Event Reports

Young Researcher's Grand Challenge Meeting

Young researchers affiliated at MANA, Satellite Institute and NIMS hold the Young Researcher's Grand Challenge Meeting at Kanagawa Prefecture for two days from November 12, 2012. The meeting aimed to try to create a new field of science and technology via discussion on more-advanced generation grand challenging themes by young researchers. In the meeting, participants explored the possibility in collaboration among them via presentations of their latest results. Then they had an active discussion on the future direction of MANA, the grand challenging themes mainly in energy field, and what were needed for researcher and organization to tackle to the themes.


Participants of the meeting

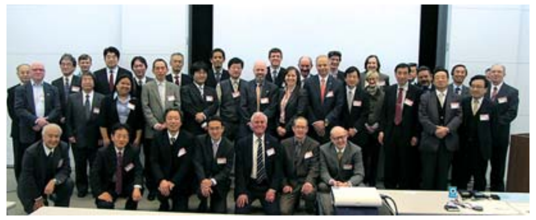
The 2nd WPI Joint Symposium: Inspiring Insights into Pioneering Scientific Research

The 2nd WPI Joint Symposium organized by MANA was held at Tsukuba International Convention Center on November 24, 2012 with an over 660 attendees. The symposium aimed to encourage close relationship between WPI centers and junior-high and high school students by providing opportunities contact with cutting-edge science conducted at the research centers in the WPI Program. In the main hall, the symposium came really alive by research presentations by WPI Program Director Toshio Kuroki and researchers from six WPI centers and a subsequently held Science Quiz event. At the booth exhibitions held at the lobby, participants attentively listened to the explanation for exhibited panels or experimental demonstrations, and enjoyed to talk with the speaker or staff from the WPI centers.


Dr. Renzhi Ma (right), MANA Scientist, explains about the unique function of titanium oxide nanosheet to participants.

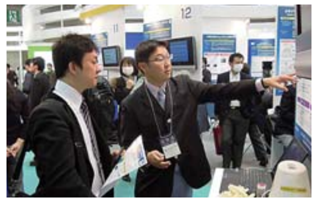
The 2nd Canada-Japan Nanotechnology Workshop 2013

On January 29-30, 2013, the 2nd Canada-Japan Nanotechnology Workshop 2013 was held at Tokyo Big Sight. The first workshop was held in 2011 at Waterloo, Canada, to strengthen collaboration in the field of Nanotechnology R&D through high-level discussions on the occasion of the 25th anniversary of the Canada-Japan Science and Technology Agreement. This time the workshop has identified to discuss about future collaboration in the filed of environment and energy, nano-electronics, quantum electronics, biomaterials, and nano-structures/tools. 5 keynote lectures including about the current Japanese policy toward science and technology and nanotechnology research in Canada were performed. In the research sessions, 20 speakers from institutes in both countries including 5 MANA researchers had oral presentations about the latest results and activities in filed of the abovementioned. Active discussions were performed among 95 participants in total and a joint statement has issued at the end of the workshop.


Participants of the workshop

nano tech 2013: the 12th international Nanotechnology Exhibition & Conference

As one of the research division in NIMS, MANA participated in "nano tech 2013" held at Tokyo Big Sight for three days from January 29, 2013. The event is the world's largest international exhibition of nanotechnology and a total of 46 thousands participants came to the event. In the NIMS booth, five MANA researchers exhibited a panel and had a short lectures to introduce their latest results in the filed of electronics device, medical and health care, and environment and energy, which gained favorable reputation.


Dr. Mitsuhiro Ebara, MANA Scientist, explains his result to a participant

WPI Joint Exhibition at AAAS Annual Meeting 2013

At the AAAS 2013 Annual Meeting on February 14-18 in Boston, USA, the World Premier International Research Center Initiative (WPI) and Japan's Science Ministry (MEXT) hosted a joint exhibition booth in Japan Pavilion. At the booth, outreach staff from WPI institutes and MEXT introduced the latest progress in various research fields at the WPI centers together with the effort to create an open and international research environment. On February 15, the WPI, RIKEN and University of Tsukuba co-organized a press conference entitled "Japan: your next career destination?" In the conference, Mr. Ueda (MEXT WPI director) and other staff introduced "the internationally-opened institutes of the WPI" and job information at 3 new WPI institutes starting from 2012.


