MANA NEWS LETTER

CONVERGENCE

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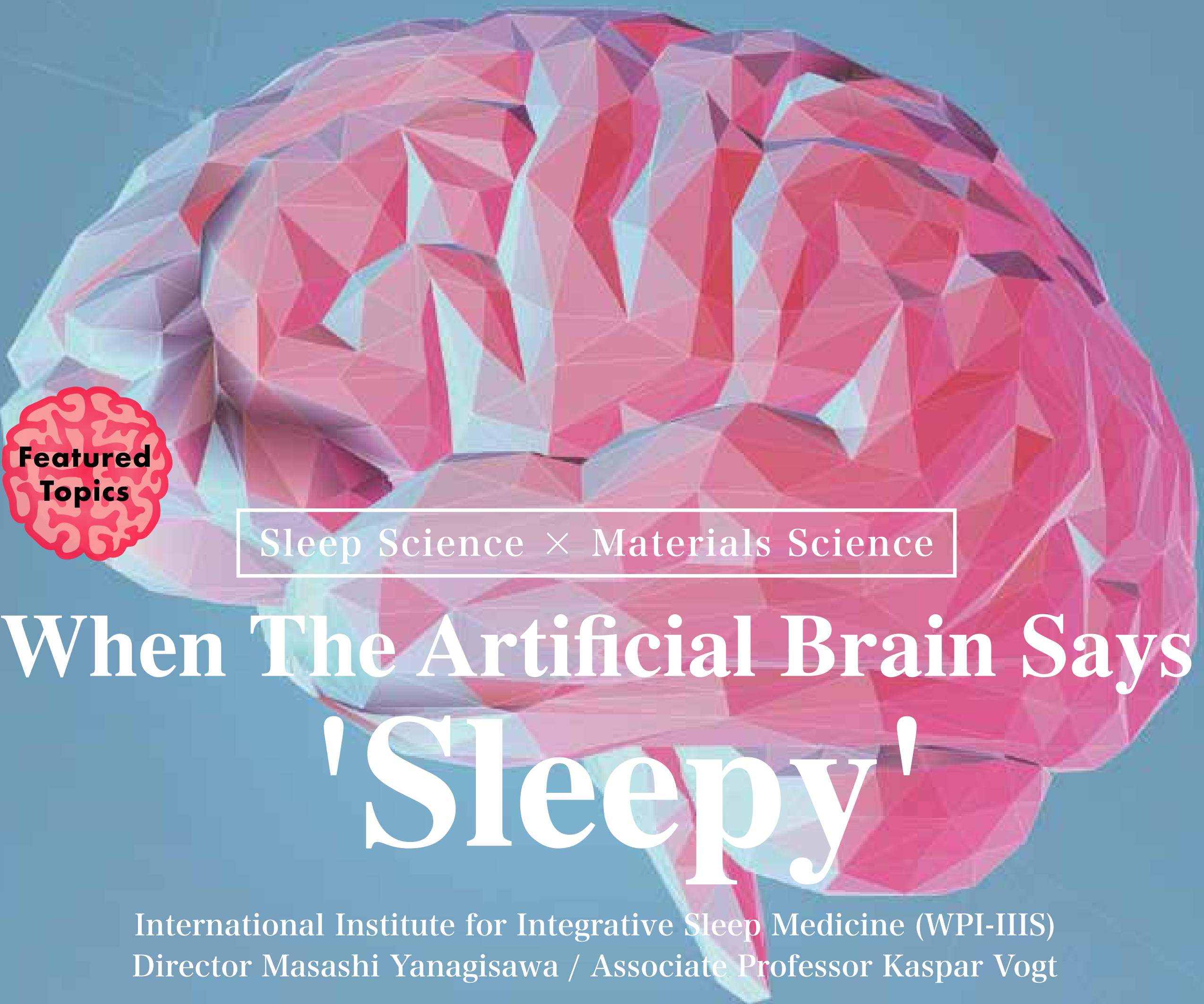
International Center for Materials Nanoarchitectonics (WPI-MANA)



Featured Topics

Sleep Science × Materials Science

When The Artificial Brain Says 'Sleepy'

International Institute for Integrative Sleep Medicine (WPI-IIIS)
Director Masashi Yanagisawa / Associate Professor Kaspar Vogt

Leader's Voice

A Conversation with
Prof. Hidetoshi Fukuyama

“The vibrant environment creates new research achievements.”

WPI-MANA Research Highlights

- METAL OXIDE/GRAPHENE NANOSHEET EXHIBITS UNPRECEDENTED ENERGY STORAGE PROPERTIES
- EVIDENCE OF A NEW TYPE OF QUANTUM EFFECT
- IONIC DEVICES LEARN HOW TO MAKE DECISIONS

What does it mean to get sleepy?

Yanagisawa (Y) : The issue about sleep is that we do not actually know anything about it. There are two big questions. One is "Why should we sleep?" With regards to the brain, the neural activity does not slow down during sleep, and as measured in metabolic rate and blood flow, the activity of the most energy-consuming cerebral cortex does not decrease either.

Nakayama (N) : The brain must take a sleep even though the energy consumption does not decrease...that is a question, right?

Y : An animal will die if it stays awake all the time. Sleep is essential to maintain life. But we cannot explain why. Firstly, we cannot explain what is happening in the brain during sleep, namely a function of sleep. "Why should we sleep?" is one big question.

N : What is known about the role of sleeping at present?

Y : We know many things about it fragmentarily. For example, it is well known that memory consolidation occurs during particularly deep sleep (slow wave sleep). Not only declarative memories, but also of "skills" such as driving, playing sports and musical instruments, are improved by sleeping overnight. A memory element of the barin is said to be the synapses. It is thought that the dynamics of synaptic connections is the actual state of memory, but we do not understand how sleep relates to it exactly.

N : Strengthening synapse connections to fix the memory while sleeping .... If we do that kind of work, I understand that the energy consumption is not reduced.

Y : Another big question is the regulation of sleep. In adults, the average of the required amount of sleep is said to be about 7 ± 1 hours per night, and staying awake all night results in sleeping longer and deeply during the next day. In other words, the longer you stay awake, the more the sleep need becomes stronger, and you get rid of it when you sleep. But we do not know what that sleep need is all about.

N : Revealing the secret of the sleep need is the key to understand why do we get sleepy, and how do we measure the necessity of sleeping... right?

Y : Yes. We know nothing regarding the physical entity of "drowsiness" and the biological mechanism in the brain. The brain seems to count how long you have been staying awake in the near past, but we do not know where this “integrator” is. We do not know how it is measured, where in the brain it is counted, and what the mechanism is.

N : The more I become to know, the more I confuse (laugh).

Y : Well, yes. we really do not know anything.

