World Premier International Research Center Initiative

Nano Revolution for the Future

International Center for Materials Nanoarchitectonics

A Message from the Director

MANA's Vision

Toward a better global future:
Pioneering a new paradigm in materials development on the basis of "nanoarchitectonics"

MANA's Mission

- Develop groundbreaking new materials on the basis of "nanoarchitectonics"
- Create a "melting pot" where top-level researchers gather from around the world
- Foster young scientists who battle to achieve innovative research
- Construct a worldwide network of nanotechnology research centers

What is MANA's target?

The International Center for Materials Nanoarchitectonics (MANA) was established in 2007 as one of the initial five research centers in the framework of the World Premier International Research Center Initiative (WPI Program), which is sponsored by the Ministry of Education, Culture, Sports, Science and Technology (MEXT). MANA's aim is to create various novel materials that support the development of innovative technologies necessary for mankind's continued development, based on our new concept called "nanoarchitectonics".

If humankind is to continue on a path of sustainable development in the years to come, we must realize a variety of innovative technologies in every field, including the environment, energy, resources, information and communications, medical diagnosis and treatment, and infrastructure, among others. However, many of these innovative technologies cannot be realized unless we develop appropriate new materials. Nanotechnology has made astonishing progress in more than 30 years and has become a pillar of modern materials discovery and development. However, MANA believes that conceptual innovation is necessary in order to extract the maximum value (potentiality) from nanotechnology. We purse this innovation on the basis of the new concept of "nanoarchitectonics" (see p. 5 for details).

The concept of "nanoarchitectonics" has been refined continuously by MANA's researchers and has grown into a concept that is accepted around the world. As we follow this concept, MANA strives to lead the world in new materials development.

Masakazu Aono, Director

World Premier International Research Center Initiative

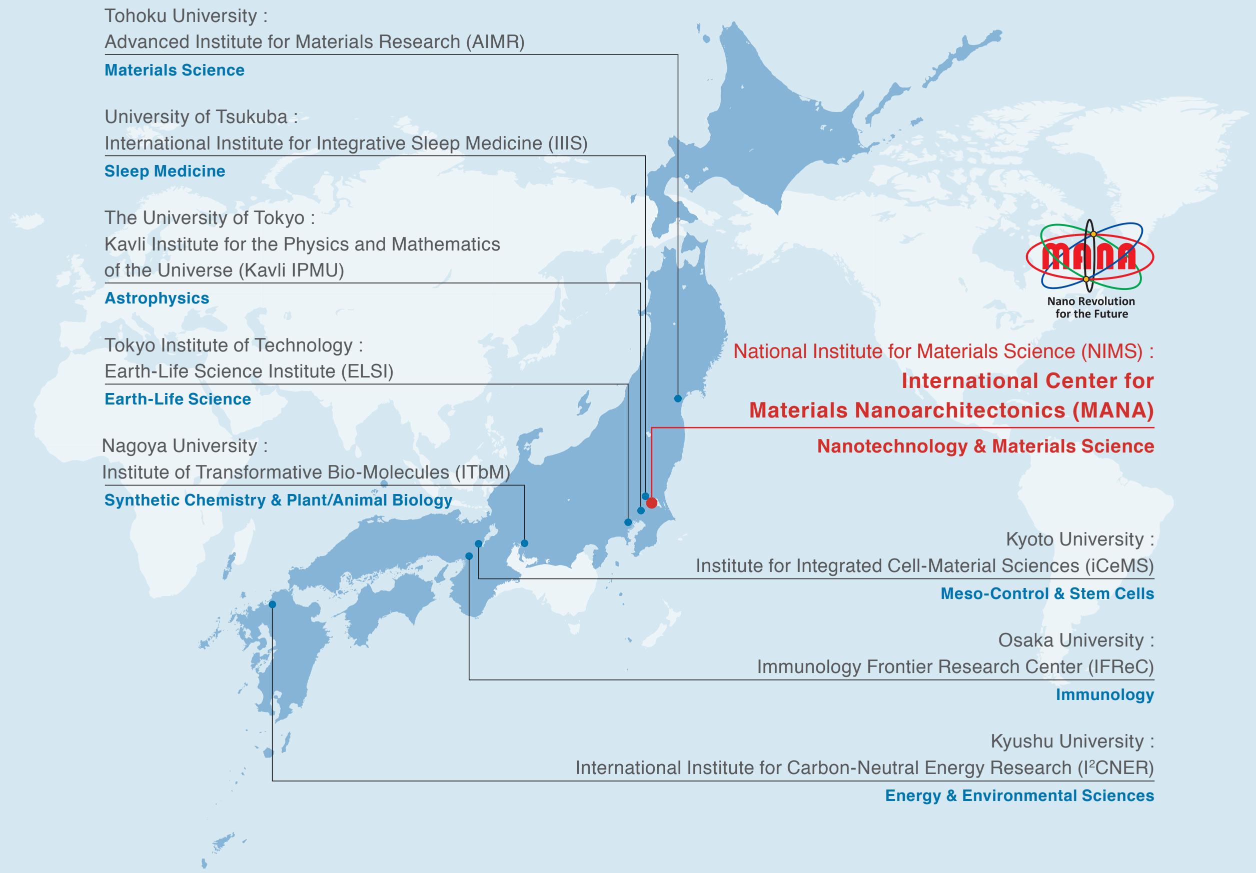
In recent years, a competitive search for the most talented minds has been advancing rapidly around the world. This trend in human resources is known as “brain circulation”.

Japan, too, needs to create a place at the forefront where researchers from around the world can gather as part of this global movement of human resources. In 2007, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) established the World Premier International Research Center Initiative (WPI) Program to promote Japan’s presence as a powerhouse of science and technology.

To date, nine research centers have been selected as WPI centers by meeting these four requirements: the world’s highest level of research standards, creation of interdisciplinary research fields, implementation of an international research environment, and openness to reform in the research organization.

WPI centers serve as models of research institutes in Japan, and are expected to bring innovations in science and technology.

WPI research centers, the highest peaks where the world's top researchers gather.

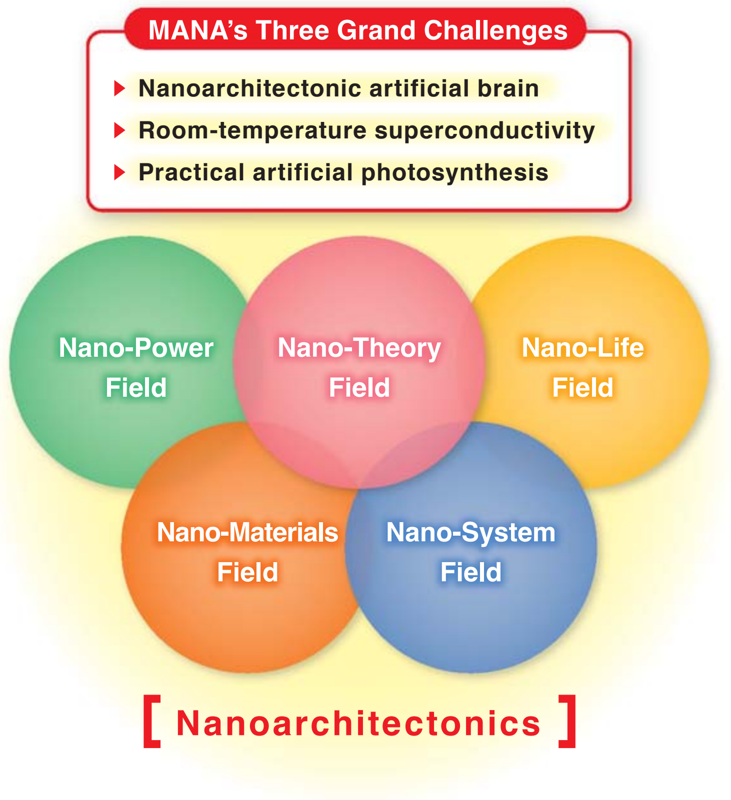


Nanoarchitectonics

What is nanoarchitectonics?

Nanotechnology plays an extremely important role in the development of new materials. Yet, nanotechnology tends to be misunderstood as a simple extension of the conventional microtechnology that has demonstrated great effectiveness in micro-fabrication of semiconductor devices–in other words, as a refinement of microtechnology. In fact, however, nanotechnology and microtechnology are qualitatively different. At MANA, we call the new paradigm of nanotechnology, which correctly recognizes this qualitative difference, “nanoarchitectonics.”

The distinctive features of nanoarchitectonics can be summarized in the following four key points:



Key points

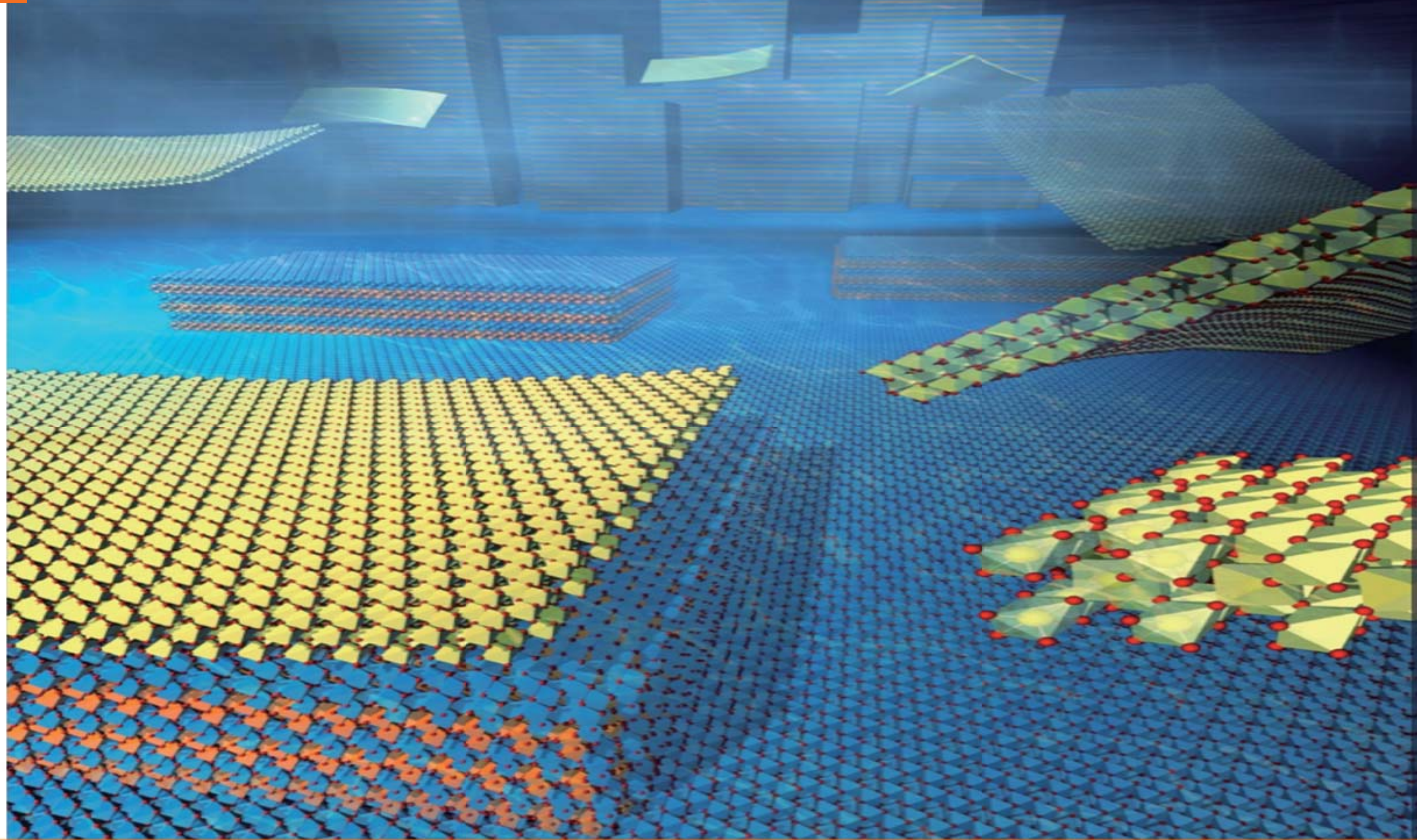
1 **“Unreliability-tolerant reliability”** - In the world of microtechnology, structures can be constructed according to a design drawing or “blueprint.” This is generally not possible in the world of nanotechnology because the world of nanotechnology is far smaller than that of microtechnology. In nanotechnology, thermal and statistical fluctuations become apparent, and at the same time, nanotechnology confronts the limits of the principles of control methods. Therefore, the viewpoint of realizing reliable functions with structures that contain ambiguity is important.

2 **“From nano-functionality to nanosystem-functionality”** - Nanoscale structures (nanoparts) frequently display interesting new properties, but there are limits to their functionalities, either as individual units or as simple aggregates. Thus, creating completely new functionalities by effectively utilizing interactions among nanoparts of the same type or different types is important.

3 **“More is different”** - In complex systems that consist of an enormous number of nanoparts, unexpected new functions often emerge in the system as a whole. Therefore, utilizing, and not overlooking, the phenomenon that “quantity changes quality” is another key point.

4 **“Truth can be described with plain words”** - Finally, it is also necessary to pioneer a new theoretical field, which is capable of handling the three above-mentioned points. In this, it is necessary to construct a theoretical system that not only treats atoms, molecules, electrons, photons, spin, etc. on a first-principles basis, but also consciously introduces “appropriate bold approximation.”

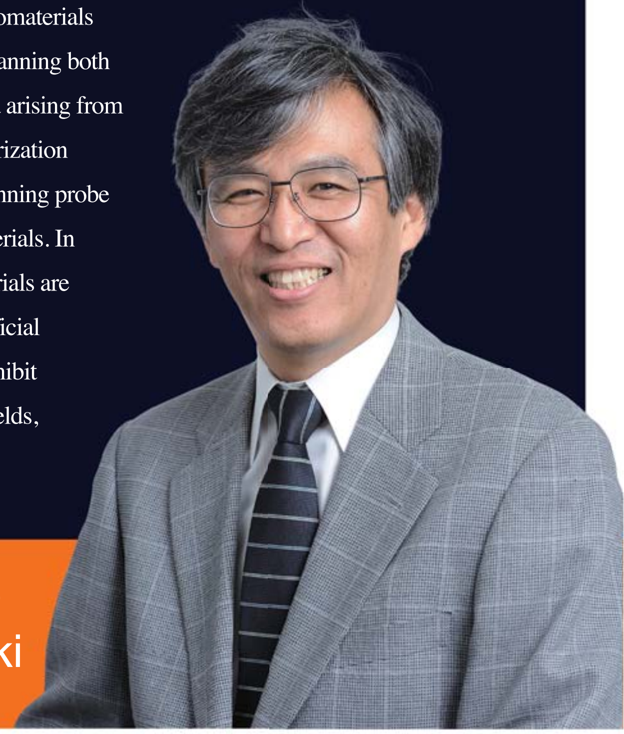
Research Field 01



Creating new materials and eliciting novel functions by sophisticated control of compositions and structures at the nano level

- Soft Chemistry G
- Functional Nanosheets G
- Mesoscale Materials Chemistry G
- Nanotubes G
- Supermolecules G
- Frontier Molecules G
- Semiconductor Device Materials G

Making full use of MANA's advanced chemical synthesis technologies, beginning with soft chemistry, supermolecular chemistry and template synthesis, we are researching the creation of new nanomaterials such as nanotubes, nanowires, and nanosheets. Based on a wide range of material systems, spanning both organic and inorganic materials, we aim to discover novel physical properties and phenomena arising from size and shape in the nanometer range. MANA also develops and owns cutting-edge characterization facilities, including an integrated system of the transmission electron microscope with the scanning probe microscope, and is actively using these instruments for *in-situ* analysis of individual nanomaterials. In addition, we are promoting chemical nano- and mesoarchitectonics, in which these nanomaterials are precisely arranged, integrated and hybridized in the nano-to-meso range. By constructing artificial nanostructured materials in a designed manner, our aim is to create new materials that will exhibit advanced, innovative functions, and contribute to progress in a wide range of technological fields, including electronics, energy and the environment.

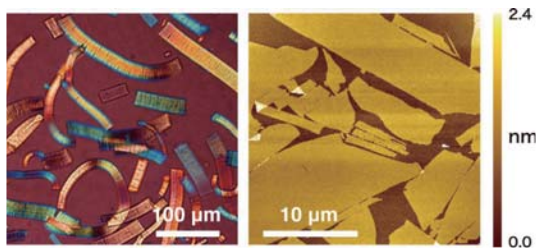


Nano-Materials

Nano-Materials Coordinator
Takayoshi Sasaki

Creating two-dimensional nanomaterials (nanosheets)

MANA has synthesized two-dimensional oxide and hydroxide nanosheets as a graphene analogue by delaminating layered crystals into single layers in a solution, after inducing them to swell by more than 100 times. High grade nanosheets with diverse electronic, magnetic, optical and chemical functions were created this way with precise control of the composition, structure, and thickness and width dimensions. Development of new materials that demonstrate novel functions, is progressing via soft-chemical nanoarchitectonics, in which these nanosheets are assembled and hybridized layer by layer.

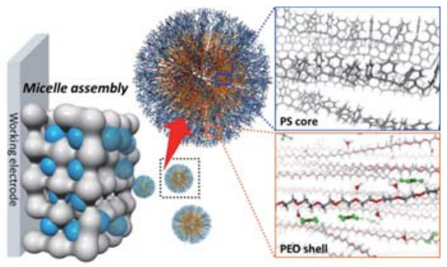


(Left) Crystals displaying huge hydration swelling
(Right) Delaminated titanium oxide nanosheets

Creating nanoporous materials with highly crystallized frameworks

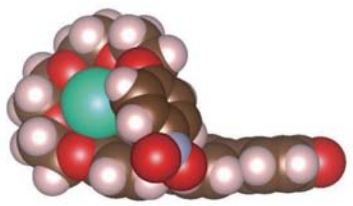
Focusing on porous substances that have a large surface area (i.e., nanoporous materials), and particularly on nanoporous materials with high crystallinity skeletons, MANA is developing applications of these materials as adsorbents, catalysts, catalyst carriers, sensor materials, and etc. It is doing so by utilizing amphiphilic molecules, such as surfactants and block copolymers. MANA is also extending the framework compositions to metals by electrochemical processes, and has developed synthesis techniques that are applicable to all metals. The high electrical conductivity of the framework of metallic nanoporous materials is expected to lead to new applications in the electrochemical field, which are not possible with the existing porous materials.

Synthesis of metallic nanoporous material using the micelle assembly method (metal ions are coordinated in a diblock copolymer micelle consisting of polystyrene-polyethylene oxide (PS-PEO), and the metal ions are reduced on the micelles by electrodeposition)

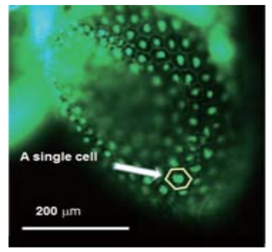


Creating supermolecules that can detect designated substances

Detection and capture of a designated object by a molecule is the action of a "supermolecule." We developed the new molecule "Cesium Green" (below left), which coils around a cesium ion and emits green fluorescent light. Because this molecule was designed to precisely match the size of the cesium ion, it only causes fluorescence of cesium ions (for example, fluorescence does not occur in the case of sodium and potassium ions). The location of cesium ions in plant cells can be identified by this fluorescence (below right). By using the principle of the supermolecule, it is also possible to detect various important substances, such as amino acids and drugs.