WPI Booth in Japan Pavilion

Awards

Received the 9th JSPS Prize

Japan Society for the Promotion of Science (JSPS) has announced 24 winners of the 9th JSPS Prize and Dr. Kazuhito Tsukagoshi, MANA Principal Investigator, was selected as one of awardees on December 17, 2012. The prize was founded in FY 2004 to recognize and support young researchers, in the fields of the humanities, social sciences and natural sciences, with rich creativity and superlative research ability at an early stage in their careers. Dr. Kazuhito Tsukagoshi was recognized for his marked work on "Nano-Electronics Researches Based on Electrical Conduction Control in Nano-Carbon Conductors".


Dr. Kazuhito Tsukagoshi

Newly Appointed Researchers

◆MANA Scientist◆


Dr. Yusuke Ide

CONVERGENCE No. 13, Eng. Ed., issued on February, 2013

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

International Center for Materials Nanoarchitectonics (MANA)

No.13
Feb.2013

CONVERGENCE

Becoming a Center That Stimulates Industry and Fosters Creative Researchers
— Teruo OKANO

Having the Confidence to Make a Breakthrough
— Yusuke YAMAUCHI

MANA Administrative Support System, Letting Researchers Focus on Their Work

Becoming a Center That Stimulates Industry and Fosters Creative Researchers

✣ Interviewew: Akio ETORI, Science Journalist

Teruo OKANO

Professor Okano is the vice-president of Tokyo Women's Medical University and the director of the Institute of Advanced Biomedical Engineering and Science. He earned his engineering doctorate in applied chemistry from the Faculty of Science and Engineering at Waseda University in 1979. He has worked as an assistant at Tokyo Women's Medical University, and went on to become a lecturer there. He worked as an associate professor at the University of Utah College of Pharmacy and then at Tokyo Women's Medical University, before taking up his present post in 1994. Professor Okano became the director of the Institute of Biomedical Engineering in 1999 and the director of the Institute of Advanced Biomedical Engineering and Science in 2001. He became the vice-president of the Tokyo Women's Medical University in 2012. He has been a member of the Science Council of Japan since 2005. Professor Okano's specialties include biomaterials, artificial organs, and tissue engineering. He is currently focusing on developing intelligent biomaterials for regenerative medicine, and controlling macromolecular ultrastructures. He is a pioneer in cell sheet engineering and has developed regenerative medical techniques for various organs, including the cornea, myocardium, and esophagus. In 1992, Professor Okano was awarded the Japanese Society for Biomaterials prize. He was also awarded the Clemson Award for Basic Research by the Society for Biomaterials in 1997. In 1998 he received an award from the Society of Polymer Science in Japan. His other awards include the 2nd Leo Esaki Award in 2005.

Dedicated to World Firsts

—What kind of research are you working on in the FIRST Program*?

We are investigating the regeneration of tissue and organs from a patient's own cells. The impetus for this research was the discovery that temperature changes can be used to remove a cultivated cell sheet from a culture dish. Until this point, enzymes had been used, but they partially damage the cell proteins, so transplantation didn't work well. But we found that the sheet could be recovered without damaging the cells by lowering the cultivation temperature from 37 to 20°C, which was a world first.

After that, we created a circular sheet 3.5 cm in diameter from a 2 mm^2 portion of mucous membrane from the mouth, and used it to regenerate a cornea. This breakthrough attracted great interest worldwide. In France, clinical trials are already underway toward approval of our method for clinical use. After esophageal cancer treatment, attaching a cell sheet to the ablated part of the esophagus can prevent stenosis and accelerate recovery. Also, patients with dilated cardiomyopathy, for which the only conventional treatment is a heart transplant, have improved to the point where an artificial heart is no longer needed as a result of receiving a cell sheet transplant, where muscle cells from the patient's leg were cultivated and laminated. This procedure has been carried out in almost 20 patients. We're also developing other clinical treatments for the periodontal membrane and leg cartilage. Furthermore, we've built vascular networks in cell sheets and are regenerating organs that have structures for supplying oxygen and nutrition. Our cell sheets are continuing to produce many new medical treatments.