Masashi Yanagisawa

Director
International Institute for Integrative Sleep Medicine (WPI-IIIS)
University of Tsukuba

Featured Topics

Sleep Science × I

When The Artif

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Tomonobu Nakayama, researching
As we explore the possibility of an artificial
attention on "sleep" which is a characteristic
hear from Masashi Yanagisawa, the Director
Sleep Medicine (WPI-IIIS), University of
research institute and an Associate Professor
a commonality between sleep and the
develop? As we started talking, unexpected

Atomic switch, artificial brain, and sleep

N : WPI-MANA has developed a completely new element called an atomic switch, which actuates by controlling the movement of atoms. This atomic switch has already been practically used as an ON-OFF switch element, however, we are researching on how to create an artificial brain with atomic switches. These switches do not only have ‘on’ and ‘off’ states, but also continuous intermediate states. They exhibit the interesting nature where the switching action and the on/off state are influenced by past actions. These "continuous intermediate states" and "behaviors dependent on past history” are similar to the characteristics of synapse. For example, if most people learn things intently, they tend to be able to recall them for a long time, and if they learn things less intently, they will forget it easily; the atomic switch is an element that has this kind of behavior.

Y : Well, that might be a new approach to understand the brain.

N : If we mention artificial brain, we immediately imagine AI. The current AI consists of a computer software and database, i.e. Soft AI. You can turn off the computer, and then Soft AI will stop functioning completely. But, the complete stop of the human brain means 'death'. That is, there is no complete stop in the human brain, but at least there is sleep instead. If these features are similar to those of the artificial brain we are about to make, I think it will be completely different from Soft AI.

Y : In my opinion, the function of sleep with regard to the brain is maintenance, not in the switched-off state but in the offline state, disconnected from the outside world. I think that the situation is comparable to defragmentation or garbage collection on a computer.

N : It is a very interesting metaphor. We can see it as resolving computer storage fragmentation. We strengthen the system by stopping the input of external data and organizing internal memory.

Is synaptic behavior similar to that of atomic switches?

N : In atomic switches, synaptic-like plasticity[※1] is represented as a change in conductance, that is, a single signal. On the other hand, synapses in the brain are complicated and involve multiple types of molecular transport/signaling. Right?

Y : If we describe synapse movement very simply, it will be like this. The synapse has a front (presynapse) and a back (postsynapse). Basically, when the action potential comes to the presynapse through the axon, neurotransmitter are released from synaptic vesicles. At the postsynapse, there is a receptor for the neurotransmitter, and a signal is transmitted. When the action potential of the postsynapse exceeds a

Material Science

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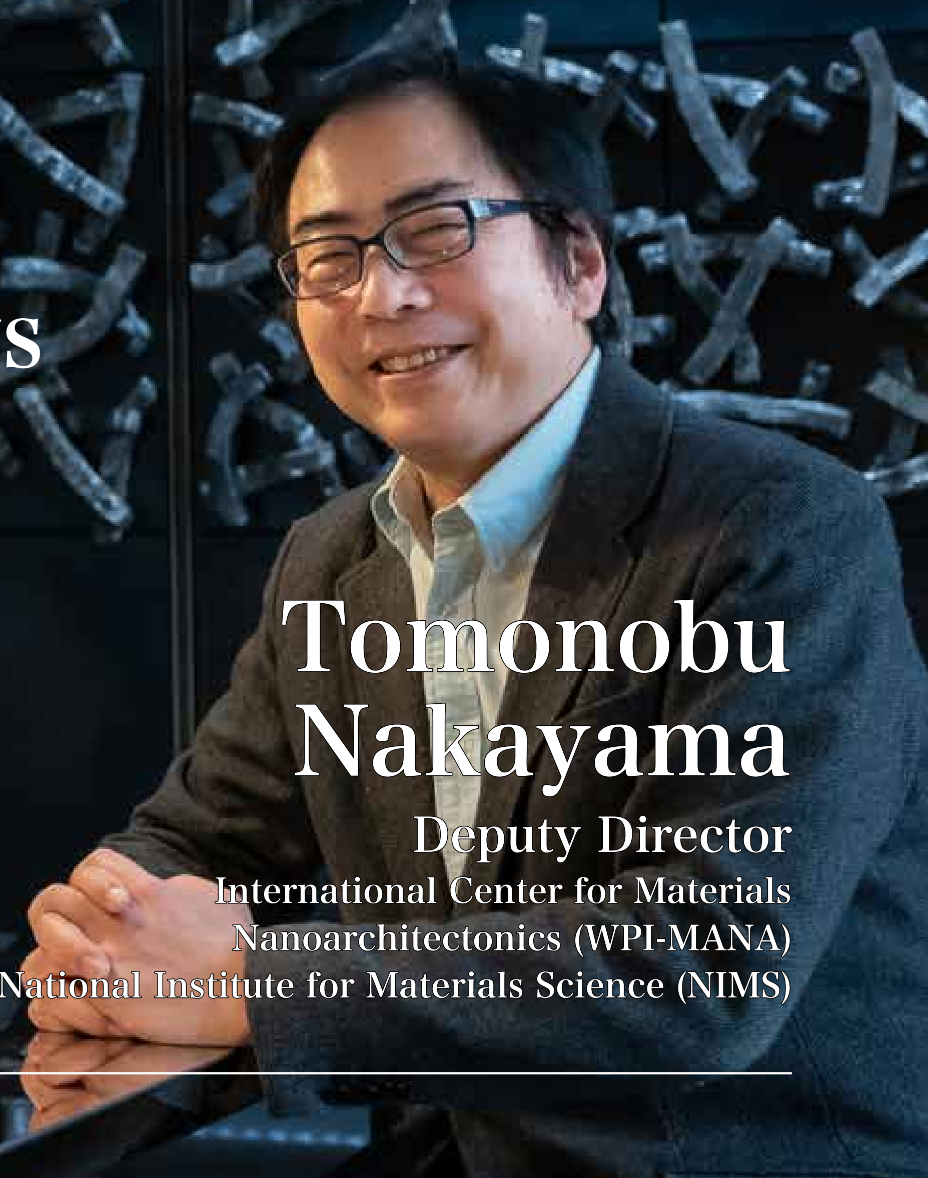
nanosystems at WPI-MANA.
brain using atomic switches, we focus our
of the brain of an organism. Then we will
of International Institute for Integrative
Tsukuba, the world's leading sleep
at WPI-IIIS, Kaspar Vogt. Can we find
artificial brain that WPI-MANA aims to
common points emerged.

Text : Takeshi Komori (TRIXIS FACTORY)



Tomonobu Nakayama
Deputy Director
International Center for Materials Nanoarchitectonics (WPI-MANA)
National Institute for Materials Science (NIMS)

Associate Prof. Kaspar Vogt (WPI-IIIS)

certain threshold, postsynaptic cells fire. But, the amount of released neurotransmitters and receptors, threshold for the neuron to fire, and so on, are actually all variable and complicated in terms of quantity and time. However, it is an analog process overall, meaning that the stronger the stimulation, the stronger the connection formed and the strength of the synapse increases. It is similar to the atomic switch in that sense, i.e. both have analog aspects.

N : Your words are very encouraging to say that the atomic switch is even "roughly" similar to a synapse.

Y : But if I dare say that, basically each synapse is not reliable (laugh). Furthermore, even at the level of each neuron that has about a thousand synapses, it is not very accurate. Most macroscopic activities performed in the brain, like thoughts and computation, are produced by ensemble of many neurons, thereby maintaining a certain accuracy. We, living things make mistakes but maintain a certain degree of accuracy enabling to survive.

