ISSN 1346-602X

Full Research in Society, for Society

AIST TODAY

National Institute of Advanced Industrial Science and Technology

International Edition

2011
2011-3
No.41

FEATURE

The 6th AIST Advisory Board Meeting

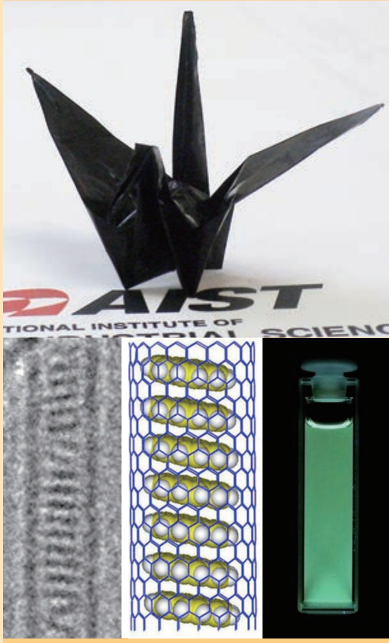
FEATURE

AIST's World-Class Carbon Nanotube-Related Research

Research Hotline

UPDATE FROM THE CUTTING EDGE (April–June 2011)

In Brief



The 6th AIST Advisory Board Meeting

AIST's mission is to contribute to social development by raising the standard of Japan's industrial technology, with "the realization of a sustainable society" as its ultimate goal.

In pursuing this, AIST holds advisory board meetings, assembling a group of leading experts in a variety of disciplines, both from Japan and abroad, who provide independent advice from an outsider's perspective to AIST regarding the organization's research activities and general operation.

On February 7, 2011, at its Tsukuba headquarters, AIST held its 6th advisory board meeting, which was the first meeting of the Third Medium-term planning period. This meeting featured a board with a new look, and was the first advisory board meeting since newly appointed president Tamotsu Nomakuchi came into office.

The foci of the Third Medium-term plan are "solutions for 21st century issues" and "reinforcing the function of an open innovation hub", leading to attaining a sustainable society, in recognition that connecting fundamental research to product development is more important than ever.

Thus, the main theme of the conference was the expectations placed on public research organizations in relation to shaping a sustainable society and the role played by the organizations in this effort. Reflecting a broad range of perspectives, the board members discussed the question of how a public research organization like AIST should contribute to resolving challenges facing the nation in the 21st century. In addition, the members took tours of the research facilities, exchanging opinions with the researchers "on site". The following report offers an outline of the meeting findings and notable comments and advice from board members.

Table 1　List of AIST Advisory Board Members

Junichi Hamada	President, The University of Tokyo
Nobuhiro Yamada	President, University of Tsukuba
Hiroyoshi Kimura	President, Kimura Chuzosho Co., Ltd.
Sadayuki Sakakibara*	Chairman & CEO, Toray Industries, Inc.
Waichi Sekiguchi	Editorial writer, Business News Department, Nikkei Inc.
Toichi Takenaka	Chairman of the Board, Astellas Pharma Inc.
Hajime Bada	President & CEO, JFE Holdings, Inc.
Sawako Hanyu	President, Ochanomizu University
Ei Yamada**	President & CEO, AnGes MG, Inc.
Alain Fuchs**	President, National Center for Scientific Research (CNRS), France
Makoto Hirayama	Professor, College of Nanoscale Science and Engineering, State University of New York, USA
Thaweesak Koanantakool	President, National Science and Technology Development Agency (NSTDA), Thailand
Jürgen Mlynek	President, Helmholtz Association of German Research Centres, Germany

（*：Absent　**：Visited for discussion before the meeting）

Table 2　Schedule

Monday, February 7, 2011

9:30	Opening of the meeting
9:40	Introduction of AIST Advisory Board Members
9:55	Welcoming address
10:20	"The role of AIST as a public research organization in resolving 21st century issues"
12:00	Lunch
13:00	Laboratory Tours: Meeting with AIST researchers
15:00	"Initiatives for realizing an open innovation hub"
17:15	Closing remarks
17:30	Adjournment

Outline of AIST Advisory Board Meeting

The new members invited to participate in discussions at this advisory board meeting were all distinguished individuals from Japan and abroad with a wealth of knowledge in technology and a broad range of other social and economic fields. The 13-member board consisted of 9 members from Japanese companies and universities and 4 members from an overseas university and public research institutes (Table 1).