***FIRST: Funding Program for World-Leading Innovative R&D on Science and Technology**

Building a Center to Realize Completely New Concepts

—What kinds of new initiatives are you planning?

We are developing a tissue factory in which robots automatically make cell sheets, and we also hope to build a research center. Aseptic conditions are crucial to whether a cultivated cell sheet can be transplanted into a patient. Currently, cell sheets are made in three cultivation rooms about 300 m^2 in size in the cell processing center. Researchers maintain aseptic conditions by carrying out sterilization procedures many times for each operation, which takes a great deal of time and expense. I thought that if these sheets could be made entirely by robots, we could save space, time, and money. To treat large numbers of patients, a massive quantity of cell sheets will be necessary. I would like to build a center for creating tissues and organs, and for the early testing completely new clinical applications. The FIRST Program combines the expertise and technologies of manufacturers, such as Hitachi, Asahi Kasei, Nihon Kohden, and Able, with those of universities and research institutions, and now the factory we have designed is on the verge of opening.

Doctors often work across many different hospital departments, and my research group brings together specialists in material science, biology, chemistry, and engineering. It's a real fusion of fields! From now on I want to bring together people from different fields, and in 5 or 10 years' time I hope to create a center where we can carry out strategic research in order to treat currently incurable illnesses. Because we've tackled neglected areas, our treatments for the cornea, esophagus, heart, periodontal membrane, and cartilage are in their infancy. I would also like to work on creating small portions of liver and pancreas tissue, which I think will appear more and more in future treatments.

Removing Barriers, Fostering Creativity, and Taking a Long-Term Outlook

—What kind of people do you hope to foster in your research center?

Japanese medical science is currently conservative. Although the mechanism behind an illness is often investigated, less research goes into finding cures. Researchers are afraid that problems will occur and do not do —or do not allow— new things. There are a great many patients who die because of current treatment strategies. Medical science is not perfect, so we must constantly change and update it if we want to make progress.

For this reason it is important to remove barriers between research fields and in education systems. If there are no barriers, researchers can access many different materials, technologies, equipment, and people. Students in the doctoral course at the graduate school come to my research establishment, along with doctors, researchers, and graduates of the medical school. Students who have completed master's courses in physical sciences, engineering, and pharmacology also enter the graduate school. There is a steady flow of people between groups engaged in collaborative research. The experience of the doctors is also different from what they'd experience if they were to stay in the hospital medical office. The environment here fosters a new type of outlook. I also tell the engineers to systematically study medical science. I guess this makes it a double major in engineering and medical science! Having an environment where there are lots of different technologies and areas of expertise and being able to attempt things that no one has done before is important. I don't just want to write papers; instead, I want to foster creative people in an integrated and multidisciplinary research center that is not vertically divided into sections like internal medicine, surgery, ophthalmology, and cardiology.

I have also received a grant and engaged in creative research in the United States. Thanks to this, I was able to think about many things and form the basis for my current research. I hope to pass on the things I have been given by creating an environment for educating young people in Japan.

From the Vertical Organization of the 20th Century to the Flat Organization of the 21st Century

—What is your opinion on the WPI system from the perspective of a research center?

I think the WPI system plays a very significant role. Having a flat organization that breaks down old divisions in scientific disciplines is important, and WPI centers have a global outlook, which will be very important in the coming years. Research establishments and universities based on the old concept of separate disciplines are unable to respond flexibly to the recent rapidly moving developments in scientific disciplines and cannot attempt new things quickly.

Creative people who produce amazing results cannot be fostered in a narrow, vertically segmented organization, and so attempting things in the WPI system with a broad, global perspective is particularly fruitful. Such organizational structures have been rare in Japan. Japan has a restrictive, vertically segmented society, which produces people who wish to conform. The time when it was enough just to pursue America has already ended. The time for Japan to take the lead globally has definitely come. If we train people and create centers now, the academic culture of Japan will change. I think the growth of Japanese academia, including the stimulation of industry, is extremely important.

