Polytechnic Institute (RPI), USA Memorandum of Understanding (MOU) for collaboration on "Design of novel nanoporous materials" Signed on 2008 February 28 Valid until 2013 February 28 (expired) For joint research activities between MANA and RPI, including research collaborations, exchange of personnel and organizing workshops.
3.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	California NanoSystems Institute (CNSI), University of California, Los Angeles (UCLA), USA Memorandum of Understanding (MOU) for collaboration on "Materials Science and Technology" Signed on 2008 March 24 Valid until 2013 March 24 (expired) For scientific and technical cooperation between MANA and the MANA Satellite at CNSI (PI Prof. James K. Gimzewski).
4.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Center for Nanostructure Characterization (CNC), Georgia Institute of Technology (GIT), USA Memorandum of Understanding (MOU) for collaboration on "Materials Nanoarchitectonics" Signed on 2008 May 6 Valid until 2013 May 6 (expired) For scientific and technical cooperation between MANA and the MANA Satellite at GIT (PI Prof. Zhong Lin Wang).
5.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Centre National de la Recherche Scientifique (CNRS), Regional Delegate of the Midi-Pyrénées Delegation, Toulouse, France Memorandum of Understanding (MOU) for collaboration on "Materials Nanoarchitectonics" Signed on 2008 May 30 Valid until 2013 May 30 (expired) For scientific and technical cooperation between MANA and the MANA Satellite at CNRS (PI Dr. Christian Joachim).
6.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Nanoscience Centre, University of Cambridge, UK Memorandum of Understanding (MOU) for collaboration on "Materials Nanoarchitectonics" Signed on 2008 June 20 Valid until 2013 June 20 (expired) For scientific and technical cooperation between MANA and the MANA Satellite at University of Cambridge (PI Prof. Mark E. Welland).
7.	Counterpart of an Agreement: Name of an Agreement:	Indian Institute of Chemical Technology (IICT), India Memorandum of Understanding (MOU) for collaboration on

		"Chemistry of Nanoporous Materials"
	Dates of an Agreement:	Signed on 2008 July 3 Valid until 2013 July 3 (expired)
	Summary of an Agreement:	For joint research activities between MANA and IICT, including research collaborations, exchange of personnel and organizing workshops.
8.	Counterpart of an Agreement:	National Center of Competence for Nanoscale Science (NCCR), Institute of Physics, University of Basel, Switzerland
	Name of an Agreement:	Memorandum of Understanding (MOU) for collaboration on "Materials Nanoarchitectonics"
	Dates of an Agreement:	Signed on 2008 July 22 Valid until 2013 July 22 (expired)
	Summary of an Agreement:	For joint research activities between MANA and NCCR, including research collaborations, exchange of personnel and organizing workshops.
9.	Counterpart of an Agreement:	Yonsei University, Korea
	Name of an Agreement:	Memorandum of Understanding (MOU) for collaboration on "Sustainable Chemical Technology and Nano-bio Fusion Technology"
	Dates of an Agreement:	Signed on 2008 September 1 Valid until 2013 September 1 (expired)
	Summary of an Agreement:	For joint research activities between MANA and Yonsei University, including research collaborations, exchange of personnel and organizing workshops.
10.	Counterpart of an Agreement:	Chemical and Biological Engineering, Indian Institute of Science Education and Research (IISER), India
	Name of an Agreement:	Memorandum of Understanding (MOU) for collaboration on "Design of novel nanomaterials and their application in energy and environment"
	Dates of an Agreement:	Signed on 2008 December 19 Valid until 2013 December 19 (expired)
	Summary of an Agreement:	For joint research activities between MANA and IISER, including research collaborations, exchange of personnel and organizing workshops.
11.	Counterpart of an Agreement:	Supramolecular Chemistry Group, Institute for Inorganic Chemistry, University of Karlsruhe, Germany
	Name of an Agreement:	Memorandum of Understanding (MOU) for collaboration on "Nanostructured Transition Metal Complexes and Oxides"
	Dates of an Agreement:	Signed on 2009 January 29 Valid until 2014 January 29 (expired)
	Summary of an Agreement:	For joint research activities between MANA and University of Karlsruhe, including research collaborations, exchange of personnel and organizing workshops.
12.	Counterpart of an Agreement:	New Energy and Materials Leboratory (NEML), Department of Chemistry, Fudan University, China
	Name of an Agreement:	Memorandum of Understanding (MOU) for collaboration on "Utilizing insulative thermo-conductive composite materials to solve safety problems of lithium ion batteries for electric vehicles"
	Dates of an Agreement:	Signed on 2009 March 16 Valid until 2014 March 16 (expired)
	Summary of an Agreement:	For joint research activities between MANA and NEML, including research collaborations, exchange of personnel and organizing workshops.

13.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	National Centre for Catalysis Research, Indian Institute of Technology (IIT), India Memorandum of Understanding (MOU) for collaboration on "Chemistry of Nanoporous Materials" Signed on 2009 April 5 Valid until 2014 April 5 For joint research activities between MANA and IIT, including research collaborations, exchange of personnel and organizing workshops.
14.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Inorganic and Materials Chemistry, Institute of Inorganic Chemistry, University of Cologne, Germany Memorandum of Understanding (MOU) for collaboration on "Research on Fabrication and applications of advanced nanomaterials" Signed on 2009 May 28 Valid until 2014 May 28 For joint research activities between MANA and University of Cologne, including research collaborations, exchange of personnel and organizing workshops.
15.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Institute of Microengineering (IMT), Ecole Polytechnique Fédérale de Lausanne (EPFL), Switzerland Memorandum of Understanding (MOU) for collaboration on "Cantilever and Probe Array Technology (CAPATEC)" Signed on 2009 July 20 Valid until 2014 July 20 For joint research activities between MANA and IMT, including research collaborations, exchange of personnel and organizing workshops.
16.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Center for Nanoscience & Nanotechnology & Innovative Instrumentation (NAST), University of Rome Tor Vergata, Italy Memorandum of Understanding (MOU) for collaboration on "Nanostructured Materials for Sustainable Development" Signed on 2009 July 30 Valid until 2014 July 30 For joint research activities between MANA and NAST, including research collaborations, exchange of personnel and organizing workshops.
17.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Kirchhoff Institute of Physics, University of Heidelberg, Germany Memorandum of Understanding (MOU) for collaboration on "Atom-scale and mesoscale infrared plasmonic structures at the metal-Si interfaces" Signed on 2009 August 31 Valid until 2014 August 31 For joint research activities between MANA and University of Heidelberg, including research collaborations, exchange of personnel and organizing workshops.
18.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Department of Chemistry, Loughborough University, UK Memorandum of Understanding (MOU) for collaboration on "Structures of Stable Aza-substituted Organic Semiconductors" Signed on 2009 October 28 Valid until 2014 October 28 For joint research activities between MANA and

		Loughborough University, including research collaborations, exchange of personnel and organizing workshops.
19.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Lawrence Berkeley National Laboratory (LBNL), University of California, USA Memorandum of Understanding (MOU) for collaboration on "Electronic Configuration Evolution in Micro-Solid Oxide Fuel Cell (μ-SOFC) Electrode and Electrolyte Materials in operating Conditions: a Real-Time Dynamic Study in Soft X-rays Spectroscopy" Signed on 2010 February 9 Valid until 2015 February 9 For joint research activities between MANA and LBNL, including research collaborations, exchange of personnel and organizing workshops.
20.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Institute of Electronic Microelectronic and Nanotechnology (IEMN), University of Valenciennes – Hainaut Cambrésis, France Memorandum of Understanding (MOU) for collaboration on "Interconnects and Nanocontacts for Nanorod- and Nanowire-based Electronic Devices Applications" Signed on 2010 May 20 Valid until 2015 May 20 For joint research activities between MANA and IEMN, including research collaborations, exchange of personnel and organizing workshops.
21.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Erlangen Catalysis Resource Center, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany Memorandum of Understanding (MOU) for collaboration on "Design of novel nanoporous materials" Signed on 2010 June 21 Valid until 2015 June 21 For joint research activities between MANA and University Erlangen-Nürnberg, including research collaborations, exchange of personnel and organizing workshops.
22.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Department of Materials Science, Fudan University, China Memorandum of Understanding (MOU) for collaboration on "Organic-Inorganic Nano Hybrid Materials for Optoelectronic Applications" Signed on 2010 July 23 Valid until 2015 July 23 For joint research activities between MANA and Fudan University, including research collaborations, exchange of personnel and organizing workshops.
23.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Center for Intelligent Nano Bio Materials (CINBM), Department of Chemistry and Nanoscience (Brain Korea 21), Ewha Womans Univeristy, Korea Memorandum of Understanding (MOU) for collaboration on "Design of novel nanoparticles, nanoporous materials and nanohybrids" Signed on 2010 August 27 Valid until 2015 August 27 For joint research activities between MANA and CINBM, including research collaborations, exchange of personnel and organizing workshops.