To open the meeting, AIST president Tamotsu Nomakuchi presented a brief outline of the organization and explained AIST's mission in the Third Medium-term planning period.

There were two discussion sessions involving all board members, one in the morning and one in the afternoon (Table 2). The theme of the morning session was "The role of AIST as a public research organization in resolving 21st century issues". Being mostly outsiders and viewing AIST objectively, the board discussed the kind of role that AIST is expected to play in society from a broad perspective.

In the afternoon session, the theme was "Initiatives for realizing an open innovation hub". The board focused on the internal structure of AIST and the nature of its projects, discussing issues and policies aimed at achieving hub functions to promote open innovation. Before the afternoon session, the board members divided into two groups for lab tours of five research sites. Through direct exchanges of opinions with researchers, the board members were able to get a real sense of the initiatives AIST is pursuing to generate innovation. This experience was a valuable resource for the ensuing discussion.

Comments & Advice from Board Members

Junichi Hamada (Chair) (President, The University of Tokyo)

In a word, the role of public research organizations is to establish networks. The key to achieving open innovation is a network of diverse research bodies. After building broad networks as opposed to closed environments, it is important to generate fruitful results.

While universities focus on education, they are limited in their openness. The private sector, on the other hand, has a high degree of freedom in terms of their openness, but tends to have difficulty with continuity and stability. The role of public research organizations lies in overcoming these limitations to tackle the challenges of open innovation. I expect to see a strong commitment to creating open networks that feature a diversity of people and organizations.

Nobuhiro Yamada (Vice-Chair) (President, University of Tsukuba)

Addressing 21st century issues is a major challenge for universities, and at every opportunity we brainstorm to question universities' vision, mission, and values. When doing this, it is absolutely necessary to demonstrate solutions to problems. To ensure this it is essential to set up a system capable of generating outcomes as rapidly as possible, harnessing the power of the whole organization. As an organization gets larger the gap between generations widens. While the older generation grew up in the high economic growth era, the younger generation has grown up in a period of economic maturity, making it difficult to establish a vision of 21st century challenges they both share. I would like to see efforts to set up management and governance measures that can fill this gap and lead to solutions.

Accordingly, on the question of what direction AIST should move in, it is important to consider how AIST can establish an environment that promotes competitiveness. The answers we find must be reflected in evaluation and practices. We tend to talk about how young people today are inward looking and lack vitality, but we need environments in which young people can work comfortably and an organizational structure that transcends generation gaps where young people can express themselves freely. I believe that this can result in creative work that delivers added value. I would like to work with AIST to help bridge the generation gap in this way.

I hope to see AIST progress actively in open innovation. It would be a waste not to fully utilize the human resources and facilities of AIST. I would like to see AIST lower various hurdles as much as possible, and deepen their exchanges with a variety of other institutes. Exchanges in which people really move in both directions are particularly important, and even in international exchanges this two-way movement is very effective in building mutual trust. When AIST, as an institution, faces any hurdles, I hope we can act together to overcome them.

On the matter of human resources, we, on the side of universities, don't want to merely push students through universities. We wish to deliver solid education at the undergraduate, masters, and doctorate levels, always taking usefulness in industry and research institutions into consideration. In this sense, we welcome your suggestions on what you need us to teach in universities. At times, we get criticism from industry and the research world that we only teach a narrow range of skills, so let us discuss together the question of what kind of human resources Japan will need over the coming years. Such discussion will surely help in the development of open innovation hubs.

Hiroyoshi Kimura (President, Kimura Chuzosho Co., Ltd.)

I think the main theme of this discussion, expectations placed on public research organizations in shaping a sustainable society and their role in this process, is very fitting. Humanity is facing serious problems and there is no time to waste in finding solutions to them, so I would like to see AIST specialize in applied and development-oriented research, rather than fundamental research. If AIST as a whole could systematically make use of "seeds" of new technology in society, it would be wonderful. On the other hand, AIST has only 1,200 researchers from companies compared to 2,100 from universities, which seems low to me. My impression is that the follow-through from applied research to research that is actually useful is rather weak.