Also, I would like to see a framework in place for non-Japanese researchers to encourage internationalization. The presence of ambitious overseas researchers with leadership skills is important for creating the special environment of WPI, in which problems can be considered laterally and globally. Diverse fields and ways of thinking, and stimuli from overseas are indispensable. I sincerely hope that we proactively invite ambitious overseas researchers with excellent leadership skills to come and work in Japan.

Two young overseas researchers on an extended stay were brought together and an energetic discussion was held about new research. (2000)
(From left) Dr. Masayuki Yamato (currently a professor at Tokyo Women's Medical University), Dr. Maya Nandkumar, Dr. Rinat Iskakov, and Prof. Teruo Okano.

We Can No Longer Stop at Just One Thing

—Promoting the bioscience field called "nano-life" is one of the big challenges at MANA. What's your opinion on this?

Nanobiotechnology is a field which industry has not yet explored, and it's an area I would like MANA to play a major role in developing. This is something we can definitely expect from MANA.

For example, Kodak and Polaroid developed outstanding materials 30-40 years ago. They produced many different functional materials and were incredibly powerful companies. These companies have now gone bankrupt. However, Fujifilm is thriving by developing cosmetics, medical supplies, and other products. Perhaps this is the difference between a company that is content with being the world's best and a company that takes on new things. The time when it was okay to do just one thing has already ended. It is the same for industry and academia; we must challenge ourselves in new areas.

A time will also come when we will need to work in medicine or the life sciences. It will be too late if we don't prepare for this situation. Nanobiotechnology is certainly a field that will grow from now on. Rather than competing in areas that we know and understand, it is important to enter the unknown when deciding which area to engage in creatively. This is also important for passing on Japanese science to the next generation.

I think it's necessary to incorporate know-how from fields such as automobiles and electronics in order to build next-generation industries, and we can do this by linking industry and academia. Nanobiotechnology should be a field where smart people gladly take on challenges, rather than one where people have negative attitudes just because there are no immediately obvious practical applications or there are goals that have not yet been achieved. Connecting MANA's excellent materials science with nanobiotechnology could achieve this. Making biomaterials into a molecular device or creating intelligent materials that can incorporate systems, and aggressively promoting these new challenges, will link MANA's current purpose to future developments.

Having the Confidence to Make a Breakthrough

Yusuke YAMAUCHI
MANA Independent Scientist

Dr. Yusuke Yamauchi (PhD Engineering) is an Independent Scientist at MANA. His research area is nanoporous materials based on inorganic substances. He was awarded the 2012 Tsukuba Prize Encouragement Award (young researcher division) in recognition of his successful synthesis of high functionality Prussian blue. We asked him how he approaches his research.

Nanoporous Materials Get the Maximum Functionality from the Minimum Amount of Material

—Dr. Yamauchi, you are currently a researcher at PRESTO*. What kind of work are you doing?

I am investigating how to create porous materials. These can be materials like metals or zeolites, but they contain vast numbers of holes, which produces unique properties. For example, imagine a solid cube of a material like a catalyst. If there are no holes, then only the outer surface can take part in reactions. Now imagine the cube contains a vast number of holes; the interior can now also participate in reactions and a much greater surface area is available. During my research, I have made a one gram cube of platinum with a surface area of over 100 m2! Similarly, porous Prussian blue is useful for removing radioactive pollution from water. Porous Prussian blue, compared with its non-porous counterpart, can absorb at least 10 times more cesium. Rare and expensive materials, such as rare earths, can be used more efficiently by making them porous. This is particularly effective for highly functional materials. The manufacturing process is fairly simple; it can be done using a 1 m square electrolytic bath.

*PRESTO: Precursory Research for Embryonic Science and Technology, a proposal-oriented research promotion project funded by the Japan Science and Technology Agency (JST).

MANA: Where Research Gets Done

—Dr. Yamauchi, you are one of the youngest Independent Scientists at MANA. What is the best way to understand the system at MANA?