24.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Karlsruhe Institute of Technology (KIT), Germany Memorandum of Understanding (MOU) for collaboration on "Metal Oxide Aqueous Interfacial Chemistry" Signed on 2010 September 16 Valid until 2015 September 16 For joint research activities between MANA and KIT, including research collaborations, exchange of personnel and organizing workshops.
25.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	CNRS, Regional Delegation Provence et Corse, and Université de la Méditerrannée, France Memorandum of Understanding (MOU) for collaboration on "Transient chemistry of metal ions for low temperature ultrafast laser-assisted growth of hetero-nanostructures in aqueous solutions" Signed on 2010 September 20 Valid until 2015 September 20 For joint research activities between MANA and CNRS and Université de la Méditerrannée, including research collaborations, exchange of personnel and organizing workshops.
26.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Anhui Key Laboratory of Nanomaterials and Nanostructres, Institute of Solid State Physics, Chinese Academy of Sciences, China Memorandum of Understanding (MOU) for collaboration on "Low dimensional Nanostructures" Signed on 2010 October 6 Valid until 2015 October 6 For joint research activities between MANA and Anhui Key Laboratory, including research collaborations, exchange of personnel and organizing workshops.
27.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Multidisciplinary Center for Development of Ceramic Materials (MCDCM), Brazil Memorandum of Understanding (MOU) for collaboration on "Research and development of nanostructured materials for alternative energy and sensor devices" Signed on 2010 October 26 Valid until 2015 October 26 For joint research activities between MANA and MCDCM, including research collaborations, exchange of personnel and organizing workshops.
28.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Laboratory for Nanotechnology (LNT), Vietnam National University Ho Chi Minh City (VNU-HCM), Vietnam Memorandum of Understanding (MOU) for collaboration on "Optoelectronic and bioelectronics nanodevices" Signed on 2011 January 24 Valid until 2016 January 24 For joint research activities between MANA and LNT, including research collaborations, exchange of personnel and organizing workshops.
29.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement:	Petrochemical Research Chair, King Saud University, Kingdom of Saudi Arabia Memorandum of Understanding (MOU) for collaboration on "Design of novel nanoporous materials and Catalysis" Signed on 2011 January 25 Valid until 2016 January 25

	Summary of an Agreement:	For joint research activities between MANA and King Saud University, including research collaborations, exchange of personnel and organizing workshops.
30.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	CNRS, Regional Delegate for Alpes and Institut Polytechnique de Grenoble (IPG), France Memorandum of Understanding (MOU) for collaboration on “Biomaterials, ferrelectric materials and photonic crystals” Signed on 2011 February 1 Valid until 2016 February 1 For joint research activities between MANA and IPG, including research collaborations, exchange of personnel and organizing workshops.
31.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Université de Montreal (UdeM), Canada Memorandum of Understanding (MOU) for collaboration on “Functional nanoparticles and interfaces for radiation-sensitive spatio-temporal therapeutic and imaging applications” Signed on 2011 July 4 Valid until 2016 July 4 For scientific and technical cooperation between MANA and the MANA Satellite at UdeM (PI Prof. Françoise M. Winnik).
32.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Flinders University of South Australia, Australia Memorandum of Understanding (MOU) for collaboration on “Research in Nanotechnology” Signed on 2011 July 19 Valid until 2016 July 19 For joint research activities between MANA and Flinders University, including research collaborations, exchange of personnel and organizing workshops.
33.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	University of Melbourne, Australia Memorandum of Understanding (MOU) for collaboration on “Innovative nanomaterials which improve quality of life whilst being safe for communities and the environment” Signed on 2011 September 21 Valid until 2016 September 21 For joint research activities between MANA and University of Melbourne, including research collaborations, exchange of personnel and organizing workshops.
34.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Biomaterials and Tissue Engineering Research Center, Shanghai Institute of Ceramics (SIC), Chinese Academy of Science, China Memorandum of Understanding (MOU) for collaboration on “Development of Three-Dimensional Porous Scaffolds for Tissue Engineering” Signed on 2011 December 1 Valid until 2016 December 1 For joint research activities between MANA and SIC, including research collaborations, exchange of personnel and organizing workshops.
35.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement:	Department of Materials Science & Engineering, Tsinghua University, China Memorandum of Understanding (MOU) for collaboration on “New Functional Nanomaterials for Energy and Environment Applications” Signed on 2012 January 28

	Summary of an Agreement:	Valid until 2017 January 28 For joint research activities between MANA and Tsinghua University, including research collaborations, exchange of personnel and organizing workshops.
36.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	International Training Institute for Materials Science (ITIMS), Hanoi University of Science and Technology (HUST), Vietnam Memorandum of Understanding (MOU) for collaboration on "Application of plasmonic materials for sensors and energy conversion devices" Signed on 2012 February 7 Valid until 2017 February 7 For joint research activities between MANA and ITIMS, including research collaborations, exchange of personnel and organizing workshops.
37.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Instituto de Fisica de São Carlos, University of Sao Paolo, Brazil Memorandum of Understanding (MOU) for collaboration on "Nanotechnology for Organized Materials" Signed on 2012 April 25 Valid until 2017 April 25 For joint research activities between MANA and University of Sao Paolo, including research collaborations, exchange of personnel and organizing workshops.
38.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	London Centre for Nanotechnology (LCN), University College London (UCL), UK Memorandum of Understanding (MOU) for collaboration on "Electronic Structure Calculations of Nanowires" Signed on 2012 October 8 Valid until 2017 October 8 For scientific and technical cooperation between MANA and the MANA Satellite at UCL (API Dr. David Bowler).
39.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Department of Polymer Science and Engineering, Kyungpook National University, Korea Memorandum of Understanding (MOU) for collaboration on "Development of advanced functional biomaterials with controllable compositions and nano/microscopic structures for stem cell differentiation and tissue regeneration" Signed on 2013 January 18 Valid until 2018 January 18 For joint research activities between MANA and Kyungpook National University, including research collaborations, exchange of personnel and organizing workshops.
40.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Centre Interdisciplinaire de Nanoscience de Marseille (CINaM-CNRS) and Physique des Interactions Ioniques et Moléculaires (PIIM-CNRS), France Memorandum of Understanding (MOU) for collaboration on "Low-dimensional nanomaterial architectonics" Signed on 2013 May 2 Valid until 2018 May 2 For joint research activities between MANA and CINaM-CNRS and PIIM-CNRS, including research collaborations, exchange of personnel and organizing workshops.
41.	Counterpart of an Agreement:	National Center for Nanoscience and Technology (NCNST), China

	Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Memorandum of Understanding (MOU) for collaboration on "Quest for neuromorphic behavior of materials" Signed on 2013 June 24 Valid until 2018 June 24 For joint research activities between MANA and NCNST, including research collaborations, exchange of personnel and organizing workshops.
42.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	School of Materials Science and Engineering, Huazhong University of Science and Technology (HUST), China Memorandum of Understanding (MOU) for collaboration on "Advanced Functional Materials for Energy and Environment Applications" Signed on 2013 July 29 Valid until 2018 July 29 For joint research activities between MANA and HUST, including research collaborations, exchange of personnel and organizing workshops.
43.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Center for Nanostructure Characterization (CNC), Georgia Institute of Technology (GIT), USA Memorandum of Understanding (MOU) for collaboration on "Inorganic Nanomaterials for Energy-Related Applications" Signed on 2013 November 25 Valid until 2018 November 25 For scientific and technical cooperation between MANA and the MANA Satellite at GIT (PI Prof. Zhong Lin Wang). Renewal of expired MOU.
44.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Centre National de la Recherche Scientifique (CNRS), Regional Delegate of the Midi-Pyrénées Delegation, France Memorandum of Understanding (MOU) for collaboration on "Molecular devices and related materials" Signed on 2013 December 10 Valid until 2018 December 10 For scientific and technical cooperation between MANA and the MANA Satellite at CNRS (PI Dr. Christian Joachim). Renewal of expired MOU.
45.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	St. Petersburg State Electrotechnical University (LETI), Russia Memorandum of Understanding (MOU) for collaboration on "Nanoarchitectonics on Future Electric Devices" Signed on 2014 February 28 Valid until 2019 February 28 For joint research activities between MANA and LETI, including research collaborations, exchange of personnel and organizing workshops.
46.	Counterpart of an Agreement: Name of an Agreement: Dates of an Agreement: Summary of an Agreement:	Bristol Centre for Nanoscience and Quantum Information (NSQI), University of Bristol, UK Memorandum of Understanding (MOU) for collaboration on "Nanomaterials and Nanodevices" Signed on 2014 March 7 Valid until 2019 March 7 For joint research activities between MANA and NSQI including research collaborations, exchange of personnel and organizing workshops.

6. Holding international research meetings

* Give up to twenty examples of the most representative ones of international research conferences or symposiums held between FY2007-2013 using the table below.

Date	Meeting title and Place held	Number of participants
March 10th - 13th, 2008	1st MANA International Symposium Tsukuba, JAPAN	262
February 25th - 27th,2009	2nd MANA International Symposium Tsukuba, JAPAN	310
October 23th, 2009	Symposium on Frontier in Nanotechnology and Materials, 2009 Tsukuba, JAPAN	146
March 3rd - 5th, 2010	3rd MANA International Symposium Tsukuba, JAPAN	326
March 23th – 24th, 2010	Materials Nanoarchitectonics for Sustainable Development Hakone, Japan	37
January 19th, 2011	Workshop on Dirac Electron Systems 2011 Tsukuba, JAPAN	105
March 3rd - 5th, 2011	4th MANA International Symposium Tsukuba, JAPAN	406
March 2nd – 4th, 2012	5th MANA International Symposium Tsukuba, JAPAN	396
May 10th – 11th, 2012	Australia/MANA workshop on Nanoarchitectonics for Innovative Materials & Systems Tsukuba, JAPAN	98
October 1st, 2012	PCCP-MANA symposium On Nontechnology, Materials and Physical Chemistry Tsukuba, JAPAN	106
October 3rd, 2012	MANA 5th Anniversary Memorial Symposium Tsukuba, JAPAN	257
October 7th, 2012	The summer school on ferroelectricity 2012 Tsukuba, JAPAN	49
November 6th - 7th, 2012	NSQI-MANA joint symposium Tsukuba, JAPAN	50
December 1st, 2012	1st Workshop on Nano-Life Montreal, CANADA	100
February 29th - March 2nd, 2013	6th MANA International Symposium Tsukuba, JAPAN	414
March 19th, 2013	Material Architectonics for Sustainable Action (MASA 2013) Tsukuba, JAPAN	60
June 28th – 29th, 2013	International Workshop on Thermoelectric Research & Thermal Management Technology Tsukuba, JAPAN	87