One of the difficulties of small and medium-size enterprises (SMEs) is that it is hard to establish a business by means of only one kind of engineering. Our company, for example, cannot rely on metallurgy alone. We need a wide array of technologies, spanning information technology, mechanical and electrical engineering, and chemistry. SMEs may be good in their area of expertise, but they face difficulties adopting other necessary related technologies, and in collaboration and problem solving. For this reason, I would like to see AIST branches that are equipped to support SMEs in multifarious ways right across Japan.

Our business is casting, which serves as a core industrial service. Core industries like this generally have a long history, and the technology behind them is essentially fully mature. Yet there are still many fields of "tacit knowledge", where the combination of IT with old-style technologies can open up new pathways and lead to innovative developments. SMEs, however, generally use computer systems with very limited capabilities. Thus, it would be good if AIST could offer a service lending out high-performance computer equipment.

Another point I'd like to make here is that the number of researchers working in universities on these old core industries is gradually declining. In another decade there may not be any university researchers left in the field of foundry engineering. Given this trend, I worry that the fundamental engineering technologies that humanity has developed may not be handed down to future generations in Japan. I hope that AIST can take up this task and work to reestablish these technologies through industry.

Waichi Sekiguchi (Senior Editorial Writer, Business News Department, Nikkei Inc.)

I would like to make three points regarding public research bodies. The first has to do with, standardization. With the diffusion of Internet use, directions of standardization are now typically discussed and decided amongst engineers, whereas in the past standards were generally established by de facto or de jure processes. Companies tend to draw inspiration from each other in rivalry in their product development work, and if they are left alone they will tend to produce very different things. In light of this, it's very important for public research bodies to set directions for Japan as a whole, but they should be neutral in their involvement with companies.

My second point is about networks of researchers. Looking at citations of recently published research papers reveals that Japanese researchers seem to be drifting further apart from their colleagues around the world. In the past, there seemed to be pipelines through which technology from the U.S. and Europe was brought to Japan, where we played catch-up. But after a certain point, when our technology reached international state-of-the-art levels, there was a shift in focus to trying to solve new challenges within Japan. As a result, the pipelines were broken, and my feeling is that Japan has been left behind in rapidly absorbing new technology from around the world and applying it to product development. Given that companies are not sending people overseas so much, one of the key duties of AIST is to strengthen these pipelines.

My third point is about horizontal collaboration. For example, recently, horizontal collaboration has become increasingly important between nanotechnology and IT, and between IT and robotics. The research body of the Agency of Industrial Science and Technology has been reorganized as AIST, but it needs to be made into a system that produces synergies.

Next, I want to talk about three points regarding the realization of an open innovation hub. One is about technology research associations. It is good that various companies are involved, but since funding is from the Japanese government, only Japanese companies tend to participate. I understand that to be necessary to some extent, but I think this approach should be revised, so that overseas companies are also invited to take part. I appreciate that it is difficult to call on direct competitors, but it is important to actively invite foreign client companies and overseas companies that can help to promote Japanese-developed technology more widely.

Secondly, I want to mention the promotion of venture investment. In Silicon Valley too, technology cultivated by public research institutes is developed externally through venture initiatives. I wonder whether we can set up a scheme that can actively support people who create and cultivate particular technologies in launching ventures based on those technologies. Recently some overseas venture capital firms like Intellectual Ventures, for example, have been trying to buy Japanese technologies. I feel that it is necessary to establish good contacts with such companies, to help in our efforts to disseminate Japanese technologies more widely around the world.

As my third point, I suggest setting up a forum where researchers can freely keep in touch with each other. To illustrate, consider why the U.S. west coast became so successful in the IT industry, while the industry faded on the east coast. East coast companies applied vertically integrated business models, where they tried to handle everything from software, terminals, and parts, to services internally. As a result, they could not adapt effectively to technological changes. In the Silicon Valley model on the west coast, if someone was successful in one layer, successive products or services were built on top of that layer, thereby raising the standard of the industry as a whole. In this sense, as Japanese intelligence is gathered here, it would be great if AIST, through its leadership, build a framework for enabling engineers to communicate with and enlighten each other.