MANA is a WPI research center, and attracts many leading researchers from around the world who give seminars and exchange research at MANA. Even if you don't attend a seminar, the profile of the researcher and an abstract of the talk are handed out by the administrative office, so you're always up to date with the latest top-level international research in a variety of fields. There are also many other opportunities for talking with excellent researchers from overseas, and this broadens your thinking and makes it more global. You also gradually develop personal relationships with people from overseas. The research center is filled with materials scientists, so it's fully equipped with a vast array of specialized materials science equipment. This means that MANA is a place where interdisciplinary and fusional research can be achieved quickly. MANA is widely known as a specialized center for materials science, so my name is easy to remember because it's Yamauchi from MANA.

Coming up with ideas that are one or two steps ahead

—You trained at Waseda University graduate school, what do you think about the education of students?

It is probably because I am young, but I feel daunted by the pressure to achieve and that I have to come up with ideas that are one or two steps ahead just to maintain my dignity. I often hear from the senior professors that they are energized by the younger students and that young people are brimming with imagination. In my case, I feel that I am working as one of the students instead of being energized by them; good relationships produce good research results. I think the communication here is good, and the opinions of students are heard.

The Importance of Sticking to Your Own Specialization

—I have heard that you are a capable coordinator with a broad perspective.

Although it is flattering to be praised for bringing together different fields, it is essential to not lose sight of your own specialization. If you spread yourself too thin, you may lose your focus. It is important to have your own specialization that you stick to. I specialize in porous materials. However, to make this my core research area, I need the confidence that I'll make a scientific breakthrough.

—MANA has just passed the halfway mark of its 10-year project. Please tell us about your own outlook for the future.

It's impossible to know what will happen in 5 years. Research can seem endless and there isn't a finish line, but perhaps that's what motivates us to work so hard at it. As we continue our work, our interest in the field grows, and I think it would be great to have produced acclaimed research results within 5 or 10 years. In the future, I would like to make a breakthrough, and I hope to become a world leader in the field of porous materials.

Yusuke YAMAUCHI

Dr. Yamauchi graduated from the Department of Applied Chemistry in the School of Advanced Science and Engineering at Waseda University in March 2003 and received his doctorate from the Graduate School of Advanced Science and Engineering at Waseda University in March 2007. He was an ICYS researcher at NIMS from April 2007, and took his current position as an Independent Scientist at MANA in October 2007. He became a PRESTO-JST researcher and visiting associate professor at Waseda University in 2008, and has also been a visiting professor at Tianjin University (China) since 2010.

MANA Administrative Support System, Letting Researchers Focus on Their Work

To build an international research center, it's important to cultivate an environment where researchers from around the world can easily come together to engage in research and other activities. Currently, over half of the researchers at MANA hail from outside Japan, so we have put together a team of experienced office staff who are proficient in English and who can help with a variety of administrative tasks. In this way, all researchers—including researchers from overseas—can focus on their work.

■ English is the official language

With the aim of creating international research environment at every level, English has been made the official language of MANA. Seminars and meetings, e-mail communications, research plans, office procedures—everything is available in English. Guidebooks and the official website have been put into English and Japanese. For newly joined researchers, the orientation session and laboratory tour are conducted by staff who are fluent in English. We've also published a manga comic book in English called *The Challenging Daily Life*, which is full of practical tips that should be helpful to international researchers new to Japan.

A lab tour for newly joined researchers on.

■ Support for daily life in Japan

A support system has been put in place at MANA so that all international researchers, even those who haven't learned Japanese yet, can start their lives in Japan without difficulty. We provide guidance on matters such as getting your alien registration card and setting up a bank account. We also provide information necessary for daily living, for example, about public agencies, searching for a house or apartment, and emergency support. For international researchers, the system provides support for being with family during illness or childbirth, and for registering children at school.

Staff providing administrative support to researcher

■ Japanese language and culture classes

Japanese language and culture classes are held for overseas researchers at MANA in order to help deepen their understanding of Japan. The Japanese language classes are divided into introductory, beginner, and intermediate levels, and are held in three terms throughout the year. Students hold a speech contest during the final lesson of each term. The Japanese culture class is held monthly. Specialist instructors are invited to give lectures on traditional Japanese culture, including tea ceremony (*sadō*), calligraphy (*shodō*), and Japanese drumming (*wadaiko*) and so on.