October 9th – 11th, 2013	Swiss-Japanese Nanoscience Workshop: Materials Phenomena at Small Scale (Joint) Tsukuba, JAPAN	197
January 29th – 31th, 2014	Trends in Nanotechnology Japan 2014 (Joint) Tokyo, JAPAN	325
March 3ed – 4th, 2014	MANA/ICYS Reunion Workshop 2014 Tsukuba, JAPAN	107
March 5th – 7th, 2014	7th MANA International Symposium Tsukuba, JAPAN	425
March 11th – 12th, 2014	Japan-Taiwan Joint Workshop on Nanospace Materials March 11-12, 2014 Fukuoka, JAPAN	102
March 24th – 25th, 2014	International Symposium on Smart Biomaterials Tsukuba, JAPAN	118

World Premier International Research Center Initiative (WPI)

1. Host institution's commitment

1-1. Contributions from host institution

(1) Fund, Personnel

(2007-201)

<Fund> **(million yen)**

Fiscal Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Total**
Personnel									
- Faculty members (including researchers)	54	88	135	167	1	1	32	0	613
Full-time	※ 4	※ 9	※ 1	※ 45	※ 1	※ 1	※ 32	0	93
Concurrent	50	79	134	122	0	0	0	0	385
- Postdocs	0	0	0	0	0	0	0	0	0
- RA ect.	0	0	0	0	0	0	0	0	0
- Research - support staffs	0	52	6	5	0	0	0	0	63
- Administrative staffs	0	17	0	1	0	0	0	135	153
Project activities	237	555	680	497	458	582	535	435	3979
Travel	5	69	87	68	32	36	13	54	364
Equipment	31	250	260	154	109	140	87	108	1139
Research projects	1187	920	1054	1089	736	877	986	809	7658
Total	1514	1951	2222	1981	1336	1636	1653	1541	13834

<Personnel> **(person)**

Fiscal Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**Total**
Personnel									
- Faculty members (including researchers)	10	27	25	26	0	0	0	0	88
Full-time	0	0	0	0	0	0	0	0	0
Concurrent	10	27	25	26	0	0	0	0	88
- Postdocs	0	0	0	0	0	0	0	0	0
- RA etc.	0	0	0	0	0	0	0	0	0
- Research - support staffs	0	4	2	1	0	0	0	0	7
- Administrative staffs	0	4	0	1(1)	0	0	0	3(3)	8(8)

* Regarding "Fund" entry, describe with reference to the items in the Progress Report(実績報告書,Jisseki-hokoku-sho)based on Article 12 of the Grant Guidelines(交付要綱,Kofu-yoko).
* Don't include competitive funding obtained by researchers (used as research project funding)
* Under "Personnel", enter the number of full-time administrative staff within the parenthesis.

Note: The description was changed in the same manner as other four WPI centers. After FY2011 personnel costs of concurrent members, which had been paid from NIMS's indirect costs, do not appear numerically since they have been all paid from WPI grants.

※The number indicates the sum of unexpected extra personnel expenses such as overtime pays. This was paid by NIMS operations subsidies as part of host institution's commitments but this amount is not converted into the number of personnel since it is impractical.

(2) Provision of land and/or building(s), lab space, etc.

- WPI-MANA building: 6,354 m^2
- MANA building: 12,934 m^2
- Collaborative building: 298 m^2
- Main building: 606 m^2
- Administration and Research building: 918 m^2

1-2. System under which the center’s director is able to make substantive personnel and budget allocation decisions

- Annual allocation of research project expenses and center activity expenses from NIMS’s operations subsidies to MANA
- Provision of approximately 90 tenure positions to MANA

1-3. Support for the center director in coordinating with other departments at host institution when recruiting researchers, while giving reasonable regard to the educational and research activities of those departments

- Making MANA a permanent research organization and its researchers full-time by abolishing part of existing research organizations (one division and three centers)

1-4. Revamping host institution’s internal systems to allow introducing of new management methods
(e.g., English-language environment, merit-based pay, cross appointment, top-down decision making unfettered by conventional modes of operation)

- Stipulating MANA’s role in promoting some of NIMS’s system reforms (internationalization and development of young researchers) in the NIMS’s five-year plan
- Revision of individual performance evaluation system for tenured researchers with the aim of enabling them to tackle challenging research topics
- Implementation of programs to improve the English proficiency of NIMS administrative staff to establish an institute-wide bilingual administration system.
- Establishment of funded joint research system to make PIs in the satellites undertake MANA research

1-5. Accommodation of center’s requirements for infrastructural support
Utilities and other infrastructure support provided by host institution.
(*In addition to listed in the item 1. Contributions from host institution)

※ All of the support is included in “Research projects” of the item 1: start-up funds for newcomers, operating expenses for MANA Foundry, installing costly shared-use equipment, NIMS supercomputer’s CPU time to MANA theoreticians, required utilities, etc.

1-6. Support for other types of assistance

- Bolstering of MANA workforce by assigning new permanent staff
- Research Abroad Program for sending permanent researchers to overseas institutions
- Livelihood support for foreign researchers
- Establishing various joint graduate school programs with domestic and overseas schools to recruit research assistants
- NIMS Invitation Program and NIMS Internship Program for inviting scientists and students
- ‘Seeds’ development research grants for all the permanent researchers

3. Transition in the number of female researchers

Enter the number and percentage of female researchers in the top of each space from 2010 to 2013 and the total number of all the researchers in the bottom.

(Person)

		FY2010	FY2011	FY2012	FY2013	Final goal
Researchers		38, 19.3%	45, 22%	45, 22.6%	43, 20.8%	50, 25%
		197	206	199	207	200
	Principal investigators	1, 3.5%	2, 8%	2, 8.3%	2, 9.1%	3, 12%
		28	25	24	22	25
	Other researchers	37, 21.9%	43, 24%	43, 24.6%	41, 22.2%	47, 27%
		169	181	175	185	175

National Institute for Materials Science
Operational Goals
(Mid-Term Goals)
March 1, 2011

Ministry of Education, Culture, Sports, Science and Technology

(snip)

1. Basic research and fundamental R&D for materials science and technology

1.1 Basic research and fundamental R&D in priority R&D fields

For Japan to create cutting-edge technologies in a wide range of fields, it is necessary to raise the level of fundamental science and technology in various areas by way of fusion and cooperation, so NIMS must promote interdisciplinary advanced R&D in an effort to achieve breakthroughs in the creation of new materials. In the 4th Science and Technology Basic Plan, "green innovation" in the fields of environment and energy is defined as a major pillar of growth. Since materials science and technology holds the key to solving major issues in this area, NIMS must promote R&D that will contribute to those solutions.

In light of this situation and given the outcomes generated by the institute to date as well as potential uses for its people and research, NIMS will strategically promote 1) interdisciplinary advanced R&D to achieve breakthroughs in the creation of new materials, and 2) R&D to advance materials in response to societal needs during the mid-term plan period. The interdisciplinary advanced R&D in 1) shall guide and support R&D aimed at solving the issues in 2).

1.1.1 Promoting interdisciplinary advanced R&D in an effort to achieve breakthroughs in the creation of new materials

This item comprises two fields, advanced key technologies and nanoscale materials, and the details for each are outlined below.

(snip)

2) Nanoscale materials field

To discover and cultivate the technological seeds needed to create new materials before anyone else in the world, it is crucial for NIMS to utilize the unique properties expressed by nanoparts, regardless of whether they are inorganic or organic. In addition to focusing on properties unique to nanoparts, it must also concentrate on revolutionary material properties that can serve to replace existing materials and devices or stimulate innovation in manufacturing processes in order to cultivate this field into a next-generation growth area,.

For this reason, NIMS will develop and use advanced nanoscale synthesizing techniques to create entirely new nanostructures. It will also optimally combine the unique functions of nanotubes, nanosheets and other nanoscale materials and undertake research into developing a system for dramatically enhancing said functions through the effective interaction thereof. In this way, NIMS will create the revolutionary technological seeds required to create new materials.

NIMS will also cooperate with other research institutions to promote interdisciplinary research in this field as part of its research into creating systems for combining various nanoscale materials.

(snip)

3. Activities as a core center

NIMS is Japan's only research institute dedicated to basic research and fundamental R&D in the field of materials science and technology, and it is important that the Institute make its presence known within Japan and around the world and unflaggingly endeavor to improving its profile. As such, NIMS will respond to the changes in the international situation, technological trends and societal needs and undertake its activities with a recognition of its duties as a core center.

(snip)

3.2 Cultivating and improving the quality of researchers and technicians

To cultivate and improve the quality of researchers and technicians at NIMS, it is essential to sustain and develop the intellectual infrastructure to support Japan's materials research.

With the globalization of business and research activities, international competition has also intensified in the field of materials research. As such, NIMS shall cultivate its researchers into internationally-viable human resources in a well-planned manner. In addition, NIMS will work to enhance university and graduate school education and actively accept post-docs in an effort to train the next generation of materials researchers. Furthermore, NIMS will cultivate and improve the skills of technicians with expertise in advanced analysis and processing to support a variety of research activities in the field of materials science and technology.

(snip)

3.4 Developing international networks and research hubs for materials science research

As brain circulation progresses on a global scale and competition to secure outstanding talent intensifies, NIMS will strive to activate its research activities by promoting the development of a border-less research environment and interaction among different people and different research fields. To do this, NIMS will proactively utilize the international networks it has built by way of initiatives such as the World Materials Research Institute Forum. NIMS will continue developing the internationally open research environment it has built with the International Center for Materials Nanoarchitectonics (MANA), a MEXT-designated World Premier International Research Center, and use it as a springboard for pursuing challenging research. It will also enact reforms aimed at spreading MANA's initiatives throughout the rest of the Institute.