Toichi Takenaka (Chairman of the Board, Astellas Pharma Inc.)

Rather than pursuing various kinds of fundamental research like universities, as a public research organization, I think that AIST should focus on *Full Research* that would serve as a bridge between academia and industry. To play this role effectively, it is vital that AIST fosters people who have the ability to make judgments about matters such as technological strategy. While there are many who can conduct research, developing strategies for research management is very difficult. The same is true in companies. If the strategy is weak, however much research is done, the results will be fruitless. For this reason, it is extremely important to foster this kind of talent. Compared with other research bodies, AIST has many opportunities to provide this kind of experience. It needs to cultivate the ability to

identify promising "seed technologies" from university research findings, and to bring to life promising technologies that are dormant within the confines of universities. This is what I expect AIST's role to be.

As for open innovation, projects that AIST conducts with companies can be broadly divided into two kinds: research associations and joint research with individual companies. In the case of research associations, research themes will generally be pre-competitive and focused on development of fundamentals. Many companies join these kinds of associations simply to take part, or because sharing development costs between many participants makes participation inexpensive. In practice, such companies often hold projects back, so effective selection of participating companies is essential. Focusing narrowly on the theme is also very important. Desired research tends to steadily increase, but the budget is limited, so funds need to be collected from the private sector to pursue additional research tasks. In this case, by narrowing down the theme we can rightly say, "We narrowed the research scope, with open innovation being a natural extension of the process." If we claim that anything is possible no one will believe it, so I would like to see AIST grasp the need to narrow its research focus.

I would also like to say that the fact that there are not many female researchers at AIST tarnishes the image of the organization slightly. There are many women in the life sciences, but it would be good to see more women in other research fields too.

Hajime Bada (President & CEO, JFE Holdings, Inc.)

If we talk about finding solutions to 21st century issues, we have an extremely broad target to aim at, ultimately the whole of humanity. For this reason, we cannot make clear what our goal is, unless we hear a broad spectrum of opinions from "final users". The flow of a project generally starts by establishing a core technology, then examining how to manufacture, market, and commercialize a product from that. Yet, what we really need is a system that works in the opposite direction, considering what is necessary at each step in reverse order. The problems of the 21st century are complex and multifaceted so it is important to aim at solving them efficiently, by some combination of government agencies together with various companies, and across geographical borders (foreign countries). In view of this requirement, I would like to see AIST function in a linking role, and as a provider of human resources. Companies look to AIST to provide them with services that a single company or enterprise cannot handle, such as standardization and verification of safety performance. Ultimately, standardization efforts should be directed toward establishing international standards. The process of international standardization is pivotal, because it can determine competitiveness. I would like to see standards established rapidly, but with governments, national organizations, and the private sector being involved.

To realize open innovation, it is important to conduct joint research with companies, but only 4 billion yen of funds has been received from the corporate sector (companies), which is a small proportion of the total revenue of AIST. Thus, more effort is necessary here. Today we inspected three representative AIST facilities: a super clean room (a common platform); a leading-edge iPS technology lab, where work is evolving from applied research to development; and a carbon nanotube lab, where work is focusing on practical implementation. I thought that if AIST used various resources, know-how, human networks, and systems, and demonstrated what can be made with all this, and if it proposed to develop ideas with a team of selected members, many individual companies would readily join the team. To help achieve this kind of environment, I would like to see more opportunities for people to visit AIST. There are few opportunities for the general public to see research facilities. If you open the gates a little wider, so that a broader range of people, from young children to company employees, can see what's going on here, I think it will lead to insights that can help to make projects more successful. I know that AIST has an open house once a year, but I would like to suggest that opportunities to come here be expanded.

Sawako Hanyu (President, Ochanomizu University)

In considering the role of public research institutes, there are three basic considerations. First is the need to think at an international level at all times, and to keep an eye on international standards. Second is the need for horizontal links with similar organizations, such as universities and public and private research institutes. Finally we need to keep in mind what the people who stand to actually benefit from technologies are thinking and seeking. These three considerations are essential.