Capture of cesium ion (green)

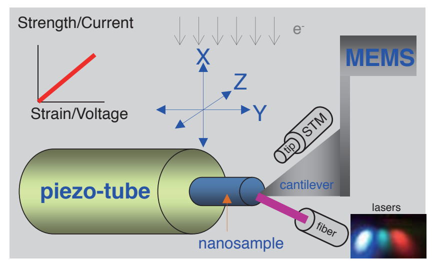


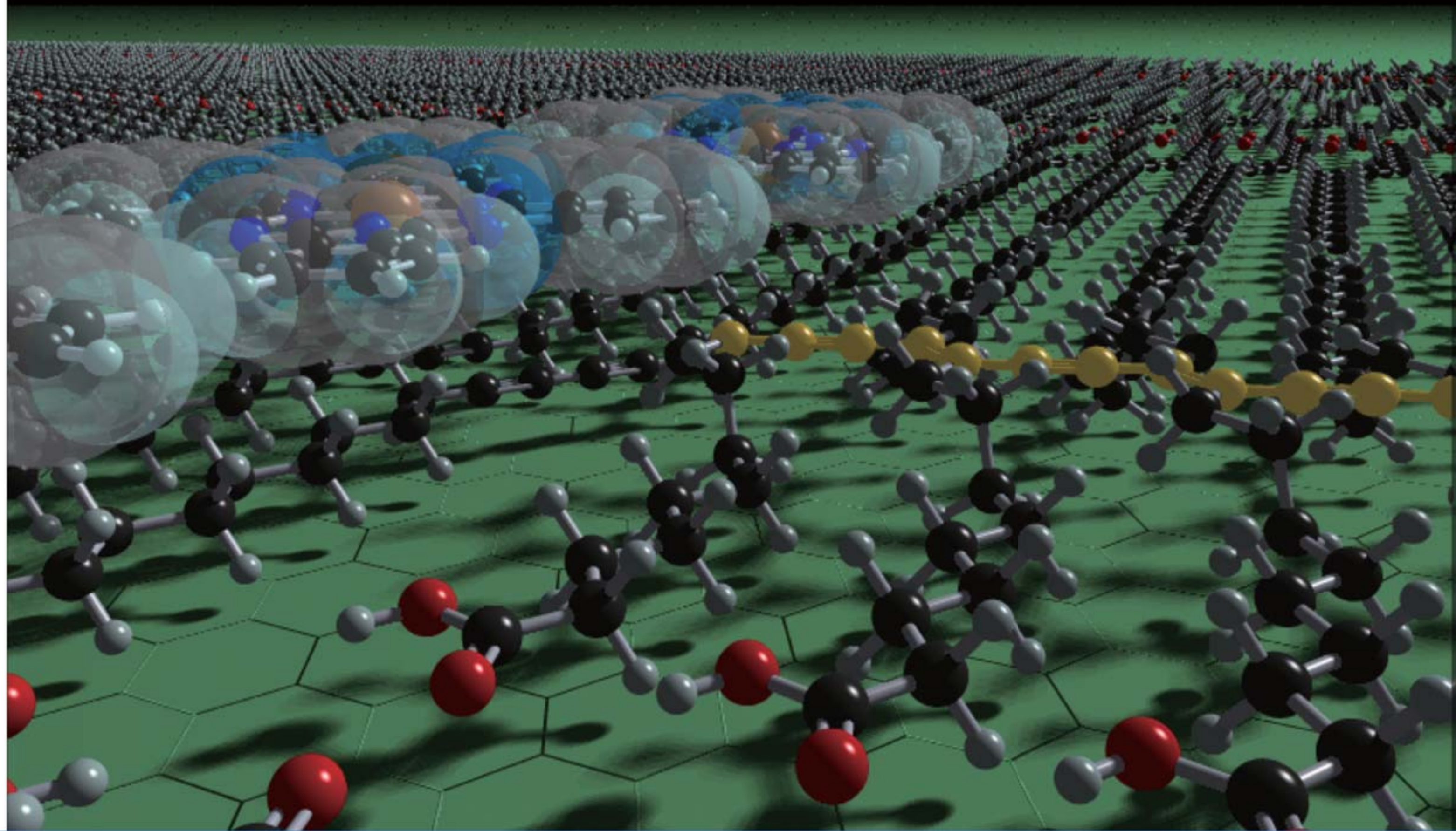
Visualization in a plant cell (cesium is concentrated in the part that displays green fluorescence)

Pioneering techniques for nanoscale property analysis using a high resolution transmission electron microscope

We are developing pioneering *in-situ* techniques for measuring nanotube, nanowire and nanosheet properties by combining the highest spatial, energy and temporal resolutions peculiar to the HRTEM with the unique possibilities created by precise manipulations of an individual nanoobject. Such techniques involve its manipulating, electrical biasing, resistive heating, charging, bending, stretching, peeling, and illuminating with light of various wavelengths and pulse frequencies under continuous control of all electromechanical, thermal and optoelectronic parameters. Ultimately, we can establish an unambiguous structure-property relationship, shining a new light on prospects for any nanomaterial applications.

A general setup inside the HRTEM for in-tandem imaging and probing an individual nanomaterial with an STM-tip (electrical property analysis), AFM-cantilever (mechanical property analysis) and light (optoelectronic/photovoltaic property analysis)

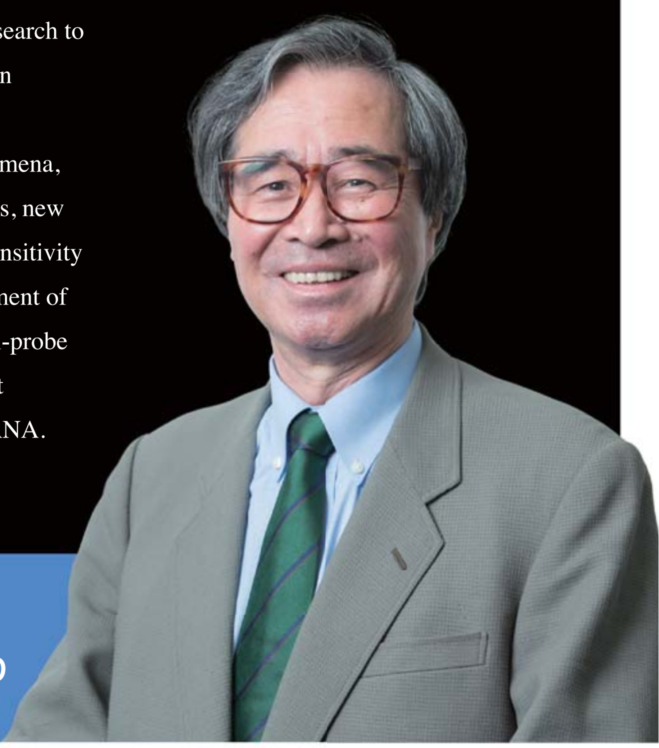




New nano-systems are changing the world: from artificial intelligence to energy and the environment, diagnosis and medicine

- Nano Functionality Integration G
- Nanoionic Devices G
- Thin Film Electronics G
- Quantum Device Engineering G
- Surface Quantum Phase Materials G
- Nano-System Theoretical Physics G
- Nano Frontier Superconducting Materials G

This research field is searching for various nano-systems that will express novel functions by the interaction of nanostructures with unique characteristics, and is engaged in research to utilize those new nano-systems systematically. Concretely, based on basic research on nanoscale materials, such as atomic and molecular transport and chemical reaction processes, polarization and excitation of charge and spin and superconducting phenomena, we are conducting research on atomic switches, artificial synapses, molecular devices, new quantum bits, neural network-type network circuits, next-generation devices, high sensitivity integrated molecular sensors and other new applied technologies. Since the development of new nanoscale measurement methods is also a high priority, we are developing multi-probe scanning probe microscopes and other cutting-edge instruments. We also attach great importance to interdisciplinary fusion-type research with other research fields in MANA.

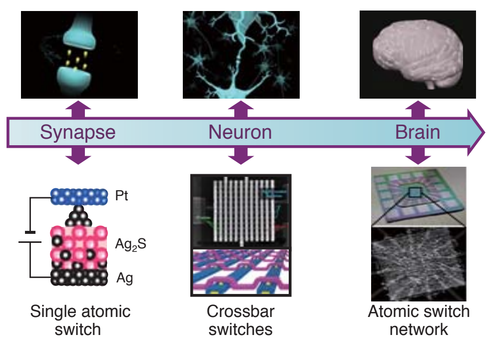


Nano-System

Nano-System Coordinator
Masakazu Aono

Driving innovation in research on artificial intelligence by new nano-systems

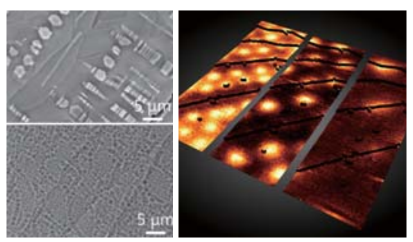
The "atomic switch," which functions through nanoscale atomic and ionic transport, is an original and unique technology developed in Japan, mainly at MANA. We discovered that, like the synapses in the brain's neural network, this atomic switch exhibits plasticity in response to input signals. Taking advantage of this characteristic, we are developing novel devices that mimic the functions of the human brain by constructing nano-systems consisting of large numbers of self-assembled atomic switches. Our aim is to create intelligent information-processing functions with a totally different architecture from today's semiconductor device-based von Neumann computation.



Development of neural network devices using atomic switches

Innovations in the science of superconductivity brought by new nano-systems

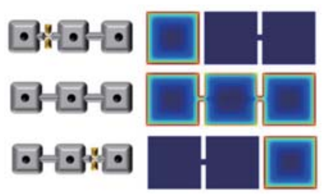
Nano-systems shed the light of innovation on the future research of superconductivity. Layer-structured FeSe is known as the simplest material among Fe-based superconductors with a superconducting transition temperature of Tc~8K. We have highly organized the fine structure of KFe_2Se_2, which has FeSe layers in its crystal structure, and elucidated that the appearance of superconductivity at Tc~31K or Tc ~44K depends on the morphology of the fine structures. This relationship between the fine structure and Tc will lead to better understanding a mechanism for increments of Tc. We have also created an indium atomic layer two-dimensional material on the surface of silicon, and have clarified for the first time ever that macroscopic supercurrents and Josephson quantum vortices exist in this atomic layer. Research activities at MANA involving the design and systemization of superconducting materials based on the concepts of nanoarchitectonics are accelerating progress in superconductivity science.



(Left) Fine structures of a KFe_2Se_2 superconductor, which has FeSe layers
(Right) STM image of Josephson vortices formed in a surface atomic layer superconductor

Theoretical search for the great potential of new nano-systems

Uncertainty due to fluctuations is unavoidable in the nano world, so new theoretical investigations are necessary to achieve novel functionalities by nano systems. For example, although quantum computation has power far superior to the capacity of computers used at present, quantum states are fragile and lose coherence easily. We are focusing on Majorana quasiparticle excitations of topological superconductivity, which appear at the edge of a topological superconductor containing an odd number of quantum vortices, while they disappear in the case of an even number. Utilizing this feature, we developed a method to manipulate quickly and stably the charge-neutral Majorana quasiparticles by applying local gate voltages at junctions between superconductors, and demonstrated theoretically that this could be used for quantum bit manipulation. MANA is also carrying out experimental research with the goal of realizing such a quantum device.