(snip)

Revised: March 30, 2012

National Institute for Materials Science
Mid-Term Goal Achievement Plan
(Mid-Term Plan)
March 31, 2011

National Institute for Materials Science

(snip)

1. Basic research and fundamental R&D for materials science and technology

1.1 Basic research and fundamental R&D in priority R&D fields

1.1.1 Promoting interdisciplinary advanced R&D in an effort to achieve breakthroughs in the creation of new materials

For Japan to create cutting-edge technologies in a wide range of fields, the advancement of fundamental science and technology in various areas is a necessary condition. For this reason, NIMS will conduct basic materials research and fundamental R&D, including developing measurement technologies, simulation technologies, materials design techniques, and novel fabrication process and searching for phenomena and functions unique to the nanoscale world in both organic and inorganic materials, in an effort to achieve breakthroughs in the creation of new materials.

(snip)

2) Nanoscale materials field

In this field, NIMS will create new materials by taking advantage of the unique properties of nanoparts, be they organic or inorganic, expressed by way of manipulating and controlling atoms and molecules on the nanoorder scale (i.e., one billionth of a meter). Since research will be promoted on a medium-term time scale aiming for the practical application of materials in five to ten years, NIMS will focus not only on properties unique to nanoparts, it will also concentrate on revolutionary material properties that can serve to replace existing materials and devices or stimulate innovation in manufacturing processes.

Since this field will cover research in domains such as electronics, chemistry and biotechnology, NIMS will promote the sharing of issues and achievements across these multiple research areas while creating systems to enable functional expression through the combination of various nanoscale materials. NIMS will undertake management improvements, such as promoting the regular interaction of researchers in this field, and cooperate with other nanotechnology research centers.

Concrete projects include the following:

- System nanotechnology
- Chemical nanotechnology
- Nanoelectronics
- Nanobiology

With these projects, NIMS will achieve the following technical goals by FY2015:

- Develop atomic switches and related devices required for the development of “Beyond CMOS” nanoelectronics;
- Create new nanoscale materials by achieving valence control and other means of precisely controlling compositions and structures;
- Develop higher-K materials that can interface directly with Si and amorphous metal gate materials with large effective work function differences;
- Create self-healing composite biomaterials tailored to cardiovascular disease patients.

(snip)

3. Activities as a core center

As a core center for materials research, NIMS will actively participate in the policies of the national government and deliberately and steadily promote activities such as the administration of an advanced research base and the cultivation of human resources who can succeed in the global arena.

(snip)

3.2 Cultivating and improving the quality of researchers and technicians

To cultivate its researchers into internationally-viable human resources amid a backdrop of intense global competition, NIMS will provide opportunities for capacity-building in foreign research centers, by dispatching permanent researchers overseas for long-term assignments and other means, and it will promote participation in international research networks. NIMS will also contribute to the advancement of university and graduate school education by sending its researchers to universities as lecturers.

NIMS possesses a highly internationalized research environment with its International Center for Materials Nanoarchitectonics (MANA) and International Center for Young Scientists (ICYS). Placing young researchers in an international environment is a highly effective way to cultivate them into global human resources, so in recognition of this, NIMS will utilize its cooperative graduate school system to admit graduate students and research students and actively admit post-docs by way of various research support programs. In particular, NIMS will accept an average of 350 young researchers annually.

Furthermore, NIMS will strive to steadily cultivate and improve the skills of its technicians because technicians with expertise in advanced analysis and processing play an extremely important role in supporting the diverse array of materials science research activities.

(snip)

3.4 Developing international networks and research hubs for materials science research

NIMS has developed international networks by administering the World Materials Research Institute Forum, which is comprised of world-leading materials research organizations, and concluding international partnership agreements. Going forward, NIMS will take full advantage of these international networks to engage in international initiatives, including discussions with foreign researchers as part of routine research activities, the invitation and dispatch of researchers to and from NIMS, and the convocation of international symposia. At the same time, NIMS will undertake strategic research partnerships while keeping an eye on trends in the developing nations of Asia where rapid growth is expected. NIMS will maintain an annual average of 200 partner institutions with which it keeps international cooperation agreements for the duration of the Mid-Term Plan period. Given the importance of turning international activities into concrete research results, NIMS will maintain publishing an annual average of 300 international joint works on an institute-wide basis.

To retain outstanding foreign researchers in response to efforts to accelerate global brain circulation, NIMS has established international research environments and has striven to secure and train young researchers, as typified by MANA; it will apply these experiences to institute-wide internationalization efforts. In particular, NIMS will establish a research environment in which foreign researchers do not experience inconvenience by making its administrative division bilingual. It will also maintain an annual average foreign researcher ratio of at least 35% on an institute-wide basis.

In light of the results of the annual follow-up and mid-term evaluations for MANA, NIMS will strengthen efforts to reform the research and development system, including building international and interdisciplinary environment, cultivating young researchers and young leaders, and internationalization by making English the official language.

(snip)

World Premier International Research Center Initiative (WPI)
Progress Plan Application
(For Extension Application Screening)

Host Institution	**National Institute for Materials Science (NIMS)**	Host Institution Head	**Sukekatsu Ushioda**
Research Center	**International Center for Materials Nanoarchitectonics (MANA)**	Center Director	**Masakazu Aono**

* *Write your report within 6 pages.*
* *Use yen (¥) when writing monetary amounts in the report. If an exchange rate is used to calculate the yen amount, give the rate.*

1. Mid- to Long-term Research Objectives and Strategies Based on the Center's Results obtained to Date

Describe new challenges that are included in the Center's research objectives and plans for the extension period. If major changes will be made in the Center's operation, such as newly set research themes/objectives or a change in the director, describe the strategic background to the adjustments.

Outline

Based on its vision of "Pioneering a new paradigm of nanotechnology for new materials development," MANA has pursued research in the four fields of Nano-Materials, Nano-Systems, Nano-Power and Nano-Life fields. Based on the new concept of nanoarchitectonics we devised, we have sought out the "new paradigm of nanotechnology" in the aforementioned vision, and we have accomplished numerous outstanding research achievements (see "Progress Report of the WPI Center" which was submitted at the same time). The outstanding nature of MANA's research results is evidenced in various indicators. For example, over the past 6.5 years, we have produced 80 papers that are in the top 1% in the world by number of citations – a figure that exceeds those posted by many other world-class research institutes.

In preparation for MANA's extension application, we conducted a detailed analysis on our research achievements to date, which clearly highlighted the importance of cross-linking theoretical and experimental research and fusing nanotechnology (nanoarchitectonics) with life sciences. In the extension period, MANA will vigorously promote these two types of fusion.

When we analyzed the progress made on our three grand challenges that MANA has declared, we found that several promising preliminary outcomes had been obtained, so we decided to continue pursuing these in the extension period and add a fourth grand challenge.

These goals are described in more detail below.

Theory-Experiment "Cross-linkage" (Fusion)

To date, many of MANA's research outcomes have been the product of the fusion of theory and experimentation. Therefore, in the extension period, we will add a fifth field, Nano-Theory field, to our four existing research fields. ~~(see~~As we describe in detail in Section 2-1~~ for details).~~, ~~The~~ the Nano-Theory field will be a large group of about 50 theoreticians~~)~~.

Researchers in the Nano-Theory field will be able to effectively utilize some of the world's most advanced computers such as the K-computer. However, one of our goals is to be the first research center in the world to create a new paradigm for theoretical research not bound by first principles calculations. Despite the fact that many interesting nanoscale phenomena are accompanied by excited states, dynamic processes and many-body effects, contemporary first principles calculations are not necessarily good at handling these. To overcome this obstacle, we will introduce bold yet appropriate approximation methods to spur a new trend in theoretical research. This will encourage the fusion of theoretical research with experimentation. Not only will the Nano-Theory field fuse theory and experimentation, it will act to promote interdisciplinary research among MANA's four other experimentation-oriented research fields.

Firstly, one research project will use first principles calculations that were improved by CONQUEST, the ultra-large-scale computational code that MANA researchers played a key role in developing, on the K-computer to elucidate the electronic states and structures of large systems structures that include more than a million atoms. This will likely serve to encourage experimental research at MANA. Despite the fact that these processes – i.e., excited states and processes with a very small probability of occurring that correspond to the tails of probability distributions – occur frequently in the real world, it is next to impossible to elucidate the atomic and molecular movements in these processes by using existing first principles calculations to run simulations on a realistic time scale (these processes are caused by dramatic structural changes at the atomic and molecular level). In first principles calculations, these phenomena are nothing more than rare events, but the real world is strongly governed by them (this resembles the process by which organisms evolve based on spontaneous mutation, which is not easy to predict). To overcome this obstacle, researchers at MANA and their external research collaborators have recently formed a group to study rare event sampling methods, and the Center is strongly supports this effort. Spurred on by the theoretical research of topological insulators, which explores principles without relying on conventional computer science, a new realm of solid state physics has started to open up, and MANA researchers have contributed significantly to this development. By combining this research with MANA's outstanding nanoarchitectonics technologies, we hope to develop entirely novel quantum devices.

~~Creation of~~ MANA's Unique Nano-Life Research ~~Field~~

MANA established the Nano-Life field with the aim of creating a new field that fuses MANA's world-leading nanotechnology with life sciences. One important feature of MANA is this environment in which high caliber nanotechnology and life science researchers work side-by-side and gain a thorough understanding of each other's disciplines. This has recently started producing remarkable results. In the extension period, we will take advantage of this environment to create a Nano-Life field that is unique to MANA. We aim to create new, never-before-seen things and systems by studying the functions of cells (which are the building blocks of life), sensory organs and the brain, the most complex biological structure, and incorporating the knowledge gained into our best nanoarchitectonics technologies. Conversely, we will also promote the active utilization of nanoarchitectonics technologies in Nano-Life research.