N : That is exactly the point that excites nanomaterial researchers. Generally, it is thought that if you make extremely small things in nanoscale, it becomes precise and operation will be fast and reliable. This is correct in a sense. But the smaller the size, the greater the fluctuation. If I am told to prepare one million atomic switches with exactly the same performance and operate them precisely, I will be distressed. In order to hide performance variations (laugh), I will have to use only clear-cut states, like 'on' and 'off.' If elements with somewhat varied characteristics can be operated on with a certain accuracy by aggregating them as an ensemble, a new possibility of nanosystems will be opened up.

Computers are using excessive energy

Y : Classical computers, now in practical use, are very accurate but seem to waste a lot of energy.

N : Exactly. Lots of energy is very necessary to control all the elements as expected.

Y : That is a big difference from organisms. The biological brain is a system that works properly as an ensemble by cleverly organizing elements that are not very accurate as I told.

N : Is that a biological strategy to give fluctuations to the system moderately, and find a more stable and safe condition?

Y : Well, maybe yes. In that regard, I think that there is a possibility that sleep is involved.

N : As computer performance gets better and better, Soft AI gets to use more and more databases, and it will consume more energy. To avoid this, a system like biological brain would be required as a new kind of computer which provides reasonably acceptable solutions. And sleep will play an importat role in operating the system.

Y : Yes, I believe so.

Synapses during sleep operate with a dynamism

Y : With regards to the function of sleep, there is a hypothesis called the Synaptic Homeostasis hypothesis. In that hypothesis, as long as a person is awake, i.e. conscious, his/her brain continues to respond in realtime to constantly changing input. Continuing that, the average synaptic intensity in the brain gradually increases. However, because it cannot keep increasing forever, at some point, it will collapse eventually. In order not to collapse, our brain counts something that increase along with the average synaptic intensity and switch to the state of sleep. That is the essence of the hypothesis.

N : Well, I certainly get tired when I think too much... It is not an abstract thing "too much thinking", but some physical quantity equivalent to it is changing.

Y : Yes, when switching to the state of sleep, renormalization (optimization / leveling) occurs. Because it is necessary to be unbiased when renormalizing occurs, the brain goes offline state, that is, the state of unconscious sleep. Very plausible hypothesis, but there is still no rigorous biological proof so far.

Vogt (V) : The important thing is that renormalization must be done without erasing memory. If memory is lost, there is no point formatting it. Either way, I do not think that memory can be completely erased. Some say that renormalization could mean introduction randomness into the network. If so, the random activities of neurons do not make sense, and we cannot do normal activities. So, at that time, we may need to lose consciousness. But this has not yet been proven. In the end, we have not understood the detailed mechanism of what kind of synapse renormalization occurs at which time yet.

N : Very interesting. It is definitely troubling if we are in conscious state while neurons work randomly. It would be very dangerous if we act under the random commands from the brain. Do we need to lose consciousness in order to live? However, in such a state with or without consciousness, the activity dynamics of the brain should be different.

Y : That is exactly what Associate Professor Vogt is attempting to unravel in one of his recent works. He statistically measured the action potential of neurons. And his conclusion was that the entropy of the neuron spikes during slow wave sleep was higher than that of the waking state. This is a result that does not conflict with the story that the brain is more active while sleeping.

V : Interestingly, the brain works in several ways. When awake, you can predict firing pattern of neurons by giving clear input to them or visual cortex. If there is no clear input, it shows an unpredictable firing pattern even when awake.

N : Then, how about the firing pattern during sleep?

V : At the moment of entering slow wave sleep, the firing pattern changes dramatically. During slow wave sleep, unpredictable firing pattern appears, while the “on” state (active) and “off” state (silence) of neurons in the cerebral cortex are strongly synchronized. This pattern is very similar to that of awakening, but it shows important differences. In that state, individual neurons were not ignited independently, but a large number of neurons were operating at the same time. Our research found that the pattern in which neurons synchronize is more random in slow wave sleep than during awakening.

N : The pattern of neuronal activities get more randomly when entering slow wave sleep, but it is a phenomenon accompanied by neural entrainment.

V : Yes, the interlocking patterns of neurons in the cerebral cortex during wakening and during slow wave sleep are quite different.

N : During slow wave sleep, the physical connection between neurons are maintained?

V : It is known that the conjugation between neurons is quite dynamic.

N : You mean, although it is synchronized, the conjugation between the neurons changes dynamically and controls the whole system.

V : That is right. I am not sure when the physical network actually changes. What we now know is that the individual connections between neurons and collective activities are completely different things.

Considering the dynamics

N : What if all synapses of the human brain worked individually and precisely, what would happen? Can we get smarter (laugh)?

Y : Who knows (laugh). As I see it, so-called flexibility would disappear. The great thing about living beings is that they can adapt the environment even if it changes a little bit, without being taught anything.

N : Keep the brain flexible... The brain made of the synapses that works so accurate seems to be a stubborn thing that only works deterministically.

Y : Yes. It excels in doing one thing, but it cannot do anything if unexpected thing happens. It is not the way actual life is doing.

N : It is one of the problems AI currently has.

Y : Yes. In short, the current AI is very good at solving well-defined problems. But the problem with the current AI right now is that it cannot tell what the problem is or what is interesting to solve.

N : That is so true. You said, "each synapse is not very accurate in a sense.” Does that part lead to this flexibility?

Y : Well, yes.

N : Systems with flexible functionality could be developed by making aggregates of nano-parts with varying properties. This idea could give a new direction to many material researchers. Even though there is a huge gap between sleep science and materials science, it is very interesting that there is a kind of same way of thinking.

Y : The research subjects are quite different, but the concepts seem to be similar.

N : Yes, our research fields share the similar concept towards the understanding how components make the ensemble.