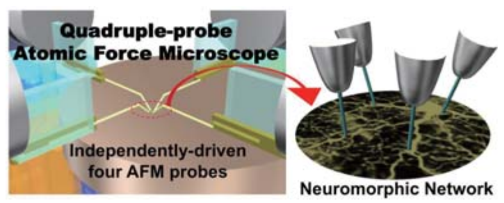


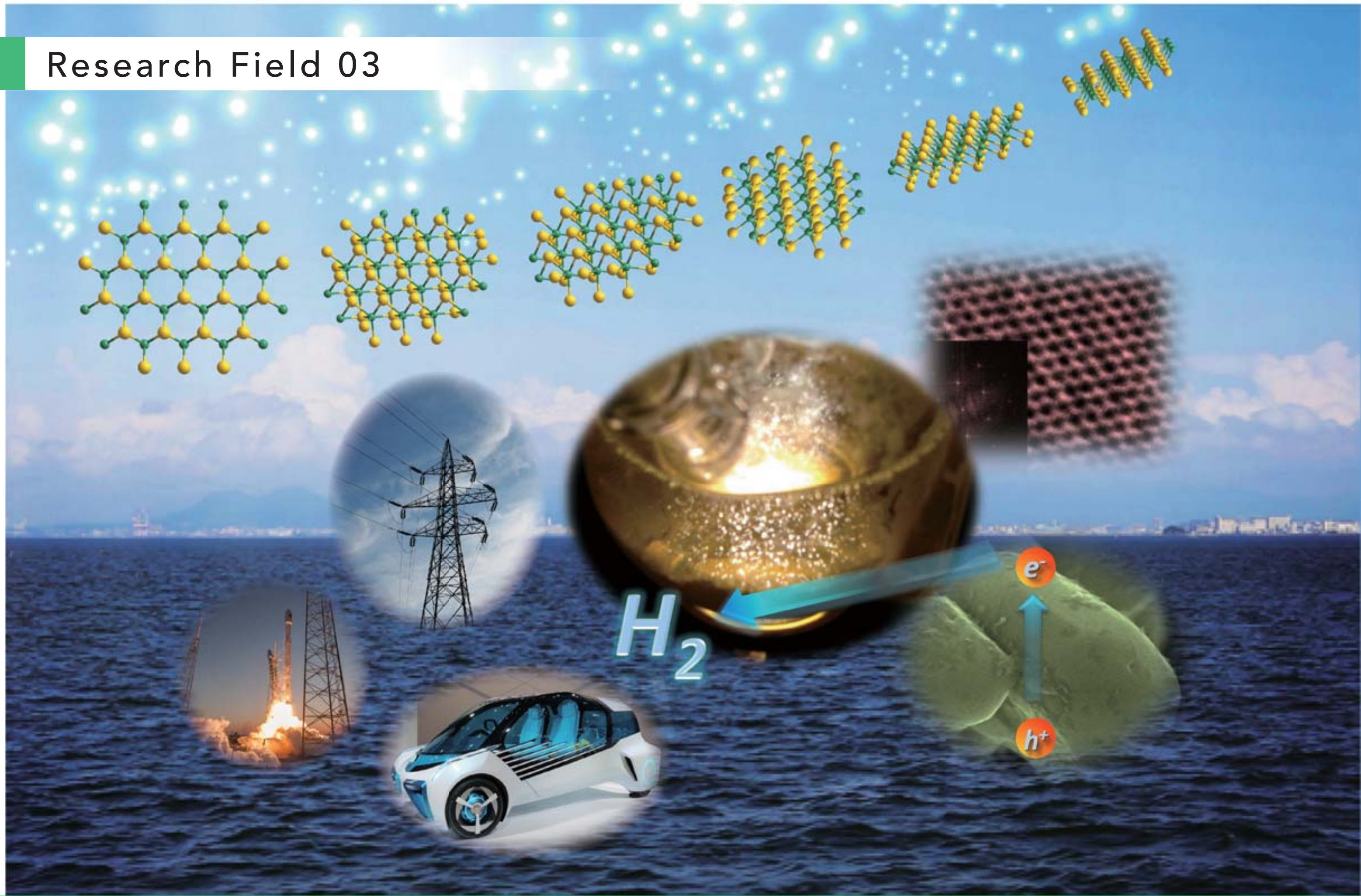
Schematics and computer-simulation results of a device for manipulating charge-neutral Majorana quasiparticles by local gate voltage

Pioneering new methods for precisely measuring novel nano-systems

In pioneering novel nano-systems, new instruments and methodologies are indispensable to cover a wide range of characterizations, from measurements of physical properties of individual nanomaterials to the evaluation of functionalities of nano-systems constructed at the micrometer and larger sizes through nanoarchitectonics. We were the first in the world to develop the multi-probe scanning tunneling microscope (MP-STM) and the quadruple-probe atomic force microscope (MP-AFM). These new instruments and techniques are essential in the development of innovative nano-systems because they provide nanoscale resolution in a local vicinity while measuring electrical properties at both nano- and macro-scales. We are now developing a precise measurement methodology for ultratrace substance detection using nanoplasmonics.

Schematic diagram of quadruple-probe atomic force microscope and its application to the characterization of a neuromorphic materials network





High efficiency materials and energy conversion system for a sustainable society

Photocatalytic Materials G

Photonics Nano-Engineering G

Thermal Energy Materials G

Nanostructured Semiconducting Materials G

The key to efficient use of solar energy is the arrangement of the molecules responsible for various functions such as electron transport or reaction. For example, when converting, storing and transporting energy in photothermal or thermoelectric conversion materials, secondary cells, next-generation transistors, etc., the efficiency of ion and electron transport has a large effect, and control of atoms and molecules at interfaces is essential. In realizing high selectivity and efficiency in catalysts, which are indispensable for resource- and energy-saving chemical processes, how atoms and molecules are sequenced on the catalyst surface is key. In short, the scientific basis for realizing a sustainable society is designing the interfacial atomic and molecular arrangement corresponding to a specific purpose and carrying out the actual arrangement as designed – in other words, "interfacial nanoarchitectonics". Based on the concept of interfacial nanoarchitectonics, researchers in the Nano-Power Field are engaged in research and development for high efficiency matter-energy conversion by free manipulation of atoms and molecules and control of nanostructures.

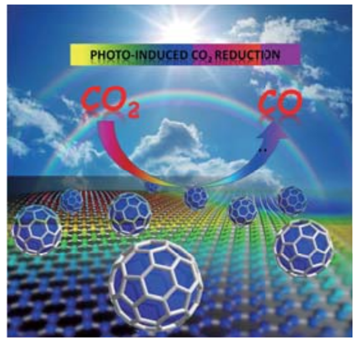
Nano-Power

Nano-Power Coordinator

Jinhua Ye

Design and construction of advanced nano-photocatalytic materials for efficient solar to chemical energy conversion

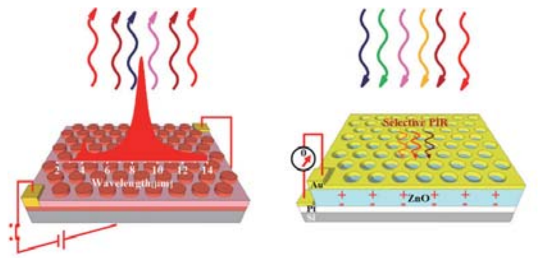
By developing composition- and morphology-controlled nanometals and organic/inorganic semiconductor materials and hetero integration and hybridization of those materials, MANA aims to realize advanced utilization of sunlight and its efficient conversion to chemical energy. Also, through conducting fusion research between theoretical calculations and *in-situ* measurements, we are elucidating reaction mechanisms in order to provide crucial design guidelines for new material development. Our research target is to develop photocatalytic material technologies for advanced environmental purification and new energy production, and in particular, a way to convert CO_2 to fuel.



High sunlight absorption and utilization, and selective conversion of CO_2 to CO, were realized by creating a nano Fe catalyst derived from an organic metal framework encapsulated by carbon nanosheets. (*Adv. Mater.* 2016, DOI: 10.1002/adma.201505187)

Development of nanomaterials and devices for efficient energy transduction between light and heat

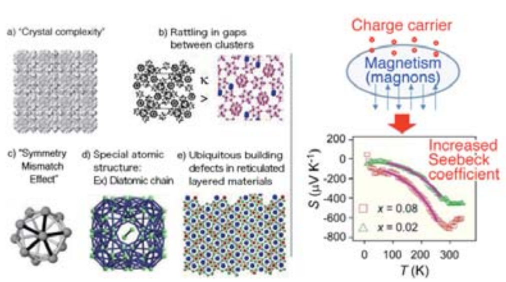
MANA is pushing forward with research to elucidate phenomena related to nanofocusing of electromagnetic energy at the surface and interface of nanoscale materials. We also study energy conversion phenomena, such as photoelectric and photothermal conversion, to establish methods for controlling visible and infrared light energy at the nanometer scale. Through the feedback between the simulation and the characterization, we develop nanostructure-controlled materials using physical, chemical and lithographic methods, developing materials and devices that realize high conversion efficiency between light, heat, and electricity.



(Left) Infrared emitter, which generates thermal emission (infrared beam) with a designated wavelength. (Right) Pyroelectric infrared detector (PIR), which produces electricity in response to a designated wavelength

Development of thermoelectric materials and thermal management technology utilizing nanostructure control and new principles

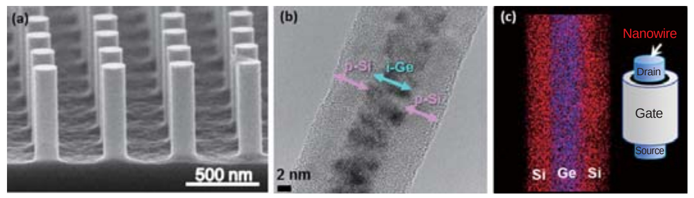
More than half of the primary energy consumed is waste heat. We have taken on the challenge of developing thermoelectric materials suitable for wide-scale applications for the first time ever, and also advanced thermal management technology, in order to use this enormous energy resource. To realize high thermoelectric performance by more effective selective scattering of phonons, we are developing a new nanostructure control technique, and are also elucidating various mechanisms at the atomic structural level, as shown in the figure. We are also searching for new principles, so we are now attempting to control thermoelectric properties through magnetism and design new high performance materials.