Research in this field includes one study using neuromorphic network circuits composed of hundreds of millions of MANA-developed synaptic atomic switches, whose interesting emergent functionality we have already detected, to create a material-based prototype unit of an artificial brain. We also aim to physically apply new calculation algorithms borrowed from the remarkable functionality of single cells to inorganic materials. Doing this will require cross-linking with theoretical researchers. We have already developed ultrasensitive/ultraparallel molecular sensors that borrow from our knowledge of animal olfactory organs and enable the early detection of cancer from an analysis of exhaled breath (this is a joint research project with Switzerland's University of Basel). We will revolutionize methods for analyzing gases and liquids in a wide range of fields by developing these sensors further. In addition, we are promoting applied research for medical care, including the development of a smart polymer fiber mesh that can attach to a cancerous area and release cancer-fighting drugs when an electromagnetic field is applied from outside the body.

MANA's Grand Challenges

The following three grand challenges were declared by MANA.

★ **Nanoarchitectonic artificial brain**
★ **Room-temperature superconductivity**
★ **Practical artificial photosynthesis**

We consider these as long-term research objectives and do not expect to achieve any results over the short term, but some intriguing preliminary outcomes have already been obtained. We will continue striving toward these goals in the extension period as well. The following is a report on the current state and future plans for these grand challenges.

★ **Nanoarchitectonic artificial brain**: We have uncovered an interesting fact about the atomic switches we have been developing, namely, that they possess properties similar to the synapses in the brain. When we created a network circuit from several tens of millions of these atomic switches, we observed several unexpected characteristics (e.g., the electrical conductivity increases and decreases randomly when a direct current voltage is applied). In the extension period, we will develop new computation methods using these interesting properties. At present, experimental researchers are cooperating closely with theoreticians where appropriate.

★ **Room-temperature superconductivity**: We are attempting to transform insulators and semiconductors into superconductors by physically injecting electrons or holes by field effect. In one experiment, we successfully used the field effect to introduce a hole into a diamond and metalize it, but we have not yet created a room-temperature superconductor. Although we will continue this kind of research in the extension period, an unexpected theory has been posed by researchers at MANA. They theoretically predict that, when heavy atoms, such as gold, are formed into a two-dimensional buckled honeycomb lattice and an electric field is applied perpendicularly, current will flow along its edge with zero resistance even at high temperatures up to 600 K. An experiment has been launched in an attempt to prove this theory.

★ **Practical artificial photosynthesis**: We have already successfully achieved several photo-synthetic reactions using new photocatalysts, and going forward, we will focus on developing systems to boost the efficiency of these reactions. We are currently studying systems that intensify light by effectively using plasmonics technology, which is already one of MANA's strong suits. In another interesting endeavor, we demonstrated high photosynthetic conversion efficiency in a system simulating the fine structure of plant leaves. A further study has revealed that the high conversion efficiency can be attributed to not only the increased surface area, but also the three dimensionally interconnected tunnel structure.

In the extension period, we will add a fourth goal to the Grand Challenges:

★ **Nanoarchitectonic ~~revolution of~~supreme bio-sensing**

This goal is closely related to efforts to open up a new area of study within MANA’s original Nano-Life field described above. To do this, we will need to make full use of MANA’s original nanoarchitectonic sensing methods, which have not been achieved anywhere else. These methods include multiple-probe scanning probe microscopy (STM, AFM, KFM) to analyze signaling between specified points in a neuron network, ultrasensitive/ultraparallel molecular sensors that can sense stimuli at more than 1000x the sensitivity of human sensory organs, and bio-imaging with near infrared light that can pass through the human body – something that has been impossible up to this point. The ultimate aim of this Grand Challenge goal is to generate innovations in the life sciences by striving to develop these kinds of nanoarchitectonic bio-sensing methods.

Nano-Materials, Nano-Systems, Nano-Power, Nano-Life & Nano-Theory Fields

The initial four fields we established form the core of MANA's research. In these fields, we made clear distinctions between various opposing factors, i.e., fundamental vs. applied research, materials vs. systems and inorganic materials vs. living organisms, but these groups were intentionally organized to encourage fusion among the fields. In the extension period, we will establish a new fifth field, the Nano-Theory Field, where we will fortify our theoretical research (as was already mentioned). Primary examples of the ambitious research that will be undertaken in these five fields in the extension period are~~is~~ as follows.

● **Nano-Materials Field**: This field aims to exploit the science and technology for the creation of new nanosheet-based materials that MANA has accumulated to date to realize~~ a room temperature superconducting devices,~~ metamaterials (e.g. a material not found in nature that possesses a negative refractive index) and a room temperature superconducting devices by using nanosheets with massive electric permittivity, etc. We will also develop more novel nanomeasurement methods to support these kinds of research projects.

● **Nano-Systems Field**: This field aims to use a network of atomic switches to realize the basic unit of a nanoarchitectonic artificial brain; to achieve the world's first truly monomolecular device; to develop a new, decoherence-free quantum bit using topological insulators; to develop a room temperature superconducting device etc. We will also promote the development of methods to enable the measurement of local (i.e., nanometer scale) electrical conductivity at any position, something that is essential for conducting these kinds of research.

● **Nano-Power Field**: This field aims to realize highly efficient nanoarchitectonic systems in order to achieve practical artificial photosynthesis. To do this, we will actively promote plasmonics technology and close cooperation with researchers conducting theoretical calculations using rare event sampling methods.

● **Nano-Life Field**: As mentioned above in "Features of MANA's Unique Nano-Life Research", we will promote fusion of life science and nanoarchitectonics research. We believe some of this work will lead to technologies that can be used by diagnostic technicians and medical care professionals working on the front lines.

● **Nano-Theory Field**: As mentioned above in "Theory-Experiment 'Cross-linkage", we aim to develop new theoretical research techniques driven by rare event sampling instead of the first principles calculations used by the K-computer, the world's fastest supercomputer, and we will promote the fusion of theory and experimentation in a wide range of research, including theoretical research into the latest topological insulators.

2. Management System of the Research Organization

2-1 Describe the Center's research organizational management system that will execute the research strategy and plan described above.

** In Appendix 1, list the PIs who will ensure that the Center's project is sustained and advanced in the extended period.*
** In Appendix 2, diagram the Center's organizational management system.*

In April 2016, one year before the end of the 10-year project period, we will launch the NIMS's next Seven-Year Plan and implement the following key structural reforms.

i) We will strengthen MANA operations by adding a new Deputy Director (Dr. Takayoshi Sasaki) to assist the current administrative triumvirate composed of the Director-General (Dr. Masakazu Aono), Chief Operating Officer (Dr. Yoshio Bando) and the Administrative Director (Mr. Takahiro Fujita).

ii) We will significantly invigorate the PI ranks by replacing about half of the PIs with new ones. While most of these PIs will be selected from within NIMS, some positions will be filled by international public recruiting. When doing this, we will strive to select young researchers, become multinational and hire more women.

iii) We will constructively dissolve the MANA satellites, which have contributed significantly to MANA's achievements by raising the level of research, cultivating young researchers and internationalizing the Center. Meanwhile, renowned outside researchers who conduct research that resonate with MANA's principles and who could contribute to joint research and/or personnel exchange with MANA will be asked to serve as MANA PIs.

iv) We will establish a new Nano-Theory field at MANA staffed by about 50 theoreticians. By combining the 35 researchers from the NIMS Computational Materials Science Unit who were moved to the new Theoretical Research Building (next to the WPI-MANA Building) with MANA's more than a dozen theoretical researchers, nearly one-fourth of MANA's researchers will be theoretical researchers. In addition to boosting the number of theoreticians, we will establish a Theoretician-Experimentalist Pairing (TEP) Program to more-or-less force the integration of theory and experiment. In principle, all theoretical researchers will be paired with experimental researchers, and the pairs will work on various research topics together. By doing this, we hope to significantly accelerate linkages between theory and experiment and dramatically escalate nanoarchitectonics research.

v) To achieve a unique shift in the Nano-Life field to focus on basic scientific research, we will transfer those researchers whose expertise does not suit the field's directions to NIMS (Note: This accounts for about half of the current researchers), and we will hire new researchers (including PIs) whose expertise dovetails with the directions of Nano-Life or transfer such researchers from other research fields of MANA.

vi) Aiming to achieve the four goals of the MANA Grand Challenges, we will strategically invest research resources (e.g., research funds, post-docs etc.) into these topics. We will also invite guest researchers to lead workshops and brainstorming sessions on specific topics (e.g., atomic switches, nanosheets, topological insulators/superconductors etc.).

vii) We will continue encouraging efforts to tackle innovative and challenging topics and conduct interdisciplinary research by holding Grand Challenge Meetings and setting up special funding programs.

2-2 Initiatives and plans that will impel system reforms

Describe the Center's action plan that embodies the national policies for research institutions(e.g., the National University Reform Plan, policy documents for independent administrative agency reform), and the Center's plan and strategies that lead to host institution reforms either directly or via ripple effects (also to other institutions, if applicable). Describe also the Center's strategies for fostering and securing the next generation of researchers (e.g., introduction of tenure tracks), and the system for enhancing the Center's organizational management, such as the implementation/verification PDCA system.

a) Reforming NIMS

The administrative experience cultivated at MANA, including the culture of encouraging free-ranging research, methods used for recruiting and retaining outstanding young researchers, and thorough clerical and technical support systems, will be transplanted into NIMS.

b) Internationalizing NIMS and Other Japanese Research Institutions and Universities

NIMS is expected to nearly complete its internationalization initiatives, which were modeled on MANA's endeavors, in its third Five-Year Plan. In the extension period, we will strive to export MANA's research environment to other research institutions and universities aside from NIMS.