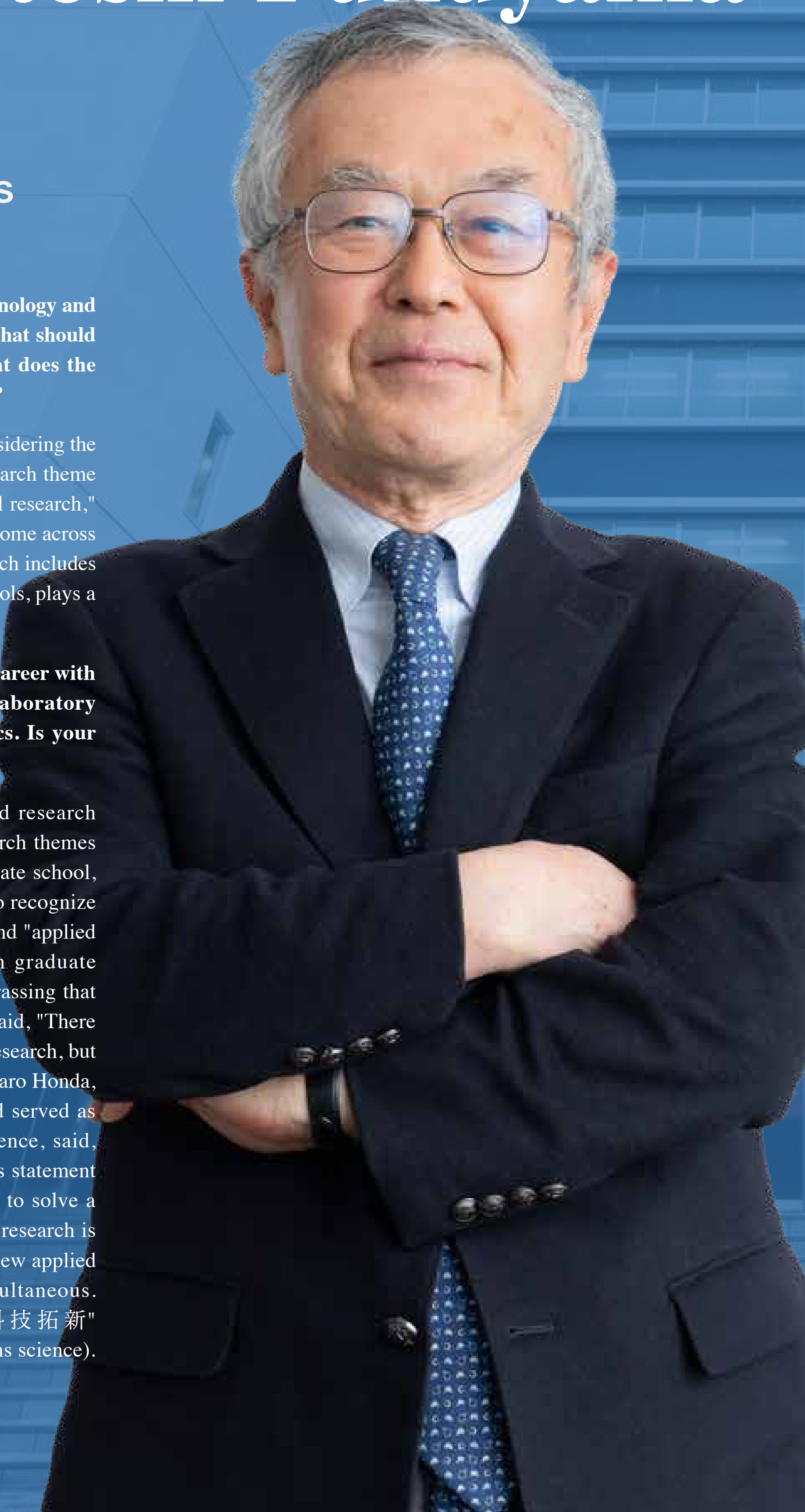
Y : Yes, that is right.

N : Modern technologies are based on bottom-up approach, namely building up from each component one by one. For developing an artificial brain, we might need to take another approach from the dynamics aspect to design it. When an artificial brain that says “I’m sleepy” is created, we will make big progress both in the sleep science and the materials science. ■

※1 : **Synaptic plasticity**
The characteristics of the synapse, which is the transmitter of information between neurons, changes from moment to moment in adaptation to various signals from outside (for example, sensory stimulation). It is thought to have an important role in memory and learning.

Leader's Voice

A Conversation with Prof. Hidetoshi Fukuyama



Good research themes never fade

—WPI-MANA conducts basic research on nanotechnology and materials science. As an advisor for WPI-MANA, what should a young researcher aim for in research life? What does the research theme mean in terms of the basic research?

Basic research does not mean "anything is ok." Considering the meaning of life as a researcher, the setting of the research theme is very important. If you do not focus on "meaningful research," then what is the research for? The problem is how to come across "good theme." Regarding this, the "environment," which includes advisors and senior graduate students in graduate schools, plays a crucial role.

—Professor Fukuyama, you began your research career with a member of the laboratory, hosted your own laboratory later, and led the Institute for Solid State Physics. Is your early research theme special even now?

Yes. Sometimes, I find myself pursuing my old research theme, which was raised by my mentor. Good research themes never fade. After learning basic knowledge in graduate school, we shift to the full-scale research stage, but I came to recognize that there is no difference between "basic research" and "applied research." Professor Ryogo Kubo, my mentor in graduate school, had been saying the same thing. It is embarrassing that I did not notice it until recently. I remember that he said, "There is no difference between basic research and applied research, but trivial research and essential research." Professor Kotaro Honda, who was one of founders of Tohoku University and served as the first president of the Tokyo University of Science, said, "Industry is a hall for science." I understand that this statement is similar in meaning. Science develops in attempts to solve a series of industrial challenges. It means that applied research is based on basic research, and basic research leads to new applied research studies. Progress is in tandem and simultaneous. Recently, I started describing this philosophy as "科技拓新" (Science opens up technology and technology deepens science).

PROFILE: Hidetoshi Fukuyama

1942.7.31	Born in Tokyo.
1970.3	Ph.D. Tokyo University.
1970.4	Research Fellow - Tohoku University
1971.7-1973.3	Post-doc, Division of Engineering and Applied Physics, Harvard University.
1973.4-1974.3	Post-doc, Bell Telephone Laboratories, Murray Hill NJ.
1974.10	Associate Professor, Faculty of Science, Tohoku University.
1977.4	Associate Professor, Institute for Solid State Physics, Tokyo University.
1984.4	Professor, Institute for Solid State Physics, Tokyo University.
1992.4	Professor, Faculty of Science, Tokyo University.
1999.2	Professor, Institute for Solid State Physics, Tokyo University.
2003.10	Professor, Institute for Materials Research, Tohoku University.
2004.6	Professor Emeritus, Tokyo University.
2006.6-2016.3	Professor, Tokyo University of Science.
2016.4-	Research Adviser to the President, Tokyo University of Science.

● Administration ●

1999.4-2003.3	Director, Institute for Solid State Physics, Tokyo University.
1999.10-2002.10	Secretary, Commission 5 (Low Temperature Physics), IUPAP.
1999.10-2006.4	Member of Working Group "Women in Physics", IUPAP.
2002.10-2005.10	Vice President, IUPAP (Also Chair of Commission 5).
2004.4	Director, International Frontier Center for Advanced Materials, Tohoku University.
2006-2007	Member of Committee on CMMP2010, NSF.
2008.1-2016.3	Director, Research Institute for Science and Technology, Tokyo University of Science.
2010.1-2013.12	Vice President, Tokyo University of Science.

※IUPAP: International Union of Pure and Applied Physics.

● Honor ●

1985.11	Fellow, American Physical Society.
1987.12	1st IBM Japan Science Prize.
1999.4	2nd Science and Technology Prize of Superconductivity.
2003.4	National Medal with Purple Ribbon.
2015.11	The Order of Sacred Treasure, Gold Rays with Neck Ribbon.
2016.11	Person of Cultural Merit.
2017.3	Honorary Member of Physical Society of Japan.

What should be transfered to young researchers is to understand "What is research?"

—You have been conducting solid state physics research for a long time. Are there any parts that seem to have changed by comparing today's environment with the research environment of the past?

Yes. I think that researchers could pursue science purely back in the day. In that respect, today's young researchers are in a very unfortunate situation, largely because of the introduction of various kinds of evaluation. Unlike in the past, today's young researchers are being asked for "evidence" of the validity of their research. It means that research studies are quite often being evaluated by the name of the journal(s) in which their papers are published, not by their quality. This is an extremely serious situation. Originally, the main purpose of publishing papers was to report the facts accurately to society, but now I feel that the practice is becoming a publicity tool.

—By introducing those indices, the process of evaluation has become easy, but we often hear that there is the risk that researchers may tend to prioritize research studies just to be evaluated.