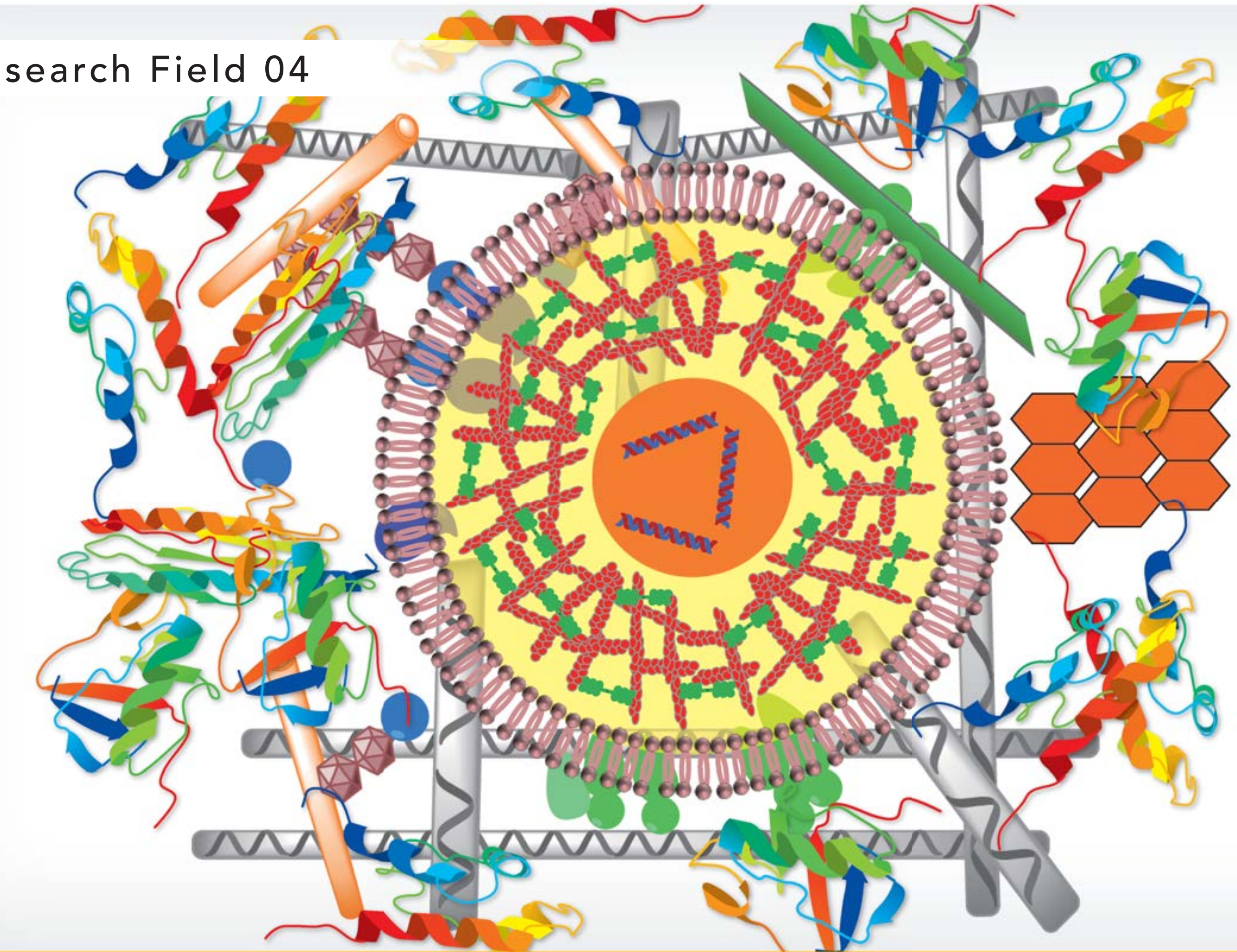
(Left) Mechanism of selective scattering of phonons due to atomic structure (Right) An image of the thermoelectric enhancement effect of magnetism (coupling of carriers and magnons) and Seebeck coefficients of $Cu_{1-x}Fe_{1+x}S_2$

Creation of new materials and devices by functionalization of semiconductor nanostructures

By giving advanced composite functions to nanostructured semiconductor materials, we aim to realize new properties and outstanding functions in semiconductor materials. Since the Group IV elements silicon (Si) and germanium (Ge) are used as the main semiconductor materials, we are conducting research focusing on 1-dimensional nanowire structures and 0-dimensional quantum dots. As research targets, we are grappling with the development of a wide range of new materials and devices, from environmental and energy materials for generation and storage of electricity, etc., to the electronics field related to next-generation transistors that enable low power consumption.



(a) Scanning electron microscope image of nanowires formed on a silicon substrate, (b) transmission electron microscope image of a germanium/silicon core-shell nanowire and (c) results of composition analysis of the nanowire in (b) by energy dispersive X-ray spectrometry and a schematic diagram of a channel for use in a vertical transistor



- Tissue Regeneration Materials G
- Medical Soft Matter G
- Nanomechanical Sensors G
- Mechanobiology G

Innovation of biomaterial technologies by nanoarchitectonics to contribute to health and longevity

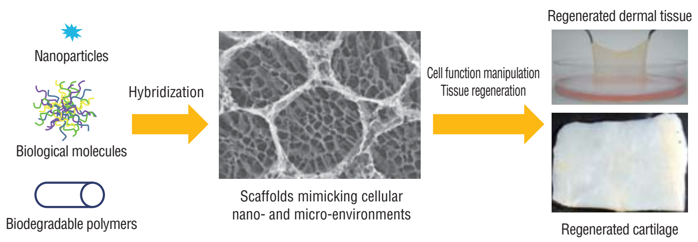
In the human body, many phenomena, such as replication and expression of genetic information, signal transduction inside and among cells, and communication between cells and their extracellular environments, are important for maintaining the functions of tissues and organs to support biological activities. Nano-scale structures, which are formed by assembly and disassembly of various types of molecules by truly ingenious methods, play a critical role in diverse vital phenomena. Thus, disturbance of nanostructure functioning may result in poor physical condition, diseases, or even death. Our aim is to design and prepare functional biomaterials based on nanoarchitectonics and use them to detect, measure and control diverse vital phenomena and biological activities. We will elucidate the causes of various diseases and innovate groundbreaking technologies for diagnosis, prevention, treatment, and tissue regeneration. By linking biomaterials innovation to advanced medical care, we will contribute to the realization of a safe and secure society where people enjoy health and longevity.

Nano-Life

Nano-Life Coordinator
Guoping Chen

Development of novel materials for tissue regeneration as next-generation medical technology

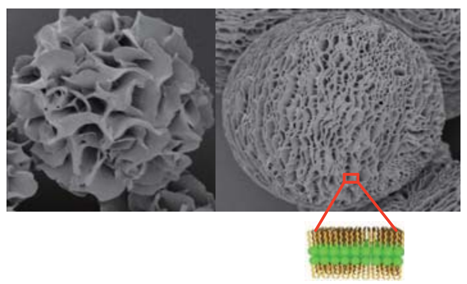
We are devoted to the research and development of biomaterials and scaffolds to control cell functions for regeneration of lost or damaged tissues due to diseases and traumas. We are designing and preparing biodegradable polymer scaffolds and hybrid scaffolds with well-controlled pore structures and mechanical properties, and highly biocompatible biomaterials with nano- and micro-structures. We are also creating nano- and micro-patterns of functional molecules and cell culture matrices that mimic the *in vivo* microenvironments surrounding cells to control the functions of stem cells, which are important for tissue regeneration.



Development of novel materials for tissue regeneration

Development of drug therapy systems using soft matter design

Drug therapy is frequently accompanied by a serious physical/mental burden on the patient. In order to develop patient-friendly drug therapy systems, we are carrying out material development mainly utilizing molecules that already exist in the body and materials that are extremely safe. In particular, mesoporous phospholipid particles, which we developed, provide many functions required for drug carriers and are very safe, and thus are expected to be used as a platform technology for drug therapy. We are also carrying out basic research to gain precise spatiotemporal control of the behavior of materials for medical treatment in the body.



Mesoporous phospholipid particles with a precisely controlled structure

Development of mobile olfactory sensors toward a healthy and peaceful society

Among the five human senses, development of artificial olfactory sensors has been the most difficult challenge. If a mobile sensor that enables simple measurement/discrimination of smells is realized, it is expected to contribute to a variety of fields, such as food quality control, environmental monitoring, security assessments, medicine, and health care. To create a mobile olfactory sensor, MANA is focusing on nanomechanical sensors such as the membrane-type surface stress sensor (MSS), which we developed recently. We are also engaged in interdisciplinary research and development from the principles of operation at the molecular level to the systems compatible with the emerging era of the Internet of Things (IoT).

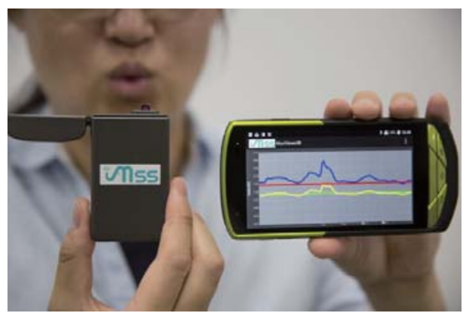
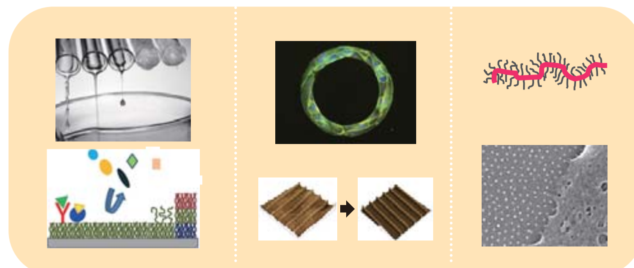