Beginner's Japanese class

Calligraphy class held in 2012

Through these efforts, particularly through hospitable administrative support for all researchers at MANA, we are working to build a internationally-opened research institutes that welcomes all researchers.

Monatomic-layer Superconducting Materials on Semiconductor Surfaces

Takashi UCHIHASHI
MANA Scientist
Nano-System Field

Since the discovery of graphene, there has been a rapid and explosive progress in researches on monatomic-layer materials. They draw extensive interests because they generally exhibit new physical properties and functions that are absent in its bulk forms. However, monatomic-layer superconductors have been elusive so far. Existence of such materials will allow us to design new superconductors from the atomic level using the state-of-the-art nanotechnology.

Very recently, we have successfully demonstrated that monatomic-layer materials can become superconducting. This was done by self-assembling a single layer of indium atoms on a silicon surface and by measuring its electron transport properties. The inset of Fig. 1 shows a scanning tunneling microscope image of its representative sample; indium atoms are epitaxially grown with a periodicity of $\sqrt{7}\times\sqrt{3}$ against the ideal silicon surface. Figure 1 shows the temperature dependence of the electrical resistance of such a sample down to a low temperature region. It is clearly visible that the resistance becomes zero suddenly around 2.8 K, indicating a superconducting transition.

For practical applications of this kind of monatomic-layer superconducting materials, it is important to be able to run large supercurrents through them. We measured the critical supercurrent density (i. e. where the superconducting state is destroyed) by flowing current incrementally (Fig. 2). We found that the critical supercurrent density is as large as 6.1×10^5 A/cm^2 at 1.8K, which is comparable to typical values for practical superconducting materials. It is surprising that atomically thin superconductor can maintain such "robustness".

We are now aiming at realizing fundamentally new superconductors by taking advantage of the features of monatomic materials on semiconductor substrates. For example, it is possible to incorporate the magnetic exchange interaction into a superconductor by precisely assembling organic molecules on the surface. Furthermore, spin-related phenomena such as the Rashba effect is important considering the spatial inversion symmetry breaking due the presence of solid surface. Based on these ideas, we expect to create topological superconductors and decoherence-tolerant quantum computers, which are strongly longed for because of their fascinating applications.

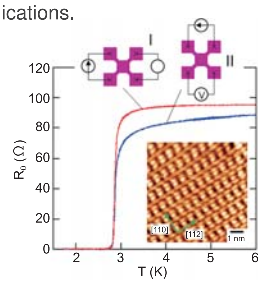

Figure 1 Temperature dependence of electrical resistance of the Si(111)-($\sqrt{7}\times\sqrt{3}$)-In surface reconstruction. Current direction was rotated by 90 ° for configurations I, II. The inset shows a scanning tunneling microscope image of the surface.

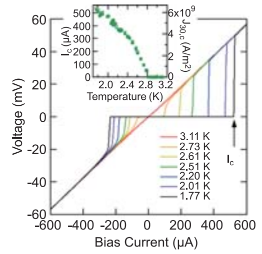

Figure 2 Temperature dependence of current-voltage characteristics. The inset shows the temperature dependence of the critical supercurrent density.

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(highlighted as an Editor's Suggestion and as a Viewpoint in *Physics*.)

A Smart Time Bomb Triggers Drug Release at Subtle Timing

Mitsuhiro EBARA
MANA Scientist
Nano-Life Field

Better control over the delivery of drugs to specific sites in the body at specific times would reduce unwanted side effects and improve medical treatment dramatically. 'Smart' polymers are promising materials for controlling drug delivery, since they change their properties in response to specific stimuli. However, they usually require continuous stimulation to maintain these changes. We have developed an approach that could allow more subtle control and timing of drug delivery.

The new technique uses hydrogels, which are a type of 'smart' polymer made of water-soluble long-chain molecules. The acidity inside a hydrogel can be controlled by loading it with a compound called photo-acid generator (PAG). This releases protons, which increases acidity, when irradiated with UV light. When PAG-loaded hydrogel was irradiated, acidity increased inside; if only part of the gel was irradiated, acidity throughout increased gradually as protons diffused.