I have strong feelings about the situation whereby papers must be published in a specific journal to be evaluated. It is my personal opinion that commercial journals publish magazines not to report scientific progress, but for business purposes not always but quite often. This situation is obvious because they are "commercial" journals. It seems that research is being evaluated according to the impact factor, but that is a big mistake. Since the impact factor is an index for magazines or journals, it should not be related to the quality of individual research. I often hear expressions like "published in xx magazine, which has a high impact factor," and I feel that this kind of phrase is similar to the expression used by prep school (e.g., "xx students went to xx university from our school"). If young researchers are tossed based on a commercial magazine's "business strategy," it is a very serious situation.

—So, what kind of attitude is necessary to properly evaluate research?

I believe that the most important thing is to understand the contents of individual papers, and then pay attention to the number of citations and keynote and invited lecturers at international conferences. For young researchers to understand "what research is all about," mentors and senior scientists have to properly lead them how to determine research themes, conduct research, make good presentations, and so on. If these aspects are not emphasized, researchers could get stuck in the future.

> “The vibrant environment creates new research achievements.”

Collaborative research opens unexplored research fields

—Most research is being conducted on a group-by-group basis in WPI-MANA. Now, we are also focusing on research activities that traverse group units. What do you think about joint research activities?

Collaborative research activity should be highly recommended

A Conversation with Prof. Hidetoshi Fukuyama

because, in research, 1 + 1 can equal 3 or 4. I have been at Bell Laboratories since I was 31, and Bell Labs at that time had such an environment. I remember that respected researchers, including Philip Anderson (Nobel Prize laureate in Physics in 1977), engaged in discussions with loud voices in the hallway or during lunch. I learned the importance of discussions and recognized that they could be fun. In addition, there were a lot of parties for researchers, and I understood that human interactions are essential for research. In research activities, sometimes unknown facts come to the forefront through the exchange of opinions between theoreticians and experimentalists. Since I experienced that environment at Bell Laboratories, I have tried to preserve the attitude that "experiment underlies theory" through communications with experimentalists. As a theoretician, I have been very happy to be introduced to an unknown interesting phenomenon first.

Objectivity in papers and identity in research

—What do you think about collaborative research, not only with theorists and experimentalists, but also interdisciplinary research studies?

In the study of physical properties, the research targets are materials that are aggregates of atoms and molecules, so there are infinite possibilities; furthermore, new and amazing phenomena are constantly emerging. I think that bio-related research studies will come on stage in the near future. Even if the research topics change, the importance of physical science remains unchanged. In fact, it will increase in the future. It is meaningful that you strive to tackle new research subjects while interacting with many researchers. The key to creating such an atmosphere is the environment. Historically, a great discovery emerged from excellent environment. Focusing on creating a mechanism to promote exchanges among researchers is the first priority of a research organization.

—Can you give me a message for young researchers?

It is difficult to answer this question with a word, but it is extremely important to acquire external funds because it is impossible to continue your research without a budget. However, repeatedly, being too conscious of a reputation in order to acquire research funds is not a scientific attitude. Ideally, promoting interesting research that will encourage people to provide funds is the best way. Needless to say, to have objectivity in mind when you report your research results to society is necessary. At the same time, in the process of striving for research results, having "identity" and "individuality" in your research is essential for attracting people. I believe that this "personal part" of the research activity is the most interesting and motivating part for us as researchers. It is related to the environment, which creates a free exchange of ideas between researchers. This is what I expect from WPI-MANA. ■

Prof. Fukuyama with Prof. Phillip W. Anderson in 1985

New Satellite Laboratories

In order to accelerate the international brain circulation and widen the nanotechnology network, two new satellite laboratories opened at Strasbourg University and The University of Pennsylvania.

Strasbourg University

Nano-Materials

Prof. G. Decher Fuzzy Assembly

Our Team is developing new and widely applicable tools for creating multi-composite materials at the nanoscale in a highly controlled way. We joined the WPI-MANA satellite network for establishing new synergies with colleagues studying the properties of multi-nanocomposites.

The University of Pennsylvania

Nano-Materials

Prof. T. E. Mallouk Nanoscale Chemistry

The Mallouk Group specializes in nanomaterials chemistry related to electrochemical energy conversion, low-dimensional physical phenomena, and powered motion on the nano- and microscales. We are interested in collaborating with WPI-MANA scientists on a broad range of problems to which our synthetic and electrochemical expertise can be applied.

Nano-Theory

D. Bowler

University College London

Large-scale Order-N DFT Calculations

Nano-Systems

C. Joachim

The National Center for Scientific Research

Molecular Device Engineering

Nano-Systems

F. M. Winnik

University of Helsinki

Functional Nanoparticles and Nanointerface

Transfered from University of Montreal

Nano-Systems

J. K. Gimzewski

University of California, Los Angeles

Neuromorphic Network

Nano-Materials

Z. L. Wang

Georgia Institute of Technology

Emerging Devices for Energy Generation

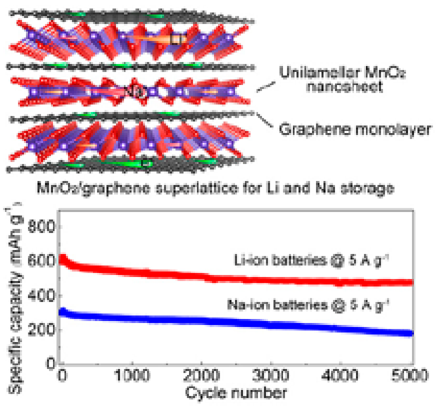
WPI-MANA Research Hig

METAL OXIDE/GRAPHENE NANOSHEET EXHIBITS UNPRECEDENTED ENERGY STORAGE PROPERTIES

Single-layer metal oxide nanosheets sandwiched between graphene layers exhibit record energy storage figures of merit.

The unique physical properties of nanomaterials are important for the realization of high performance energy storage devices. For example, the ultra-narrow spaces between multilayered two-dimensional (2D) nanosheets are suitable for high efficiency ion intercalation, namely, reversible insertion of ions into the spaces between layers. Importantly, single-layer nanosheets with nearly ideal atomic-scale thickness exhibit short diffusion distances and large numbers of active sites—properties that are essential for fabricating electrode materials of high performing energy storage devices.

However, despite extensive research on 2D materials such as graphene and transition metal dichalcogenides, the energy storage capacity has not met expectations. More recently, research has also turned to explore 2D metal oxides—materials with many more exposed active sites, and even shorter diffusion lengths. The main issues to resolve include synthesis of genuine single layered metal oxides, prevention of 'restacking' during chemical processes to fabricate electrodes, and improving their electrical conductivity.



STRUCTURE OF MNO_2/GRAPHENE SUPERLATTICE-LIKE STRUCTURE

Here, a group led by Takayoshi Sasaki at WPI-MANA reported the synthesis of superlattice-like MnO_2/graphene 2D nanostructures that exhibited the best figures of merit for energy storage reported to-date.

The researchers synthesized the MnO_2/graphene superlattice structures by 'electrostatic assembly' of single-layer MnO_2 and graphene in a solution, exploiting the differences in the charge states of the respective materials: The MnO_2 nanosheets are negatively charged and modified reduced graphene oxide (rGO) nanosheets are positively charged. The two important points about this fabrication process and the resulting nanosheet superlattices are that the MnO_2 nanosheets were 'genuine unilamellar' structures and each of the MnO_2 nanosheets was 'stabilized' between the atomic layers of graphene.