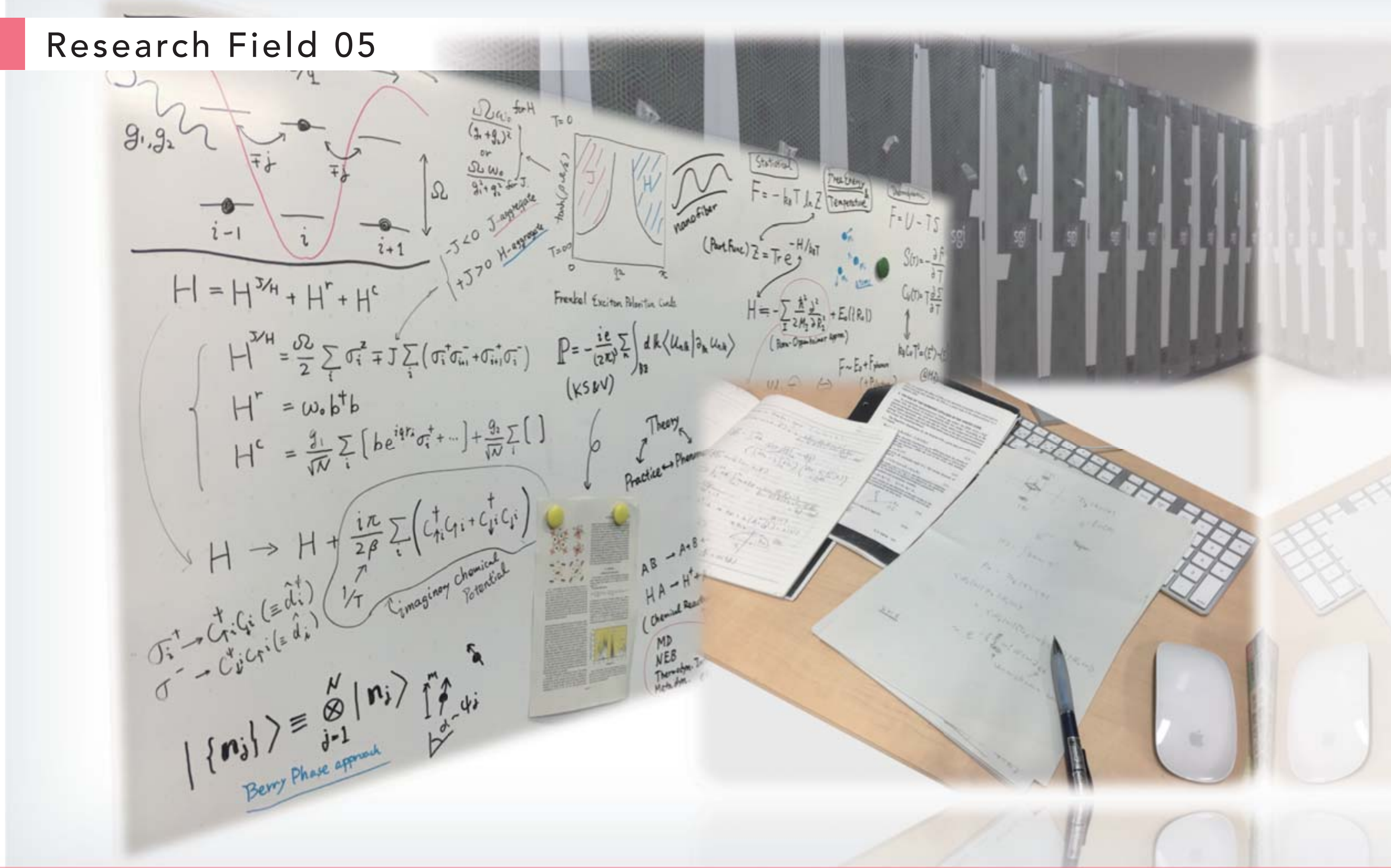
Image of a mobile breath analysis device

Development of new materials for analysis and control of cellular mechanosensing

In a similar fashion to biological molecules such as DNA and proteins, mechanical force is involved in the regulation of various biological activities. We are developing new materials whose chemical and mechanical properties are precisely controlled, and so-called "smart materials", which respond to external stimuli, in order to elucidate the mechanism of cellular mechanosensing. We are also searching for new drug candidates that can modulate mechanical regulation of cellular functions. Through these efforts, we aim to establish useful tools for mechanobiology-based medical treatments.



Novel materials for mechanobiology



Material Properties Theory G

First-Principles Simulation G

Understanding phenomena in the nanospace region, predicting new phenomena and creating novel nanostructured materials

Nanospace is a world in which common sense does not apply, where extremely small atoms are in motion, and electrons fly about in an even smaller space. Moreover, when huge numbers of these atoms and electrons act in coordination, they come to display behavior markedly different from those of single electrons and atoms. Ways of thinking and methods that are not bound by everyday common sense – namely, quantum mechanics and statistical mechanics – are essential for a proper understanding of the phenomena that occur there, and further, for devising new materials. Key activities in the field of nano-theory, which help achieve an understanding of the myriad phenomena emerging in nanospace, include building fundamental theories behind these novel behaviors by incorporating quantum mechanics and statistical mechanics, using our supercomputing facilities to obtain quantitative numerical predictions and develop new and efficient calculation methods. Besides providing interpretations of results obtained in other nanofield areas, we aim at invoking the outcomes of our research to predict as yet unearthed phenomena and to propose new materials featuring novel properties.

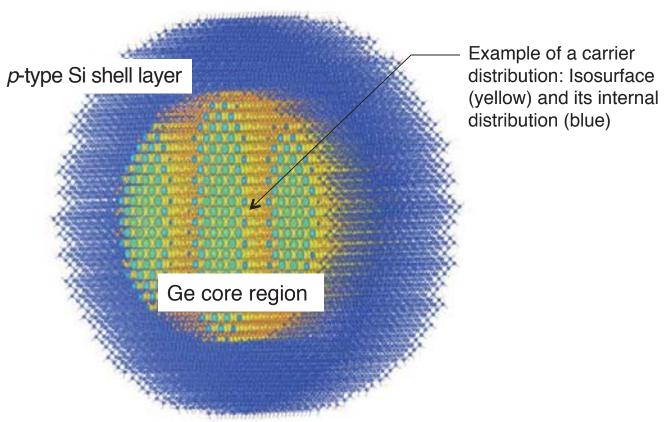
Nano-Theory

Nano-Theory Coordinator
Taizo Sasaki

Joint research of large-scale first-principles calculations and experiments to develop high performance materials for next generation devices

In the MANA Nano-Theory Field, we are developing the large-scale first-principles calculation program called CONQUEST to calculate the positions of the enormous number of atoms in actual nanoscale devices or nanostructured materials and clarify the electronic states of these materials. Although the first-principles calculations of systems comprising a few thousand atoms are difficult with conventional techniques, first-principles structural optimization and molecular dynamics simulation of million-atom systems are possible with the CONQUEST code by utilizing a new theoretical technique called Order-N method.

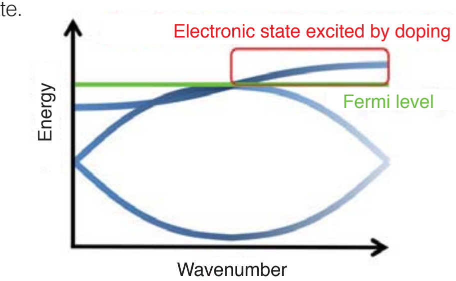
In collaboration with a MANA experimental group (Nanostructured Semiconducting Materials Group, Group Leader: Naoki Fukata), we are conducting research on Si/Ge core-shell nanowires, which are a promising material for next-generation vertical transistors. The properties of core-shell nanowires are expected to depend strongly on the size, interface between Si and Ge, impurity distribution and other factors, which could not be modeled before. It is now possible to predict the structure at atomic scale and the electronic properties by large-scale first-principles calculations. The figure shows an example of a distribution of a carrier when using *p*-type Si. At the same time, the experimental group can control the sizes of the core and shell regions, and the positions of impurities. Our aim is to develop high performance materials for next-generation devices through this joint theoretical and experimental research.



Calculated distribution of a carrier localized in the core region of Si/Ge core-shell nanowire

Elucidation of electronic state in vicinity of Mott transition and its application

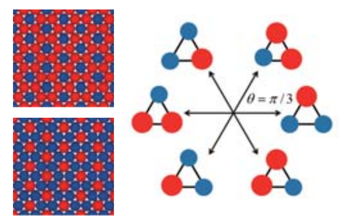
In the strong electron-electron correlation regimes, we observe physical phenomena that are difficult to understand within the free-electron picture for conventional metals. For example, although electrons are particles with charge and spin degrees of freedom, charge-spin separated excited states appear in the substances called Mott insulators: charge excitation has a gap whereas spin excitation is usually gapless. It is difficult to explain such charge-spin separated excited states by a particle electron picture. Thus, we are engaged in a theoretical study from an unconventional viewpoint to clarify the electronic state in the strong correlation regimes like near-Mott insulators, and examine possibilities of new electronic devices by applying that unique electronic state.



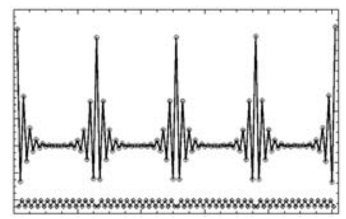
Electronic state with small amount of doping in Mott insulator

Development of methods to control macroscopic and microscopic states by modeling of cooperative interactions

In the development of memory devices that make use of the bi-stability of materials, many attempts have been made to realize switching between bi-stable states by employing various types of stimuli, such as light, magnetic fields and pressure. To elucidate the mechanism of how changes in the electronic and spin states of atoms and molecules lead to changes in macro states, we study various mechanisms of many-body effects by modeling cooperative interactions. Examples include the discovery of a new type of phase transition in a two-dimensional spin-crossover system (upper figure) and the development of a quantum coherence control method for local magnetic moment (lower figure).



(Left) Ground state (6-fold degeneracy)
(Right) 6 state-clock mode



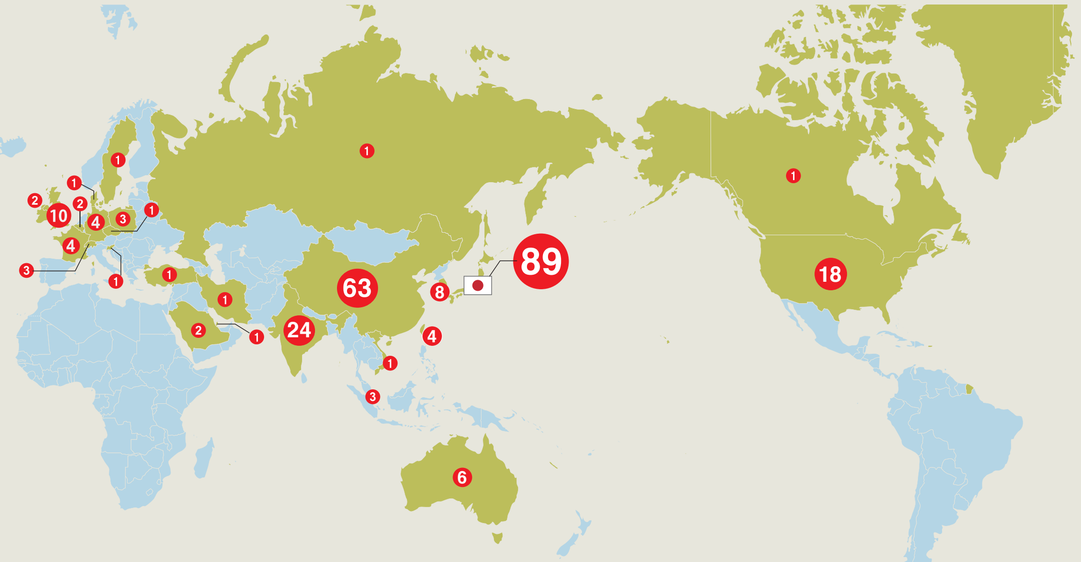
Control of local moments by external fields

MANA, the international research hub

Researchers, post-docs, and students from around the world earn their wings here.
MANA connects these scientists, serving as an international hub for nanotechnology research.