We loaded hydrogel with PAG and L-DOPA, a precursor of the brain chemical dopamine that is used in the treatment of Parkinson's disease[1, 2]. The change of acidity in the gel upon UV irradiation caused L-DOPA to be released because the acidity disrupted the interaction of L-DOPA with the molecules in the gel. Irradiation with UV not only enhanced overall L-DOPA release from the hydrogel, but also caused an extra 'explosive' release five hours after irradiation. This allowed the drug release to be timed, as well as triggered, in a controlled way. Being able to control the release of drugs from hydrogels by triggering a change in acidity could help to design programmable drug delivery techniques that offer improved targeting of treatment[3].

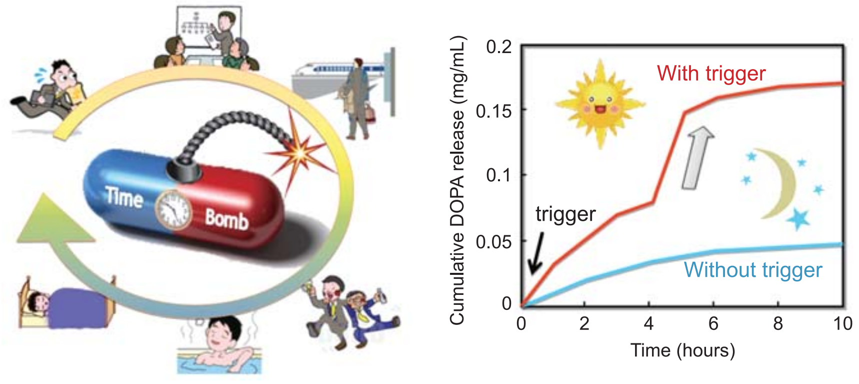

Figure. A timed explosive drug release from pH-responsive hydrogels by utilizing a phototriggered spatial pH-jump reaction.

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Multi-functional Single-electron Memory with Attractive Molecular Dots – Integration of Molecular Functionality into Si-based Devices –

Ryoma HAYAKAWA
MANA Independent Researcher

Single-electron memory is a promising candidate for future Si-based memory devices. The reason is that the charge injection into a quantum dot can be controlled at the level of individual electrons by the Coulomb blockade effect. The device thus allows multi-level memory operation and ultra-low power consumption, which are key challenges in future nanoelectronics. However, the devices are not yet realized, in spite of the idea having been proposed more than two decades ago. A major obstacle is the extreme difficulty in controlling the uniformity of size of quantum dots at the nanometer scale. Poor controllability of size and uniformity of dots hinders clear operation of single-electron tunneling, particularly at room temperature. Therefore, precise control of dot size at nanometer scale is essential prerequisites to the full development of single-electron memory devices.

To overcome these problems, we have proposed to use organic molecules as quantum dots (Fig. (a)). Organic molecules have many advantages as quantum dots over their inorganic counterparts, including the following. The molecules themselves have a uniform size at nanometer scale, and thus the problem of size controllability is solved. Furthermore, the energy levels of the molecules are tunable by attaching functional groups, such as electron-withdrawing (-donating) groups. Combination of heterogeneous molecules would realize multi-level memory operation in the devices. Another major advantage of organic molecules is that the energy levels can be controlled by light irradiation as represented by photoisomerization molecules, leading to integration of photonic functionality into current single-electron memory.

So far, we have demonstrated single-electron tunneling through various kinds of molecules in a metal-insulator-semiconductor structure that is a basic component of all single-electron memory devices (Fig. (b)). The origin of single-electron tunneling was found to be resonant tunneling through the energy levels of individual molecules. The finding indicates that the single-electron tunneling can be manipulated by molecular orbitals.

In near future, we will integrate unique molecular functionalities into new prototype devices, including multi-level operation with heterogeneous molecules and optical manipulation using photochromic molecules. We believe that organic molecules possess high potential for a breakthrough in Si-based technology.