The MnO_2/graphene nanostructures were used as anodes for Li and Na ion batteries. Electrochemical measurements showed specific capacities of 1325 and 795 mAh/g at 0.1 A/g and 370 and 245 mAh/g at 12.8 A/g for Li and Na storage, respectively. "More importantly, an ultralong cyclability with 0.004% and 0.0078% capacity decay per cycle up to 5000 cycles was achieved for Li and Na storage, respectively, outperforming previously reported metal oxide-based anodes to date," state the authors.

"The superlattice composite material described in this paper is based on MANA's concept of 'Materials Nanoarchitectonics', says Sasaki. "We have taken two types of 2D materials with differing properties and formed an advanced composite material with synergistic characteristics that are not exhibited by a single material." ■

REFERENCE

PAN XIONG, RENZHI MA, NOBUYUKI SAKAI, AND TAKAYOSHI SASAKI, GENUINE UNILAMELLAR METAL OXIDE NANOSHEETS CONFINED IN A SUPERLATTICE-LIKE STRUCTURE FOR SUPERIOR ENERGY STORAGE, ACS NANO, 12 ,1768–1777, (2018).

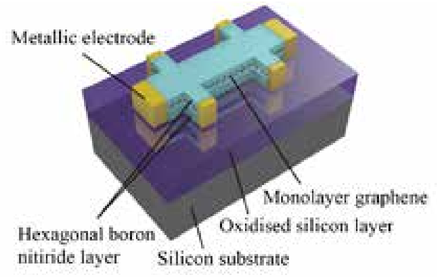
EVIDENCE OF A NEW TYPE OF QUANTUM EFFECT

The quantum Hall effect (QHE) is a phenomenon that can occur in a two-dimensional electron gas — a system in which electrons can move in a plane but not perpendicularly to it. Such a system is typically realized in a heterostructure of thinly stacked layers of different semiconductors. The QHE is usually observed at low temperatures and high magnetic fields; it manifests itself through the quantization of values of the electronic conductance (the inverse of resistance) — the values are integer or particular fractional multiples of a fundamental conductance quantum.

Recently, variants of the QHE have been discovered, such as the quantum spin Hall and the anomalous quantum Hall effect. Now, Satoshi Moriyama at WPI-MANA, NIMS, Tsukuba, Japan, and colleagues have observed yet another relative of the QHE: the quantum valley Hall effect.

The notion of 'valleys' refers to electronic states having the same energy but a different crystal momentum; the states are said to lie in different valleys. A new type of electronics called 'valleytronics', based on the valley degree of freedom, is being researched since some years.

Moriyama and colleagues demonstrated the quantum valley Hall effect in a special heterostructure capable of hosting a two-dimensional electron gas: a sheet of graphene sandwiched between hexagonal



DEVICE STRUCTURE

boron nitride (h-BN) layers. Graphene is a one-atom thin layer of carbon atoms forming a honeycomb pattern. h-BN is similar; it is also a monolayer with a honeycomb structure, but it has a slightly different lattice parameter. Due to the mismatch in lattice size, the periodicity of the combined system is much larger — overlaying the two lattices results in a moiré pattern.

Importantly, the investigated electronic regime in the superlattice was ballistic: the electrons' mean free path (the mean distance travelled between scattering events) was estimated to be 1 to 2 micrometer, which was comparable to the size of the sample.

The researchers varied the magnetic field while measuring resistances, and at a small interval centered around zero field they observed a non-vanishing resistance — a signature of the quantum valley Hall state.

An important fundamental finding on its own, Moriyama and colleagues note that it also may lead to potential applications: "[such] unconventional magnetism should have the potential for engineering the energy-band structure [of devices] even with a weak magnetic field as well as for spintronics applications." ■

REFERENCE

K. KOMATSU ET AL., "OBSERVATION OF THE QUANTUM VALLEY HALL STATE IN BALLISTIC GRAPHENE SUPERLATTICES", SCI. ADV. 4:EAAQ0194 (2018).

IONIC DEVICES LEARN HOW TO MAKE DECISIONS

Decision-making processes require the examination of complex data in order to effectively adapt to dynamic changes in the environment and make decisions about the most appropriate way to behave. Emulating these processes with computers requires enormous resources, so new avenues need to be explored.

Now, writing in Science Advances, Takashi Tsuchiya, Tohru Tsuruoka, Song-Ju Kim (currently at Keio Univ.), Kazuya Terabe and Masakazu Aono at the WPI-MANA, NIMS, Tsukuba, Japan propose to use ionic devices to perform decision-making operations. They apply their

devices, named ionic decision-makers, to the solution of Multi-armed Bandit Problems (MBPs); mathematical problems in which a gambler given a choice of slot machines must select the appropriate machines to play so as to maximize the total reward in a series of trials. MBPs have been applied to various practical technologies related to artificial intelligence. The scenario investigated by the authors is that of a user of busy communication channels who needs to select a channel to transmit information with maximum efficiency.

A two-electrode electrochemical cell, with Nafion proton conducting polymer electrolyte and Pt electrodes, is used to solve MBPs with two channels (A and B), with transmission probabilities P_A and P_B, of which the user has no a priori knowledge. The setup comprises the cell, a device controlling the flow of electric current through it, and a random number generator that determines the transmission of data packets. The electrical potential of each of the two electrodes, A and B, is used to evaluate which channel is the best to select, and it increases or decreases on the basis of whether or not the channel is open for transmission.

Ions in the electrolyte are initially randomly distributed, but there is still a small voltage across the device. This voltage is measured; if it is positive (negative), a random number is generated to emulate the selection of channel A (B), that is, to determine whether a packet is transmitted or not. In accordance with the result, a pulse current is then applied in the corresponding polarity, varying the concentration of ions and/or molecules in the vicinity of the electrodes. The rate of correct selection increases with the number of selections, because the variation in the concentration near the electrodes makes it a more or less likely choice in subsequent selections. To verify the adaptability of the system to environmental changes, P_A and P_B was inverted after some selections; the rate of correct selections initially dropped, but the decision maker quickly adapted.

A more complex problem is that of two network users trying to select an available channel. If they select the same channel the probability of it being open is split between them, so that the number of transmitted packets decreases substantially for both. This is an important practical problem for communication network systems with limited channels and many users. The authors present an extended decision maker, with two electrochemical cells and three channels, which is particularly effective at solving such problem and can maximize the number of packets for all users.

The authors comment, "The ionic decision-maker creates a new research field of 'materials decision-making' in which the intrinsic properties of materials are used to make decisions, not only for large-scale computations of human behavior but also for developing autonomous intelligent chips for mobile applications." ■

REFERENCE

TAKASHI TSUCHIYA, TOHRU TSURUOKA, SONG-JU KIM, KAZUYA TERABE AND MASAKAZU AONO, "IONIC DECISION-MAKER CREATED AS NOVEL, SOLID-STATE DEVICES", SCIENCE ADVANCES, 4, EAAU2057 (2018).

Welcome to WPI-MANA

New researchers WPI-MANA from 2018!