In AIST's case, the second consideration, to link horizontally, is particularly important. AIST engages in goal-oriented fundamental research, so one of its key characteristics is that it pursues studies after first determining what kind of fundamental research is needed to achieve a particular goal. Since universities do not necessarily set any specific goals when they conduct fundamental research, I would hope that AIST examines how it can make use of the various kinds of research done by universities when it sets itself a specific research goal, recognizing such research as "seeds".

There is currently a debate among national universities regarding specialization of functions, particularly on questions such as whether to put more emphasis on education or on advanced research. Big universities may be able to give due importance to both, but for small and medium-size universities, this choice is a very difficult one. Although universities are essentially educational institutions, they cannot specialize only in education. They need to keep in mind that education must eventually serve to promote research and contribute to society's development. If we accept this, we cannot focus only on education. In this light, I feel that the open innovation hub is an opportunity for AIST and universities to share their roles. In other words, when a university implements specific research and training initiatives, it can do this keeping close communication with public research organizations such as AIST. I feel that it is in this sense that AIST can serve as a hub or interface.

Makoto Hirayama (Professor, State University of New York, USA)

The mission of AIST is to pursue "*Full Research*", but it would be good to define, in simple and clear terms, what AIST's role and mission are, specifically in relation to a methodology for how to link this "*Full Research*" with universities and industry. The College of Nanoscale Science and Engineering (CNSE) of the State University of New York (SUNY) at Albany, where I work, engages in industry-oriented research and industry cultivation. From a Japanese perspective it may seem surprising that universities are involved in industry this way. In fields that are important policy-wise, such as solar cells, CNSE collaborates with federal research bodies such as the Los Alamos National Laboratory to promote industry. We obtain funding for this from the state government and the Department of Energy. The vision and mission in this case are so simple that they can be stated in one or two lines. It would be good if AIST could clearly define "*Full Research*" with vision and mission statements propose very specific themes of research to industry and universities, and to launch joint research initiatives.

In order for AIST to attract a diversity of people, including foreigners, it needs some kind of "magnet" that will draw propose to it. In the case of CNSE, the magnet is the constant availability of a state-of-the-art technological environment, made possible by public funding, something that most companies cannot afford. Researchers who want to make use of the most advanced equipment have no choice but to go to CNSE. This is how the magnet works! For example, at the Albany campus there is a super clean room, which is more like that of chipmakers than the clean room here, and 1.5 times bigger. Almost all the major semiconductor manufacturers, like IBM and SEMATECH make use of it. CNSE's policy regarding intellectual property (IP) is also clear, and the 300 mm lines can be used by anybody who pays the usage charges. The university makes no claim on IP derived from knowledge obtained using the line, except in cases of joint research projects. That is, only when university professors use the facilities as part of joint research projects with companies or outside research bodies, do they make a joint application for IP protection with the collaborating researchers or the university.

A vital factor for proceeding with open innovation is the question of how can AIST globalize its activities. Without operating within international standards, AIST cannot expect to attract good students and researchers from around the world. America is a contract-oriented society, but that approach is unfamiliar to Japanese. It should be understood that while Japanese may be able to sense things like the intentions of others non-verbally, this is not the case with most foreigners. For this reason, it is important to adopt international standards for operations and management wherever possible, as is done with accounting standards. Adopting internationally acceptable ways of doing things is a form of globalization, and it is necessary in the promotion of open innovation.

Thaweesak Koanantakool (President, National Science and Technology Development Agency, Thailand)

I believe that AIST has expertise and strengths in those areas desired by industry. In this way, it is possible to step up the connection between basic researches with commercialization of the private sector. It thereby induces more collaborative innovation with industry towards the commercial end. Consequently, you can respond to the private sector in a way that they expect, at the same time solving the private sector's crisis. The industry wants more innovation in order to get ahead of the competition while AIST wants more budgets out of collaboration with the private sector. I am impressed with your idea of *Full Research* as many new innovations come quickly from basic research and onto commercialization.