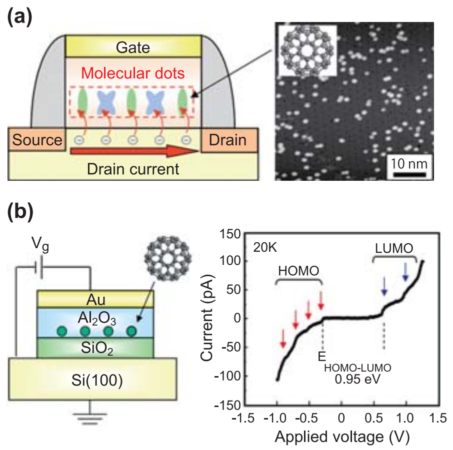

Figure (a) Schematic diagram of single-electron memory with molecules as quantum dots. (b) Electron-tunneling current through fullerene molecules embedded in a metal-insulator-semiconductor structure.

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Toward High-efficiency Photo•electricity Energy Conversion: Potential of $In_xGa_{1-x}N$-based Solar Cells

Liwen Sang
ICYS-MANA Researcher

The InGaN-based multi-junction solar cells can achieve a high conversion efficiency approaching 62% according to the balance modeling estimation, which is much higher than any other photovoltaic semiconductor materials, such as Si, GaAs, CuInGaSe, etc. This is because that $In_xGa_{1-x}N$ alloy is the only semiconductor which possesses direct bandgaps with a wide range from infrared (InN @0.65 eV) to ultraviolet (GaN @ 3.42 eV) by changing In composition. This bandgap energy range completely matches to the solar spectrum, as shown in Fig.1. Additionally, InGaN alloys have the advantages of high drift velocity, high radiation resistance, large absorption coefficient, and high carrier mobility. These characteristics enable them to operate also in severe environments such as the desert or space, in which Si-based cells are degraded.

However, the current conversion efficiency of InGaN-based solar cell is much lower (< 4%) than the ideal value, and the external quantum efficiency is poor (<60%). The bottlenecks are the difficulties in the growth of high-quality InGaN thick film and *p*-type doping especially for the In-rich InGaN.

To improve the conversion efficiency, we propose to use all the InGaN-based film for the *p-i-n* solar cell structure (Fig. 2(a)). By introducing AlN as the template, the best crystalline quality of InGaN thick film (> 300 nm) was achieved. A novel structure by inserting a super-thin AlN interlayer between the active region and the *p*-type region was developed to further improve the photovoltaic property. The short-circuit current density was increased from 0.77 to 1.25 mA/cm^2, leading to the external quantum efficiency to be around 80%, which is the highest one for InGaN-based solar cell up to now (Fig 2 (b)). The insertion of the AlN interlayer not only provides a barrier to reduce electron tunneling, but also suppresses the nonradiative recombination. The high external quantum efficiency is ascribed to the high-quality InGaN active region, high hole concentration in the *p*-InGaN and the insertion of the AlN interlayer. This work provides a strategy to develop high-performance InGaN-based solar cells.

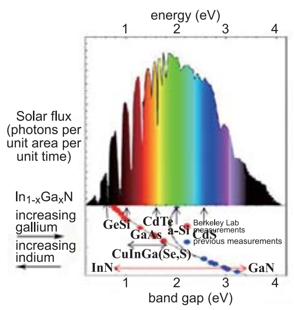

Figure 1 Absorption region of different photovoltaic materials

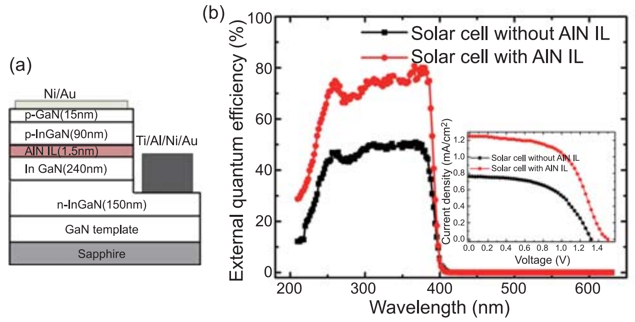

Figure 2 (a) Novel structure for InGaN-based solar cell and (b) photovoltaic properties and external quantum efficiencies

Reference
L. Sang *et al.*, *Appl. Phys. Lett.*, **99**, 161109 (2011)