I transfered from International Center for Young Scientist (ICYS) to WPI-MANA in April 2018. I am honored to be able to join the center where a number of achievements have been made.

I have been conducting research on π-conjugated molecules and polymers. They are materials having luminescent property and conductivity that play a central role in organic electronics. Especially, I have been tackling to synthesize new molecules that change their color and luminescence property in response to external stimuli (light, pressure, friction) and environments (solvent, temperature). Such functional molecules not only play an important role in vision sensing of living organism, but also work as materials having a sensor function.

Organic chemistry originates in handling molecules and macromolecules derived from "living things". Now, It is becoming possible to synthesize complex molecules along with the development of synthetic methods, but to synthesize, accumulate and move huge molecules like proteins, the key to life phenomena, is extremely difficult. So, I am trying to create new organic materials that could surpass biological functions using the precise organic synthesis method that can control their movement and physical properties at nano scale.

On holidays, I refresh myself by playing with my cats and taking pictures, and dream about future organic materials that could exceed the life.

Spending holidays with my cats.

Kazuhiko Nagura

Nano-Materials

Researcher
Frontier Molecules Group

The number of bacteria on the earth is said to be 10^{30} and literally our world is filled with this microflora from corner to corner. Electric bacteria that exchange electrons with electrodes was thought to be a special one, but it has come to be known that they are in various places including the human body and underground.

Electric bacteria have molecular leads of about 10 nm to a few μm penetrating the insulating cell membrane and metabolize by electron transpor from the inside of the cell to the extracellular electrode. By utilizing their property, we can conduct electrochemical analysis of the function of "living" enzymes, and I have refined and studied such an approach for over 10 years. We have challenged to study physically and chemically the contribution of complex biological factors, such as non-equilibrium flow of energy and cellular membranes, which can not be understood by studying isolated and purified biomolecules. Such research is conceptual reconstruction of life from the view of "electric bacteria" and sources me intellectual curiosity. Furthermore, the presence of electric bacteria in our body suggests unexplored research topics, such as communications with the host using electricity.

Maybe because I have been playing beach rugby for 8 years smeared with sand and mud, I feel very good when I am in my home garden. Or maybe microbial flora and electric bacteria in the soil work in good way on my brain through communication with my cells.

Chinese cabbage I grown!

Akihiro Okamoto

Independent Scientist

I have spent most of my academic career at NIMS (NIMS Postdoc Researcher, JSPS Overseas Research Fellow, ICYS-MANA Researcher, ICYS-Namiki Researcher), and finally I became an Independent Scientist at WPI-MANA in November 2018.

My research aim is conducting the research on "biology that can not be done by biology researchers" with smart polymer materials. Currently, I am tackling functionalization of shape memory polymers. Shape memory polymers have attracted a lot of people by their visual impact, but they have not be used in real life yet. With the intension of including some self-discipline, I have to admit that they are just "interesting materials." As a researcher who has been conducting research on shape memory materials for many years, my goal is to improve them to materials that can be used in real life from just interesting materials. On the other hand, the behavior of biological cells on the materials is very interesting and stirs my imagination. Actually, it is very tough to control them as I wish, but as a researcher at NIMS, I am trying to create materials with strong commitment. I want to reveal life phenomena and develop methods to control them by mixing up unique materials research and biology research.

On holidays, I enjoy going for a drive with my family and refreshing while touching nature etc. but my daughter won't take to me at all. Child-raising and researching are very profound.

With my daughter

Koichiro Uto

Independent Scientist

After receiving my Ph.D. in 2015 at the University of Tokyo, I researched at Cornell and Northwestern Universities as a postdoctoral fellow. In December 2018, I was honored to start my independent carrier at WPI-MANA.

My research interests focus on the synthesis and development of multi-dimensional polymers. Conventional polymers are made of spaghetti-like molecules, which entangles randomly in a bulk scale. Due to this randomness, installing desired functions in plastics still remains challenging. Multi-dimensional polymers, however, have less complexity in bulk owing to their extended molecular structures in two or three dimensions so that these new polymers are more accessible to design functions in bulk materials. During my postdoc times, I have studied to adopt these multi-dimensional polymers with pores of specific sizes for water purification treatments. Multi-dimensional polymers are a still young research field, and I am going to study their synthetic methodologies as well as their unique functions.

Since nanoscience targets at tiny systems, we cannot see them by our own eyes, and addressing those materials requires speculations. We, synthetic chemists, enthusiastically conduct daily experiments with many hypotheses but often end up to notice those hypotheses are completely wrong. Although those moments hurt us for sure, they offer, at the same time, a great chance to encounter something very new that human beings have never even imagined. Those encounters are always very thrilling and bring joy after figuring out the details. I am very excited to find further 'joy' of nano scales here at WPI-MANA.

With my 'American' family - scientific discoveries resemble meeting people

Michio Matsumoto

Independent Scientist

New Deputy Director
Yutaka Wakayama Group Leader

Yutaka Wakayama Group Leader of Quantum Device Engineering Group is to become the new WPI-MANA Deputy Director. Under the new operation system, WPI-MANA will realize active research activities that make the leap of new materials research.

I started my career as a corporate researcher. After engaging in research as a postdoctoral fellow both in Japan and abroad, I started working at the National Institute for Metals (NRIM) in 1999. In shortly, NIMS was established by merging NRIM and National Institute for Research in Inorganic Materials (NIRIM). I could experienced the process of establishing the world's leading materials research institute in real time. I joined the WPI-MANA in April 2011 and it was 4 years since WPI-MANA established as one of the WPI centers. Since then, I was blessed with an environment that I can focus on my research as a researcher.

When I quit a company quarter century ago, my mentor told me "From now on, your research will be widely evaluated in the world. You ought to be happy with it." From that day on, I have been researching with the policy that I have to ask others to evaluate my research in order not to fall into self-satisfaction, and I believe that there are scientific journals as a medium for that. In other words, the journals are just a medium to seek the evaluation, not the purpose. I really appreciate to have a chance to enroll in an organization, WPI-MANA that provides us researchers well organized free research enviroment with no boundaries of nationalities and age.

I am already in the middle of my 50s. The word "retirement" are starting to flicker in my head. It is about time to play a role not only for me but also for young researchers. I decided to undertake the job of the deputy director with such a thought.

若山裕

New WPI Centers

Hokkaido University
Institute for Chemical Reaction Design and Discovery (ICReDD)

We conduct fusion research by derivation of chemical reaction path by computational science, selection and integration of reaction pathway by information science, demonstration by experimental science ranging from organic chemistry to medical field, and feedback to theory. Through our fusion research, we aim to understand chemical reactions indispensable for mankind to survive the future as a new and complicated network and control it freely.

Kyoto University
Institute for Advenced Study of Human Biology (ASHBi)

Merging life, mathematics, and humanities, we will create a new research area "human biology" to investigate the design principles of human beings and mechanisms of pathogenesis. In addition to clarifying the essence of human, we aim to elucidate the pathogenesis of various pathologies including intractable diseases, create the foundation for developing treatment methods, and lay the foundation to support healthy and steady progress in human society.