More specifically, we will promote the following initiatives. First, we will compile the internationalization know-how that MANA has accumulated to date and publish it online and in print form. Concurrently, we will hold workshops on internationalization, open an e-mail consultation service and plan on-demand seminars. We also believe that understanding is enhanced by direct exposure to the tangible and intangible assets we have amassed on the WPI Project, so we will establish a training course on internationalization at MANA and invite participants from universities and research institutions around Japan.

c) Promoting Global Research Exchange

Over the past 6.5 years, MANA has grown into a world-class research center that attracts researchers from around the globe, and our name recognition has increased. This is evidenced by the uptick in requests from government agencies around the world to visit MANA and from researchers who want to hold joint workshops.

MANA is well on its way to achieving its mission of becoming the hub of a global network of research centers. We will continue strengthening our cooperative ties with top-tier universities and research institutions in developed nations, and we will further promote research and personnel exchange with them.

Meanwhile, we have received many requests from developing countries of Asia, the Middle East and Africa to provide them with technical guidance. As a government-affiliated research institution, we believe it is our duty to respond to these requests, so we will initiate a new program in which we invite research leaders and provide training for researchers and technical support staff from these countries.

In doing this, we will expand our network beyond the leading countries of the West to include every country and region in the world.

3. Center's Position within Host Institution and Measures to Provide It Resources

Describe the Center's future plans with regard to the following points. Though not mandatory, it is encouraged to provide plans for after the extension period ends. (In any case, the Center will be asked to provide such plans including if an extension is not granted or after the extended period ends.)

3-1 From a mid- to long-term perspective, the position of the Center within the organization of the host institution

** Describe where the Center will be placed within the host institution's overall organizational strategy under the leadership of the institution's president.*

** In Appendix 3, diagram the Center's position within the organization of the host institution, and describe that positioning using excerpts from the institution's mid- to long-term plan. If the plan has not been* *established yet, describe the progress of the discussions as to Center's positioning.*

NIMS's next seven-year plan will begin in April 2016, one year before the conclusion of the originally scheduled WPI Project period (10 years). As such, this plan will make the necessary revisions to MANA's organization and research fields before then in preparation for the extended operation of the Center beginning in April 2017. In subsequent seven-year plans, MANA will continue to handle one of NIMS's Priority R&D Fields and will remain a core part of the Institution's research. Furthermore, we plan to undertake bold reforms by reviewing MANA's research fields and strengthening theoretical research as stated in Section 2.1.

3-2 Host institution's implementation plan for sustaining and advancing the Center as a world premier international research center (e.g., providing permanent position, financial resources)

** In Appendix 4, describe the host institution's financial plans for the Center, including the allocation of posts (in both its research and administrative divisions).*

Regardless of whether the WPI program grant is extended or not, NIMS promises to provide MANA with the following research resources so that it can continue its basic activities.

i) Approximately 90 core members, including Principle Investigators, Associate Principle Investigators, Group Leaders, MANA Scientists, Independent Scientists and administrative staff will be assigned to MANA as permanent employees of NIMS. (If the WPI program grant is not allocated for these salaries, they will be covered by NIMS operations subsidies.)

ii) R&D expenses required to sustain basic and fundamental research at MANA such as research project expenses, MANA Foundry operation expenses, fees for inviting and dispatching researchers, and utilities are borne from NIMS operations subsidies totaling about ¥1 billion/year.

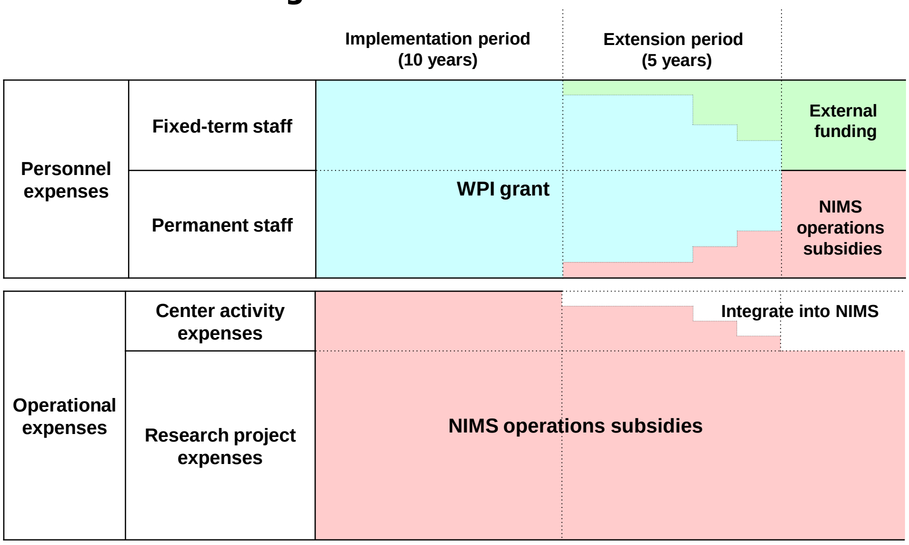
After the WPI program concludes, in addition to i) and ii) above, it will be important for us to secure post-docs, students and staff and maintain the various programs that give MANA its unique character. As such, we intend to take the following measures.

iii) We will replace the post-docs and other fixed- term employees hired using the WPI grant with those hired using external funding. To do this, we will strengthen efforts to promote challenging and interdisciplinary research and work to raise our research potential in a way that leads to a massive increase in external funding.

iv) MANA's original programs such as young researcher development programs (ICYS etc.), symposia and outreach activities will be transferred to NIMS.

v) In order to continue the administrative and technical research support that is especially advanced at MANA, we will create a replacement framework and boost research support functions by reforming NIMS's systems, such as establishing administrative offices in each Research Division and technical support stations at each campus.

Financing Structure: Present and Future



World Premier International Research Center Initiative (WPI)
List of Principal Investigators (For progress plan)

* If the number of principal investigators exceeds 10, add columns as appropriate.
* Give age as of 1 April 2017
* For investigators who cannot participate in the center project from its beginning, indicate the time that their participation will start in the "Notes" column.

Name	Age	Current affiliation (organization, department)	Academic degree and current specialties	(Notes) Enter "new" or "ongoing"
1. AONO, Masakazu	72	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. University of Tokyo, 1972 NanoSciene and nanotechnology	ongoing
2. SASAKI, Takayoshi	61	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. (Science) University of Tokyo, 1986 Nanosheet and soft chemistry	ongoing
3. ARIGA, Katsuhiko	54	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. Tokyo Institute of Technology, 1990 Supramolecular chemistry and surface science	ongoing
4. CHIKYOW, Toyohiro	57	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. Waseda University (1989), Semiconductor and electric materials	ongoing
5. GOLBERG, Dmitri	56	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. Moscow Institute for Ferrous Metallurgy, 1990 Nanotubes and nanowires	ongoing
6. GIMZEWSKI, James K	65	Dinstinguished Professor, Chemistry & Biochem. Dept., UCLA Director, Nano/Pico Characterization Lab, UCLA California NanoSystems Inst.	Ph.D. (Physical Chemistry) Univ. of Strathclyde, 1977 Nanoscience and nanobio	ongoing
7. HASEGAWA, Tsuyoshi	54	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. (science) Tokyo Inst. Tech., 1996 Nano-devices	ongoing
8. HU, Xiao	55	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. (Physics), University of Tokyo, 1990 Condensed matter physics	ongoing