Global career destination

MANA is committed to the development of young researchers so that they may use their experiences here to move ahead. Aside from the 11 researchers who have been hired by NIMS in the past eight and a half years, 255 researchers have advanced their careers and are now active in universities and research institutions around the world. Today, MANA continues to build its international network of nanotechnology researchers.



Development of international research personnel

Young researchers at MANA are encouraged to have two mentors (Double-Mentor), to research across two research areas (Double-Discipline), and to become involved with two research institutes (Double-Affiliation). This system fosters international and interdisciplinary maturity in young researchers via joint research with top-level overseas scientists. MANA calls this approach its "3D-system".

NIMS / MANA cooperates with a number of universities both domestically and abroad, and has established programs for aspiring student researchers to gain knowledge from more hands-on work. MANA also helps organize the annual Nanotechnology Students' Summer School, where excellent nanotechnology students from around the world are invited to participate in fusion research that goes beyond the borders of their nationalities, research fields, and cultures.

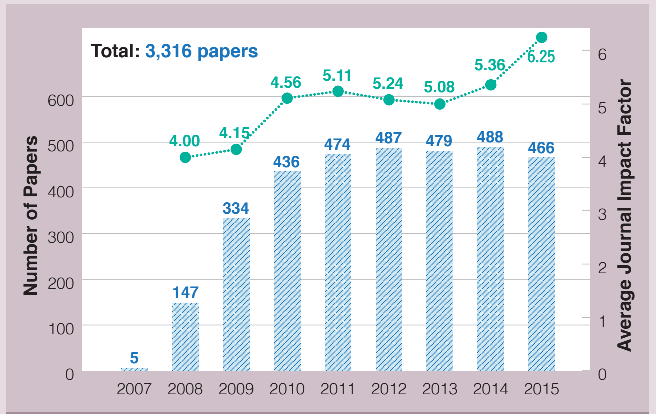
MANA's research results, in numbers

MANA has achieved many accomplishments since it was founded in 2007.
Here are some highlights through 2007–2015.

Research papers published

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

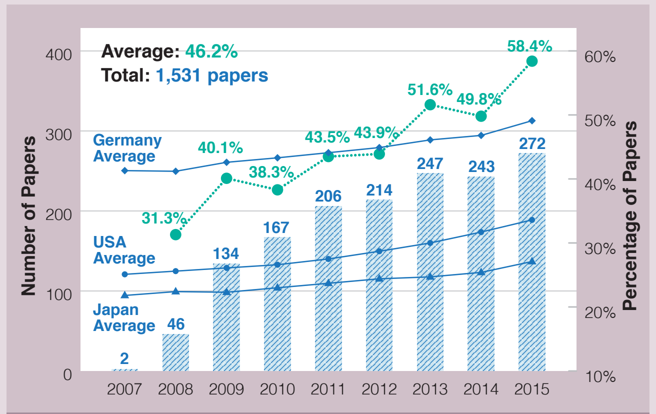
* impact factor : The degree of influence is measured and numerically expressed based on the frequency of citation of published articles in scholarly journals



MANA Affiliated Research Papers (Oct 2007 - Dec 2015)

Progress of internationally co-authored papers

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



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

Highly cited papers, highly cited researchers

Among the 3316 papers published by MANA, 118 papers have become highly cited papers, as defined by the Thomson Reuters database (*1). In 2014 and 2015, Katsuhiko Ariga, Yoshio Bando, Dmitri Golberg, Zong Lin Wang, and Omar Yaghi were selected as highly cited researchers (*2).

*1: Papers that have the top 1% citation number in the past 10 years in each research field, as defined by Thomson Reuters' Essential Science Indicator database.

*2: Authors with more than a certain number of highly cited papers, whom Thomson Reuters has selected as high-impact researchers.

Patents

The total number of patents acquired by MANA reached 581 in 2015. This shows the breadth of potential in nanomaterials, and MANA's proactive approach to the development of new technology, spanning from basic research to applied research.

MANA provides the best research envi ronment

MANA furnishes its facilities with its researchers in mind in order to provide the comfort that elicits innovation for a new era.

The world's highest-level research facilities

MANA researchers have access to state-of-the-art facilities maintained by our host institution, NIMS. The MANA-owned nanofabrication facility known as the "MANA Foundry" provides researchers opportunities to fabricate and characterize a wide variety of materials on nanoscale. The MANA Technical Support Team, with its experienced staff fluent in English, supports researchers in utilization of over 50 shared research facilities.

A melting pot environment that elicits innovation

At MANA, innovation is cultivated by the fusion of different fields and different cultures. MANA provides an environment where researchers from all over the world come together, in a “melting pot”. The WPI-MANA offices are designed as unified large rooms to encourage researchers from different fields to work together, with glass walls to ensure both transparency and safety.

Full support for researchers from all over the world

To enable foreign researchers to devote their undivided attention to their research, the official language used at MANA is English. Experienced secretaries offer support to help researchers complete their paperwork and start life in Japan. We also organize Japanese language and culture classes to cultivate a greater understanding of their host country.

Outreach activities

MANA delivers its research results to the public through publication of books and its magazines "Convergence" and "MANA Research Highlights". MANA also takes a proactive approach to public communication via participation in science and technology events, as well as open house events at our facilities.

Overview

Organization chart

Director
Masakazu Aono

Administrative Director
Tomonobu Nakayama

Deputy Director
Takayoshi Sasaki

Chief Operating Officer
Yoshio Bando

Research Section

Nano-Materials Field
- Soft Chemistry Group
- Functional Nanosheets Group
- Mesoscale Materials Chemistry Group
- Nanotubes Group
- Supermolecules Group
- Frontier Molecules Group
- Semiconductor Device Materials Group

Nano-System Field
- Nano Functionality Integration Group
- Nanoionic Devices Group
- Thin Film Electronics Group
- Quantum Device Engineering Group
- Surface Quantum Phase Materials Group
- Nano-System Theoretical Physics Group
- Nano Frontier Superconducting Materials Group

Nano-Power Field
- Photocatalytic Materials Group
- Photonics Nano-Engineering Group
- Thermal Energy Materials Group
- Nanostructured Semiconducting Materials Group

Nano-Life Field
- Tissue Regeneration Materials Group
- Medical Soft Matter Group
- Nanomechanical Sensors Group
- Mechanobiology Group

Nano-Theory Field
- Material Properties Theory Group
- First-Principles Simulation Group

Managing Researchers

Independent Scientists

ICYS-MANA Researchers

Administrative Section

- Planning Team
- General Affairs Team
- Technical Support Team
- Outreach Team

MANA Foundry

MANA Workforce

(as of April 2016)

Position	Principal Investigators	Group Leaders	Associate Principal Investigators	Faculty Scientists	Postdoctoral Researchers	Junior Researchers	Administrative and Technical Staffs	Total
Number	25	9	2	73	67	26	28	230
Non-Japanese	8	0	1	10	57	22	1	99
Female	2	0	0	9	14	11	17	53

Out of 202 researchers at MANA, 98 (48.5%) are foreign nationalities hailing from 22 countries.

Advisors and Committee Members

Advisors

Advisors, including Nobel Laureates and prominent researchers, draw on their extensive experience to provide valuable advice to MANA scientists.

International Cooperation Advisors

International cooperation advisors, including prominent researchers, provide MANA with advice on joint research with overseas research institutes and the formulation of a global nano-tech network.

C. N. R. Rao	Honorary President, Jawaharlal Nehru Centre for Advanced Scientific Research
T. Kishi	Former President, National Institute for Materials Science
J.-M. Lehn	Professor, University of Strasbourg, Nobel Laureate in Chemistry (1987)
H. Fukuyama	Director General, Research Institute for Science and Technology, Tokyo University of Science
T. Akaike	Director, Foundation for Advancement of International Science
Sir M. E. Welland	Professor, University of Cambridge
L. Schlapbach	Former CEO, Swiss Federal Laboratories for Materials Testing and Research

Evaluation Committee Members

Evaluation Committee members provide MANA with critical comments and expert recommendations on the operations and research strategies of MANA projects.

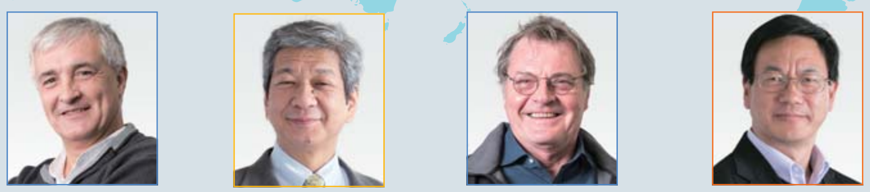
A. K. Cheetham	Professor, University of Cambridge
T. Aida	Professor, The University of Tokyo
M. Endo	Professor, Shinshu University
H. Hahn	Professor, Karlsruhe Institute of Technology
Y. Nishi	Professor, Stanford University
R. S. Ruoff	Professor, Ulsan National Institute of Science and Technology
J. P. Spatz	Director, Max Plank Institute for Intelligent System

Satellite Network

One fourth of MANA Principal Investigators (PIs) are visiting researchers from external research institutes. MANA has satellite laboratories at six research institutions with which PIs are affiliated. The satellite laboratories speedily and rationally facilitate joint research and also play a crucial role in training young researchers.