NEWS & TOPICS

Event Report

MANA International Symposium

Towards Perceptive Nanomaterials, Devices and Systems

"MANA International Symposium 2019" was held at Interanational Congress Center EPOCHAL TSUKUBA from March 4 to March 6. This year's theme was "Towards Perceptive Nanomaterials, Devices and Systems". Plenary and invited lectures by prominent researchers from all over the world and presentations about latest research at WPI-MANA, and numerous poster presentations was conducted.

Awards

Genki Yoshikawa Group Leader
Kota Shiba Senior Researcher
Gaku Imamura Independent Scientist
Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology in Development Category (2018.4)

Mitsuhiro Ebara Associate PI
Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology in Public Understandings Promotion Category (2018.4)

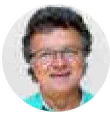
Akihiro Okamoto Independent Scientist
Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology, The Young Scientists' Prize (2018.4)

Satoshi Ishii Senior Researcher
National Physical Laboratory, Best Presentation Award "Second Grand Prix" (2018.6)

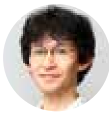
Katsuhiko Ariga PI
Yoshio Bando Executive Advisor
Dmitri Golberg PI
Jonathan P. Hill Chief Researcher
Thomas E. Mallouk Satellite PI
Zhong Lin Wang Satellite PI
Yusuke Yamauchi PI
Jinhua Ye PI
Highly Cited Researcher 2018 (2018.11)

Genki Yoshikawa Group Leader
The Seiyama Award, Japan Association of Chemical Sensors (2019.1)

WPI-MANA New Faces


G. Decher
Satellite PI


T. E. Mallouk
Satellite PI


K. Nagura
Researcher


A. Okamoto
Independent Scientist


K. Uto
Independent Scientist


M. Matsumoto
Independent Scientist


T. Iwasaki
ICYS-WPI-MANA Researcher


T. Subramani
ICYS-WPI-MANA Researcher


Y. Kaneti
MANA Postdoctoral Fellow


S. Yamamoto
MANA Postdoctoral Fellow


L. Shi
MANA Postdoctoral Fellow


H. Lyu
MANA Postdoctoral Fellow


L. Zihang
MANA Postdoctoral Fellow


B. Ghosh
JSPS Fellow


F. B. P. Sciortino
JSPS Fellow


B. Ding
JSPS Fellow


S. Jing
JSPS Fellow


Z. Chen
Postdoc


S. Yadav
Postdoc


Y. Song
Postdoc

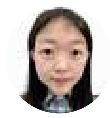

J. Tsurumi
Postdoc


M. Nishikawa
Postdoc


K. Ueji
Postdoc


B. K. Barman
Postdoc


W. Miran
Postdoc

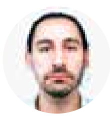

M. Mu
Postdoc

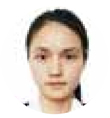

C. Chang
Postdoc


K. Sun
Postdoc


L. Nurdiwijayanto
Postdoc


E. D. K. Heragh
Postdoc

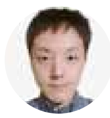

A. Guionet
Postdoc


C. Wang
Postdoc

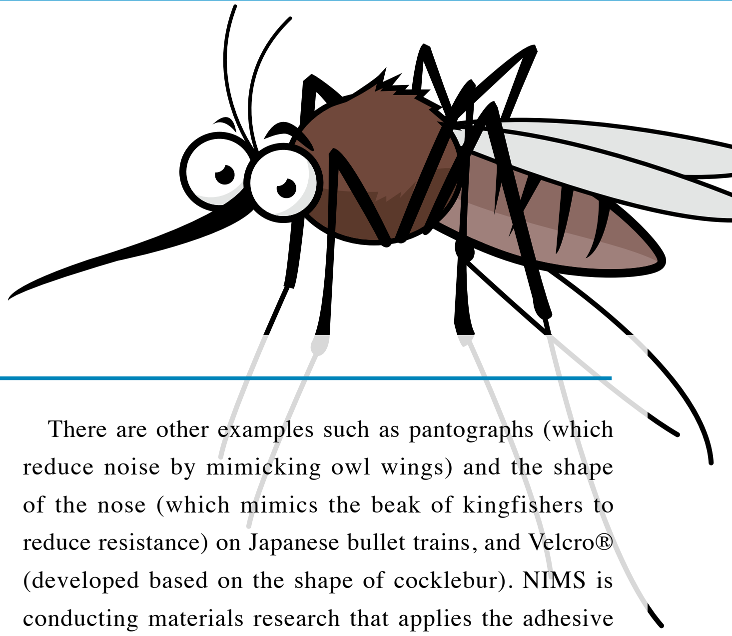

H. Xue
Postdoc


D. Thang
Postdoc


X. Deng
Postdoc


N. Sato
Postdoc

Editor's Column



Biomimetics

Those who are in charge of science news have opportunities during the course of their daily duties to come across press releases in a variety of research fields. I don't just read material sciences, but I also make sure I read popular topics in biology, earth science, and botany and so on. One that was particularly memorable was a press release entitled, "A study of frog choruses and its application in communication systems—behavior of frogs that sing in a circular canon while taking a break in- between." Simply put, if a pattern that mimics a chorus of male frogs is applied to an autonomous distributed control of a wireless sensor network, the communication state can be turned on and off all at once while avoiding packet collisions. The content itself is interesting, but what was most fascinating to me was that a familiar phenomenon such as a chorus of frogs was contributing to solving a problem in a completely unrelated field. Such a technology that mimics biology is called "biomimetics."

LZR Racer

The LZR Racer is a competitive swimsuit developed by SPEEDO. It corrects the body shape and suppresses water resistance through a fine water-repellent print that mimics shark skin. It caused a stir as it improved records too much, resulting in a few record times that could not be considered official due to the type of swimsuit worn.

Pain-free needle

Injections hurt but mosquito bites don't. A needle was developed based on this concept by incorporating the shape of a mosquito proboscis. By mimicking the jagged structure of the maxillae, the resistance during injections is reduced, lessening the pain.

There are other examples such as pantographs (which reduce noise by mimicking owl wings) and the shape of the nose (which mimics the beak of kingfishers to reduce resistance) on Japanese bullet trains, and Velcro® (developed based on the shape of cocklebur). NIMS is conducting materials research that applies the adhesive mechanism of the feet of geckos. It may be considered that reinforcement learning, which has been garnering attention in recent years, is mimicking the evolutionary process by responding to environmental dynamics through reinforcement signals in accordance to the input.

In Issue No. 27 of Convergence, we feature a conversation between a sleep scientist and a material scientist. It came about from a hope that interesting ideas could be gleaned about artificial brains that use an "atomic switch," which is a result of representative research by WPI-MANA. However, the more I heard, the more I was reminded how complex and mysterious the human brain can be. The words of Dr. Yanagisawa, the director of IIIS— "there is a function that is based on ambiguous parts dynamically operating together as a whole"—indeed reflect a fundamental concept of nanoarchitectonics. While being surprised by the similarities, I could not help but think about the potential of biomimetics in artificial brain research.

Although their research achievements go without saying, I continue to be impressed by the flexible thinking of researchers: "If modern biological forms and functions are results of the long evolutionary process, let us mimic these wherever possible."

MANA NEWS LETTER

CONVERGENCE

No.27 Eng. Ed., Issued in March, 2019

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

CONTENTS