I hope that you extend to leverage the open innovation hub with ASEAN countries. Our research problems in the ASEAN area are quite different from here. For example, in the photovoltaic (PV) field - the solar cells in Thailand will be subject to very hot and very humid weather. In addition, we have heavy rain most of the time in the rainy season. Therefore, it would be a good opportunity to present a new challenge to researchers on how to research the life, durability, and degradation of solar cells in the hot and humid region. Also, in Thailand, an automobile sector is one of the top for exports, with the main investors being from Japan. These auto industries are also shifting towards hybrid and electric cars. We have observed a move towards power semiconductors and a way to manage a smart grid in the city to fuel the battery-powered cars. This could be one new and extended area where researchers in the ASEAN countries could be participating in your open innovation.

In the near future, perhaps, AIST can show the other countries that AIST researchers have entrepreneurship with fearless risk taking activities. I am looking forward to seeing a good model of the *Type-2 Basic Research* that creates a culture of entrepreneurship with fearless risk taking.

Jürgen Mlynek (President, Helmholtz Association)

As an advisor, I would like to make comments on standing, balance, and potential. With respect to the standing of your organization, I realize that you are very successful in terms of publications. There is also some strategic relevance of the work that you do. In this two-dimensional map, which is called Pasteur's Quadrant, where you plot basic research against applied research, you are not in the field of pure basic research, nor in the field of completely applied research, you are in the field of use-inspired basic research. I think one of the strengths of this institution is also a strong basis in basic research. So my advice would be even if you want to innovate and even if you want to reach out to the private sector, your strength is also outstanding basic research and do not forget about this now and in the future.

With respect to balance, that is always the question, are we doing the right things and are we doing things right? But the real challenge is to ask the right questions. You always try to ask what your priorities are and what your posteriorities are. In view of your future budgets which will be essentially constant or even decreasing, the question of priorities is essential because in that context you can only start something new if you quit certain fields that are running fine but maybe are not that important in the future.

With respect to potential, I was really impressed by the infrastructure of AIST, this clean room facility is just wonderful. So keeping research infrastructure up at the frontier is really essential. And the other aspect potential is people. Maybe you should also make an effort to have more females in your organization essentially at all levels. People, I think in the end, is what really counts and if you can become even more diverse and more international, the better.

And finally, let me just stress one of the main transfer activities that institutions like yours and universities have are people, qualified people that you educate for the private sector. This is also part of your valuable output for society, it is not only patents and licenses, it is qualified people.

In summary, it is a wonderful institution. I think you are doing great and you should do everything to stay in that position.

Tamotsu Nomakuchi (President, AIST)

Thank you all very much for participating today in this very lively discussion. Despite the short time together, we learned a lot from your participation today. For example, you pointed out the limited presence of female researchers at AIST, the lack of mobility of our researchers, and offered thoughtful suggestions about how to address these issues. I am sincerely grateful to you all for your enthusiastic participation in today's meeting.

Discussion topics like the role of public research organizations in resolving 21st century issues and initiatives for the realization of an open innovation hub can shed light on defining the ideal nature of research and development organizations in Japan. As a public research organization, we feel that when we review our past efforts and consider our future role in the context of a globalized world, even if such discussion is not entirely positive, we should try to enhance our core functions. Doing this gives us confidence. In view of this, we set the topics of today's discussion desiring to address real issues head-on. All the board members contributed very valuable and useful opinions. I don't have enough time here to sort through all the feedback, but I will do this thoroughly in the days ahead, and work to translate the feedback into concrete action.

Research Lab Tours in Two Groups

Lab tours for advisory board members were arranged to allow members to get a real taste for AIST initiatives to promote innovation through direct discussions with researchers.

The members split up into two groups for the tours, which consisted of five labs: the Nanodevice Innovation Research Center (super clean room), the Spintronics Research Center (spintronics technology research), the Intelligent Systems Research Institute (new robot industry creation), the Research Center for Stem Cell Engineering (standardization of iPS cells and other stem cells for industrial applications), and the Nanotube Research Center (practical applications of single-wall carbon nanotubes). At each site researchers presented and explained their research findings.