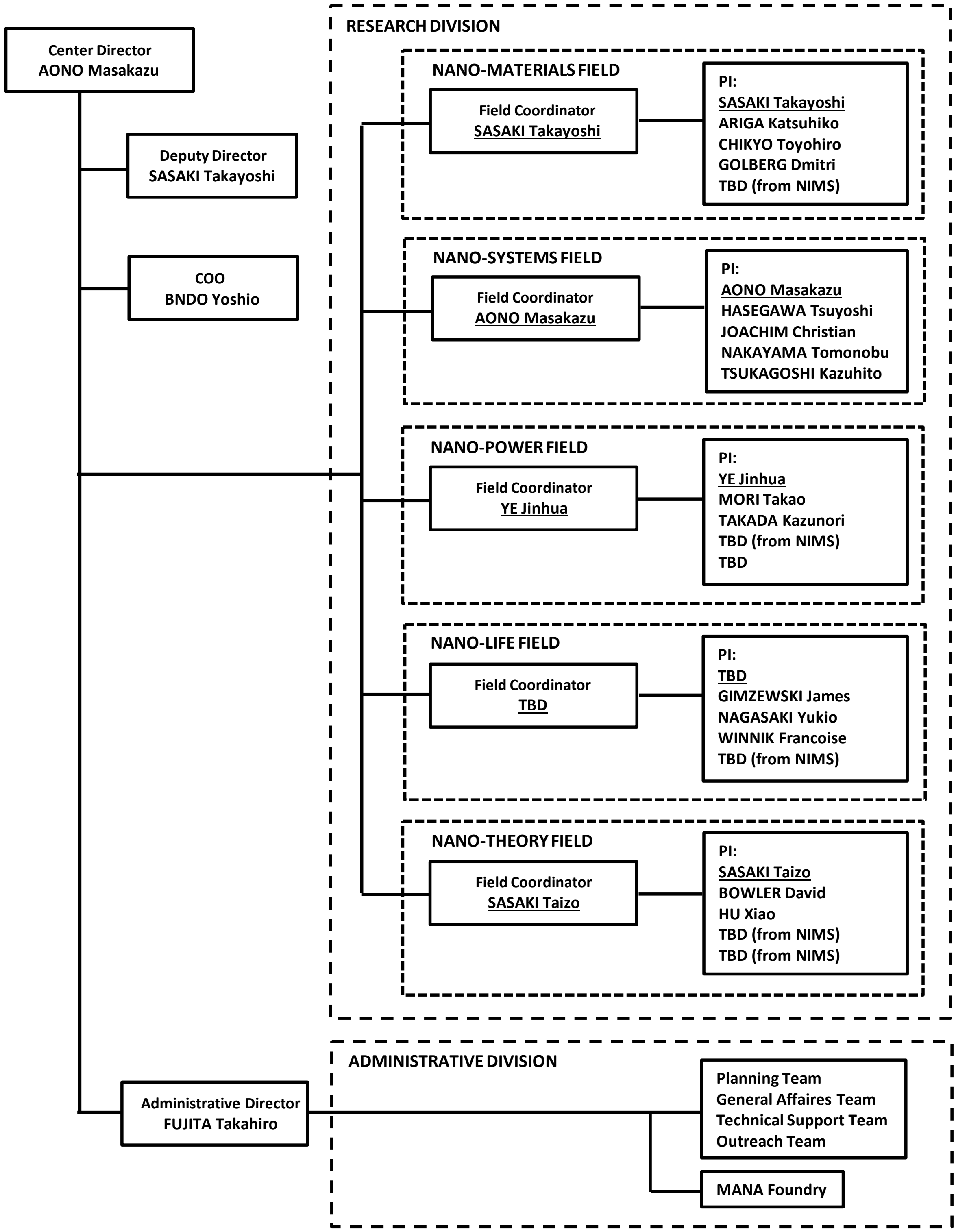
9. JOACHIM, Christian	59	Centre National de la Recherche Scientifique (CNRS) Lab: CEMES (UPR8011) Toulouse (France)	Ph.D. in Applied Mathematics Ph.D. in Quantum Physics Computer science and nanoscience	ongoing
10. NAKAYAMA, Tomonobu	55	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. in physics University of Tokyo,1999 Scanning probe microscopy	ongoing
11. TSUKAGOSHI, Kazuhito	49	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. Osaka University, 1995 Nano electronics	ongoing
12. YE, Jinhua	54	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. University of Tokyo, 1990 Photocatalyst, eco-materials	ongoing
13. TAKADA, Kazunori	55	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. Osaka University, 1986 Solid-state chemistry	ongoing
14. NAGASAKI, Yukio	57	Professor, Department of Materials Science and Master's Master's School of Medical Sciences, University of Tsukuba	Ph.D. Tokyo University of Science, 1986 Biomaterials and polymer chemistry	ongoing
15. WINNIK, Françoise	65	Faculty of Pharmacy and Department of Chemistry, University of Montreal, Canada	Ph.D. (Chemistry) University of Toronto, 1979 Polymer chemistry and photochemistry	ongoing
16. SASAKI, Taizo	58	Unit Director, Computational Materials Science Unit, NIMS	Ph.D. Tohoku University, 1987 Computational materials science	new
17. MORI, Takao	50	International Center for Materials Nanoarchitectonics (MANA)	Ph.D. University of Tokyo, 1996 Atomic network materials	new
18. BOWLER, David	46	Reader, Department of Physics & Astronomy, University College London	Ph.D. Oxford University, 1997 Condensed matter physics	new
19.		(selection from NIMS)		new

20.		(selection from NIMS)		new
21.		(selection from NIMS)		new
22.		(selection from NIMS)		new
23.		(international recruitment)		new
24.		(international recruitment)		new
25.		(international recruitment)		new

World Premier International Research Center Initiative (WPI)

Diagram of Center Management System

Organization of MANA in the Extension Period



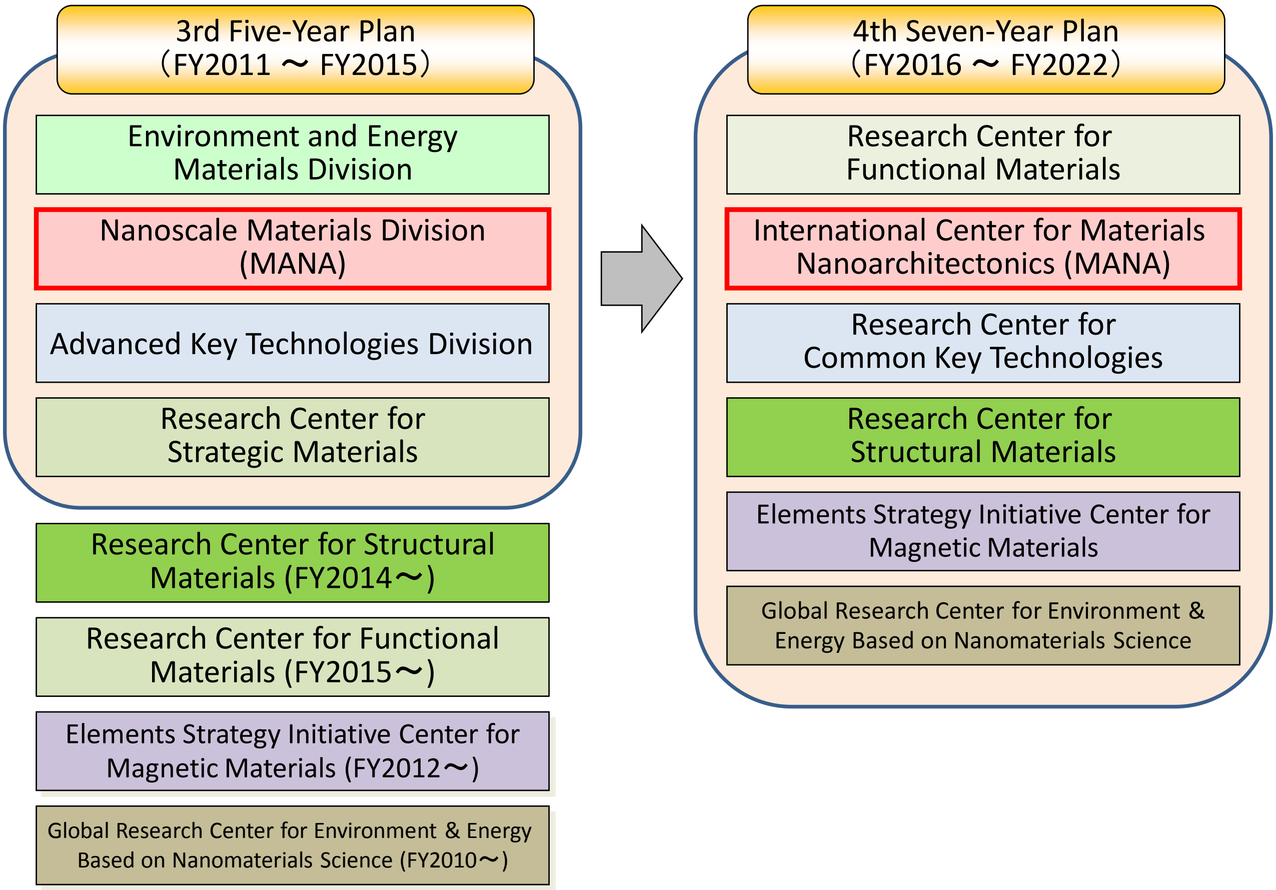
World Premier International Research Center Initiative (WPI)

Position of the Center within Host Institution

** Diagram the Center's position within the organization of the host institution, and describe that positioning using excerpts from the institution's mid- to long-term plan. If the plan has not been established yet, describe the progress of discussions as to the Center's positioning.*

At present, MANA is positioned as the Nanoscale Materials Division of NIMS's research organization, which consists of three divisions and one center. In the NIMS's next Seven-Year Plan, which commences in April 2016 and has been in the process of designing, MANA's development of innovative new materials and systems based on nanoarchitectonics will be surely recognized as one of NIMS's priority R&D fields and MANA will definitely remain a core part of the NIMS's research organization.

NIMS's Research Organization: Present and Future (under contemplation)



World Premier International Research Center Initiative (WPI)

Resource Allocation Plan for sustaining and Advancing the WPI Center (Host institution's commitment)

July 7, 2014

National Institute for Materials Science (NIMS)

Sukekatsu Ushioda, President

If the Center is selected for an extension under the WPI Program, the host institution is committed to providing it with the resources stated below.

Annual Plans (FY 2015 –FY 2022)

<Fund > **(hundred million yen)**

Fiscal Year	2015	2016	2017	2018	2019	2020	2021	2022
- WPI grant	13.0	13.0	10.0	10.0	10.0	8.0	6.0	-
- Funding from host institution	15.3	15.3	16.0	16.0	16.0	16.5	16.9	18.3
- Prospective Center-generated funding	11.0	12.0	13.0	14.0	15.0	16.0	17.0	20.0
Total	39.3	40.3	39.0	40.0	41.0	40.5	39.9	38.3

<Personnel> **(person)**

Fiscal Year	2015	2016	2017	2018	2019	2020	2021	2022
Personnel	240 (35)	240 (35)	240 (53)	240 (53)	240 (53)	240 (68)	240 (83)	230(160)
- Faculty members (including researchers)	105	105	105	105	105	105	105	100
Full-time	95 (12)	100 (12)	100 (30)	100 (30)	100 (30)	100 (45)	100 (60)	100(100)
Concurrent	10	5	5	5	5	5	5	
- Postdocs	70	70	70	70	70	70	70	70
- RA etc.	35 (17)	35 (17)	35 (17)	35 (17)	35 (17)	35 (17)	35 (17)	30 (30)
- Research support staffs	10 (3)	10 (3)	10 (3)	10 (3)	10 (3)	10 (3)	10 (3)	12 (12)
- Administrative staffs	20 (3)	20 (3)	20 (3)	20 (3)	20 (3)	20 (3)	20 (3)	18 (18)

- When entering amounts, round down numbers to the first decimal.
- When the host institution covers the expense, enter the amount in parentheses.
- When the expense is given in a range between two amounts, explain the reason for the lower and upper amounts and fluctuations between them in an annotation.