D. Bowler
Large-scale Order-N DFT Calculuations

F. M. Winnik
Functional Nanoparticles and Nanointerface



C. Joachim
Molecular Device Engineering

Y. Nagasaki
Revolutional Bio-nanomaterials

J. K. Gimzewski
Neuromorphic Nanosystems

Z. L. Wang
Emerging Devices for Energy Generation

Researchers

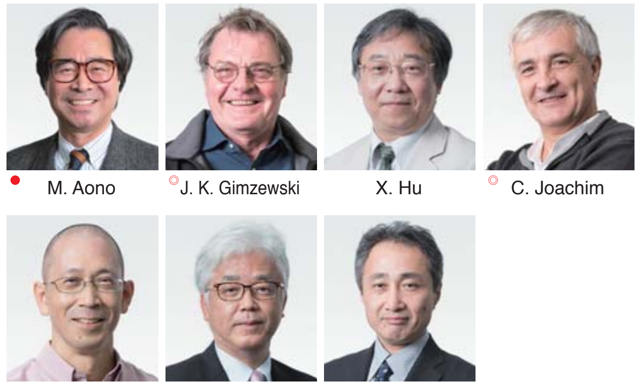
MANA Principal Investigators (PIs)

● Field Coordinator ○ Satellite PI

Nano-Materials Field

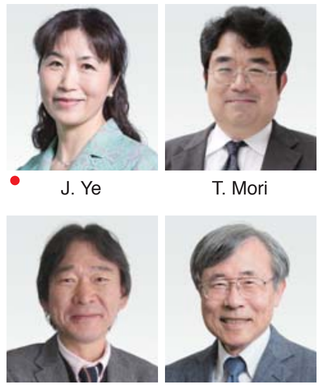
● T. Sasaki, K. Ariga, Y. Bando, T. Chikyow
D. Golberg, M. Osada, ○ Z. L. Wang, Y. Yamauchi

Nano-System Field



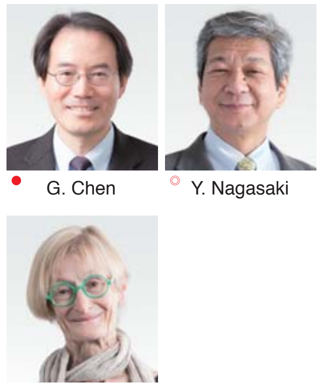
● M. Aono, ○ J. K. Gimzewski, X. Hu, ○ C. Joachim
Y. Takano, K. Terabe, K. Tsukagoshi

Nano-Power Field



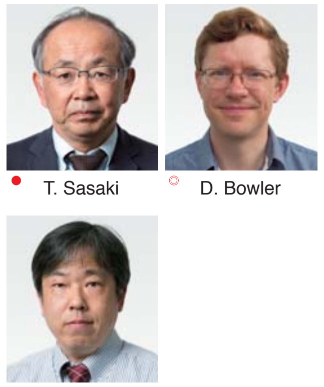
● J. Ye, T. Mori
K. Takada, K. Uosaki

Nano-Life Field



● G. Chen, ○ Y. Nagasaki
○ F. M. Winnik

Nano-Theory Field



● T. Sasaki, ○ D. Bowler
T. Miyazaki

Research Groups

Nano-Materials Field

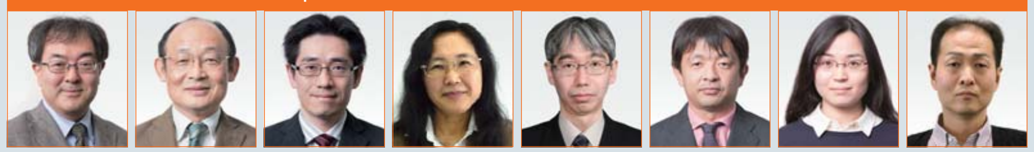
Soft Chemistry Group | **Functional Nanosheets Group** | **Mesoscale Materials Chemistry Group**

T. Sasaki, Group Leader; R. Ma, MANA Associate PI; Y. Ebina, Principal Researcher; N. Sakai, Senior Researcher; M. Osada, Group Leader; T. Aizawa, Chief Researcher; T. Taniguchi, Senior Researcher; Y. Yamauchi, Group Leader; J. Henzie, Senior Researcher; Y. Ide, Senior Researcher; S. Tominaka, Senior Researcher

Nanotubes Group | **Supermolecules Group** | **Frontier Molecules Group**

D. Golberg, Group Leader; M. Mitome, Chief Researcher; R. Souda, Chief Researcher; N. Kawamoto, Senior Researcher; K. Ariga, Group Leader; J. P. Hill, Chief Researcher; W. Nakanishi, Senior Researcher; L. K. Shrestha, Senior Researcher; T. Nakanishi, Group Leader; K. Tashiro, Principal Researcher; S. Ishihara, Senior Researcher

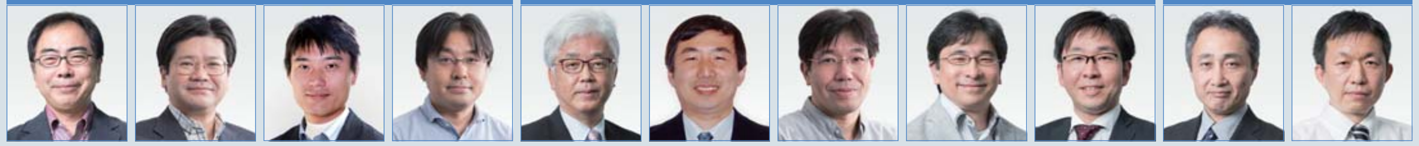
Semiconductor Device Materials Group



T. Chikyow, Group Leader; T. Sekiguchi, Managing Researcher; J. Kawakita, Chief Researcher; M. Yoshitake, Chief Researcher; S. Yagyu, Principal Researcher; Y. Yamashita, Principal Researcher; J. Chen, Senior Researcher; T. Nagata, Senior Researcher

Nano-System Field

Nano Functionality Integration Group | **Nanoionic Devices Group** | **Thin Film Electronics Group**



T. Nakayama, Group Leader; H. Arakawa, Principal Researcher; S. Kawai, Principal Researcher; Y. Shingaya, Senior Researcher; K. Terabe, Group Leader; Y. Okawa, Chief Researcher; M. Sakurai, Principal Researcher; T. Tsuruoka, Principal Researcher; T. Tsuchiya, Senior Researcher; K. Tsukagoshi, Group Leader; S. Kato, Senior Researcher

Quantum Device Engineering Group | **Surface Quantum Phase Materials Group** | **Nano-System Theoretical Physics Group** | **Nano Frontier Superconducting Materials Group**

Y. Wakayama, Group Leader; S. Nakaharai, Principal Researcher; R. Hayakawa, Senior Researcher; S. Moriyama, Senior Researcher; T. Uchihashi, Group Leader; K. Nagaoka, Senior Researcher; T. Yamaguchi, Senior Researcher; X. Hu, Group Leader; T. Kariyado, Researcher; Y. Takano, Group Leader; H. Takeya, Chief Researcher

Nano-Power Field

Photocatalytic Materials Group | **Photonics Nano-Engineering Group**

Nano-Theory Field

Material Properties Theory Group >>

J. Ye, Group Leader; M. Oshikiri, Principal Researcher; T. Kako, Senior Researcher; T. Nagao, Group Leader; S. Ishii, Researcher; T. Sasaki, Group Leader; T. Ohno, Senior Scientist w/ Special Missions; M. Arai, Chief Researcher; W. Hayami, Principal Researcher; K. Kobayashi, Principal Researcher; M. Kohno, Principal Researcher

Thermal Energy Materials Group >> | >> >>

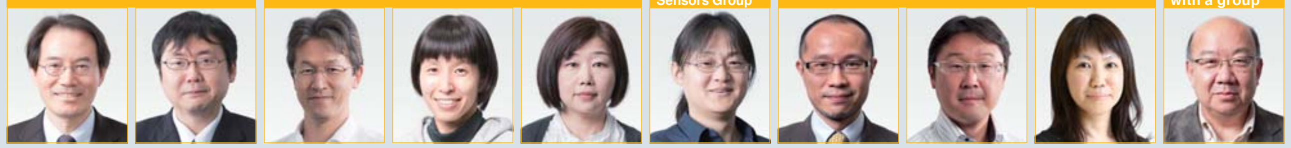
T. Mori, Group Leader; Y. Michiue, Chief Researcher; N. Tsujii, Principal Researcher; I. Ohkubo, Senior Researcher; N. Satoh, Senior Researcher; M. Nishino, Principal Researcher; Y. Nonomura, Principal Researcher; I. Solovyev, Principal Researcher; S. Suehara, Principal Researcher; A. Tanaka, Principal Researcher; J. Inoue, Senior Researcher

>> | **Nanostructured Semiconducting Materials Group** | >> | **First-Principles Simulation Group**

D. Tang, Researcher; R. Wu, Researcher; N. Fukata, Group Leader; W. Jevasuwan, Researcher; J. Shimizu, Principal Engineer; T. Miyazaki, Group Leader; A. Nakata, Senior Researcher; J. Nara, Senior Researcher; R. Tamura, Researcher

Nano-Life Field

Tissue Regeneration Materials Group | **Medical Soft Matter Group** | **Nanomechanical Sensors Group** | **Mechanobiology Group** | **Not affiliated with a group**



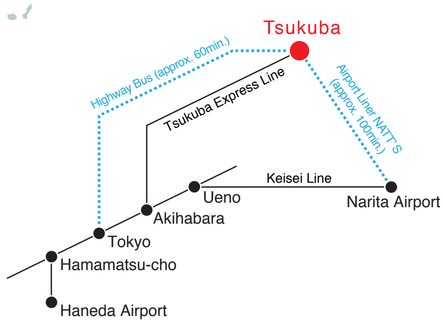
G. Chen, Group Leader; N. Kawazoe, Principal Researcher; K. Kawakami, Group Leader; C. Kataoka, Senior Researcher; Y. Shirai, Principal Engineer; G. Yoshikawa, Group Leader; J. Nakanishi, Group Leader; M. Ebara, MANA Associate PI; C. Yoshikawa, Senior Researcher; H. Kobayashi, Managing Researcher

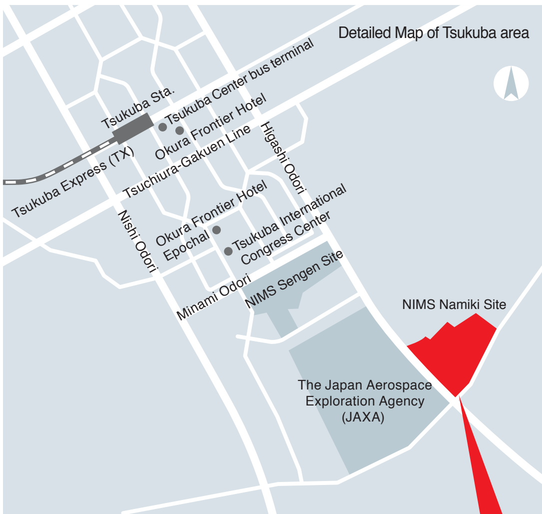
Independent Scientists

R. Arafune, T. Konoike, T. Minari, L. Sang, N. Shirahata, N. Umezawa

ICYS-MANA Researchers

O. Cretu, A. Fiori, T. C. Nguyen, H. T. Ngo, G. Rydzek, K. Shiba, S. Yoshizawa, X. Wang, X. B. Wang, H. H. Yeung





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(July, 2016)

World Premier International Research Center Initiative

International Center for
Materials Nanoarchitectonics
(WPI-MANA)

National Institute for Materials Science