< Measure to be implemented from FY 2015>

– Strategy and action plan for acquiring external funding

There are several groundbreaking research topics that have started to come out of the Grand Challenge Research Program and other interdisciplinary research efforts initiated during the WPI Program. We plan to grow these excellent seeds into large-scale, externally-funded projects.

NIMS will continue to allocate some funding from NIMS operations subsidies to MANA so that researchers at MANA can tackle challenging and interdisciplinary research. We expect this will cultivate numerous highly creative research projects and lead to more external funding. Also, we will construct a support system through which Non-Japanese scientists, who consist of more than half of the MANA research workforce, can acquire external funding in the same way as Japanese scientists.

– Strategy and action plan for allocating personnel (posts) and space

NIMS plans to maintain the MANA research workforce of 200 scientists (100 permanents plus 100 postdocs and graduate students) during the extension period and after the WPI program concludes. To promote diversification of the research workforce, we will try to hire no less than 50% Non-Japanese and no less than 25% female scientists. Also NIMS plans to maintain the size of MANA by hiring several permanent researchers every year.

NIMS has allocated the two newest buildings to MANA: MANA Building (12,934m^2) in October 2008 and WPI-MANA Building (7,629m^2) in April 2012. NIMS renovated an old building (519m^2) adjacent to the two MANA Buildings and reopened it as Theoretical Research Building in April 2014. NIMS will allocate this building to MANA in April 2016 when NIMS moves a large part of theoreticians from NIMS's Computational Materials Science Unit to the new Nano-Theory Field of MANA.

– Strategy and action plan for carrying out other necessary measures

NIMS's next seven-year plan will begin in April 2016, one year before the conclusion of the originally scheduled WPI Project period (10 years). From FY 2014 to 2015, NIMS will formulate a concrete plan regarding the revisions of MANA's organization, lineup of PIs, research fields, etc. In April 2016, one year before the start of the extension period, we will implement the revised framework.

Before the conclusion of the extension period in March 2022, NIMS will integrate MANA's original programs such as young researcher development programs and administrative and technical research support systems into its structure and system, and will be ready to operate MANA without the WPI funding after the extension period ends.

[Notes]

- When screening the Center's Progress Plan, the ongoing program for sustaining the center operation of the host institution after the WPI grant period has ended will be evaluated. Therefore, it is expected to describe an estimate of the host institution's support for the Center after the WPI grant period ends.
- The Center project was initially selected as comprehensive and long-term proposal in scope covering independent initiatives taken by the center, host institutions and partner institutions, and includes forecasted activities to be conducted after the grant period has ended. Irrespective of whether an extension is approved or not, it is naturally expected that the host institution will support for the Center to continue operating their projects in a manner flexible to change in the times and sciences.

(Reference) Details of Action Plan for Sustaining and Advancing the Center as a World Premier International Research Center

<FY 2015>

Annual Program Plan

- Provide concrete details or program to be implemented.

1) Running funding programs to promote grand challenge and interdisciplinary research
2) Further enhancement of scientists exchange to establish the research hub of nanoarchitectonics
3) Continuing 3D and YAMATO-MANA Programs, etc. to develop world-class young researchers
4) Preparation for advanced implementation of the extension period scheme (reorganization, shuffle of PI lineup, etc.) in time for the NIMS's next seven-year plan (starting from April 2016)

Expenditure Details

Items		Cost (million Yen)	Note
<FY 2015> (WPI grant) * Only costs necessary for implementing the research center project are applicable. * If satellites and/or partner institutions are established, give a separate breakdown in the use of funding. * When the expense is given in a range between two amounts, explain the reason for the lower and upper amounts and fluctuations between them by annotation in "Note".			
- Compensation of center director	19 million Yen	19	
- Salary of administrative director	16 million Yen	16	
- Salary of principal investigators	174 million Yen	174	
- Salary of other researchers	604 million Yen	604	
- Salaries of postdoctoral researchers (no. of subject person): 70	332 million Yen	332	
- Salaries of research associates etc. (no. of subject person): 18	52 million Yen	52	
- Salaries of research support staffs (no. of subject person): 7	30 million Yen	30	
- Salaries of administrative staffs (no. of subject person): 17	73 million Yen	73	
(Previously-initiated center-building efforts) * Meant by previously-initiated center-building efforts are those that cover personnel costs of researchers whose main duties are in the center, personnel costs of center staffs, costs of center's activities, costs of maintaining the research environment (excluding capital expenditures for purchasing or leasing land and buildings). * For previously-initiated center-building efforts to be carried out in combination with the WPI grant, enter data in the same manner as under the above "WPI Grant" section. * Also list the funding source(s) for the center-building efforts.			
- Salary of other researchers (no. of subject person): 12	103 million Yen	103	Projects supported by other government subsidies, etc.
- Salaries of research support staffs (no. of subject person): 3	30 million Yen	30	
- Salaries of administrative staffs (no. of subject person): 3	27 million Yen	27	
- Costs of holding international symposiums (no. of symposiums):4	20 million Yen	20	
- Other project activities	334 million Yen	334	
- Domestic travel cost	50 million Yen	50	
- Costs of equipments	80 million Yen	80	
- Other research projects	800 million Yen	800	
- Costs of Satellites	86 million Yen	86	
(FY 2015) Total		2,830	

<FY 2016>

Annual Program Plan

- Provide concrete details or program to be implemented.

1) Running funding programs to promote grand challenge and interdisciplinary research
2) Launch of Theoretician-Experimentalist Pairing (TEP) Program to develop the integration of theory and experiment
3) Continuing various programs to establish the research hub of nanoarchitectonics and to develop world-class young researchers
4) Smooth launch of the new MANA, one year before the start of the extension period

Expenditure Details

Items		Cost (million Yen)	Note
<FY 2016> (WPI grant) * Only costs necessary for implementing the research center project are applicable. * If satellites and/or partner institutions are established, give a separate breakdown in the use of funding. * When the expense is given in a range between two amounts, explain the reason for the lower and upper amounts and fluctuations between them by annotation in "Note".			
- Compensation of center director	19 million Yen	19	
- Salary of administrative director	16 million Yen	16	
- Salary of principal investigators	174 million Yen	174	
- Salary of other researchers	604 million Yen	604	
- Salaries of postdoctoral researchers (no. of subject person): 70	332 million Yen	332	
- Salaries of research associates etc. (no. of subject person): 18	52 million Yen	52	
- Salaries of research support staffs (no. of subject person): 7	30 million Yen	30	
- Salaries of administrative staffs (no. of subject person): 17	73 million Yen	73	
(Previously-initiated center-building efforts) * Meant by previously-initiated center-building efforts are those that cover personnel costs of researchers whose main duties are in the center, personnel costs of center staffs, costs of center's activities, costs of maintaining the research environment (excluding capital expenditures for purchasing or leasing land and buildings). * For previously-initiated center-building efforts to be carried out in combination with the WPI grant, enter data in the same manner as under the above "WPI Grant" section. * Also list the funding source(s) for the center-building efforts.			
- Salary of other researchers (no. of subject person): 12	103 million Yen	103	Projects supported by other government subsidies, etc.
- Salaries of research support staffs (no. of subject person): 3	30 million Yen	30	
- Salaries of administrative staffs (no. of subject person): 3	27 million Yen	27	
- Costs of holding international symposiums (no. of symposiums):4	20 million Yen	20	
- Other project activities	377 million Yen	377	
- Domestic travel cost	50 million Yen	50	
- Costs of equipments	80 million Yen	80	
- Other research projects	800 million Yen	800	
- Costs of Satellites	43 million Yen	43	
(FY 2016)	Total	2,830	

<FY 2017>

Annual Program Plan

- Provide concrete details or program to be implemented.

1) Running funding programs to promote grand challenge and interdisciplinary research including theory and experiment fusion
2) Continuing various programs to establish the research hub of nanoarchitectonics and to develop world-class young researchers
3) Construction of a support system through which MANA researchers (especially non-Japanese) can acquire more external funding to counter the decrease in the WPI subsidy

Expenditure Details

Items		Cost (million Yen)	Note
<FY 2017> (WPI grant) * Only costs necessary for implementing the research center project are applicable. * If satellites and/or partner institutions are established, give a separate breakdown in the use of funding. * When the expense is given in a range between two amounts, explain the reason for the lower and upper amounts and fluctuations between them by annotation in "Note".			
- Compensation of center director	19 million Yen	19	
- Salary of administrative director	16 million Yen	16	
- Salary of principal investigators	174 million Yen	174	
- Salary of other researchers	434 million Yen	434	
- Salaries of postdoctoral researchers (no. of subject person): 50	210 million Yen	210	
- Salaries of research associates etc. (no. of subject person): 18	44 million Yen	44	
- Salaries of research support staffs (no. of subject person): 7	30 million Yen	30	
- Salaries of administrative staffs (no. of subject person): 17	73 million Yen	73	
(Previously-initiated center-building efforts) * Meant by previously-initiated center-building efforts are those that cover personnel costs of researchers whose main duties are in the center, personnel costs of center staffs, costs of center's activities, costs of maintaining the research environment (excluding capital expenditures for purchasing or leasing land and buildings). * For previously-initiated center-building efforts to be carried out in combination with the WPI grant, enter data in the same manner as under the above "WPI Grant" section. * Also list the funding source(s) for the center-building efforts.			
- Salary of other researchers (no. of subject person): 30	273 million Yen	273	Projects supported by other government subsidies, etc.
- Salaries of research support staffs (no. of subject person): 3	30 million Yen	30	
- Salaries of administrative staffs (no. of subject person): 3	27 million Yen	27	
- Costs of holding international symposiums (no. of symposiums):4	16 million Yen	16	
- Other project activities	316 million Yen	316	
- Domestic travel cost	40 million Yen	40	
- Costs of equipments	65 million Yen	65	
- Other research projects	790 million Yen	790	
- Costs of Satellites	43 million Yen	43	
(FY 2017) Total		2,600	