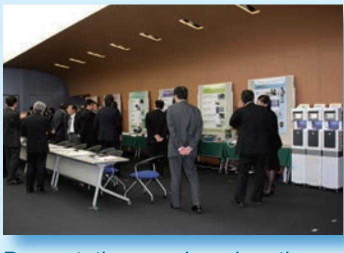
Super clean room

Spintronics technology research

New robot industry creation

Standardization of iPS cells and other stem cells for industrial applications

Practical applications of single-wall carbon nanotubes



Presentations and explanations of research findings

AIST's World-Class Carbon Nanotube-Related Research

Outline and Expectations for the Future

The National Institute of Advanced Industrial Science and Technology (AIST) has been supporting the promotion of research and development of industrial technologies in Japan and the enhancement of Japan's industrial competitiveness. The research achievements presented here are the fruits of efforts by the Nanotube Research Center and the Nanosystem Research Institute, both of AIST in the Nanotechnology, Materials and Manufacturing field. The research topics reflect our keen awareness of originality, making a strong impact on industries, and addressing challenges that may be too risky for corporations to take on by themselves. Specifically, we are aiming to develop industrial applications of nanometer-scale structures, namely single-wall carbon nanotubes (SWCNTs), organic nanotubes (ONTs), and bio-nanotubes which are tubular, and graphene which is planer. SWCNTs are expected to have wide-ranging industrial applications. Methods to mass-synthesize high-purity SWCNTs and to generate high-quality SWCNTs have finally been developed 20 years after their discovery, offering the prospects of actual industrial applications. In the area of electronic applications of CNTs, the development of techniques for the separation of semiconductor and metallic SWCNTs has advanced, and further progress in the electronics field is expected. In addition, we are also investigating applications for medical examination and treatment utilizing the excellent absorption properties of carbon nanohorns and ONTs. We are aiming to expand the use of nanotubes through nanotube formation for specific purposes and functionalization. Evaluations of the physical properties of SWCNTs by optical or electro-optical measuring methods are the basic technologies for applied nanotube research and they also contribute to international standardization (such as by the International Organization for Standardization). The development of a world-leading ultra-high-resolution electron microscope and the establishment of a method for evaluating CNTs with the microscope are world-class accomplishments of the Nanotube Research Center.

Director, Nanotube Research Center
Sumio IIJIMA

Research and Development of Carbon Nanotubes at AIST

Research base for carbon nanotubes (TIA-CNT)

The Tsukuba Innovation Arena (TIA) framework is an approach for establishing a globally attractive nanotechnology research base by integrating world-class nanotechnology research capabilities gathered in Tsukuba and combining the efforts of industry and academia.

There are six core research areas in the TIA framework, one of which is the area of CNTs. In this core area (TIA-CNT), we are aiming to develop technologies to synthesize SWCNTs, a novel carbon material, in a variety of ways to utilize their excellent properties across a range of industrial applications, and to make such applications possible by improving their quality and forming them into components. Through various basic research efforts, our aim is to create an SWCNT industry that can contribute to the realization of an energy-conserving society for the future.

Projects being implemented in TIA-CNT

TIA-CNT constructed and commenced operation of a pilot plant as a supplementary budget project in FY 2009 to verify the mass production of SWCNTs synthesized by the super-growth method, which is a process developed at AIST. We are promoting large-scale collaborative research between AIST and individual firms that can make use of a large supply of SWCNTs synthesized by this method.

The issues in realizing the practical application of SWCNTs include (1) developing synthesis and industrial production technologies for SWCNTs having optimized properties for the intended purpose, (2) developing fabrication technologies for SWCNTs that does not deteriorate their properties, (3) establishing a risk assessment method to ensure safety, and (4) finding cost-competitive specific usages. In that context, we are participating in the "Innovative Carbon Nanotubes and Their Application Project," a FY 2010-2014 project implemented by the Ministry of Economy, Trade and Industry (METI) and the New Energy and Industrial Technology Development Organization (NEDO).

In addition to the super-growth method, we are conducting research on the development of applications of SWCNTs synthesized by the enhanced direct injection pyrolytic synthesis (eDIPS), which is a method developed at AIST, and semiconductor and metallic SWCNTs, which are isolated by the gel column separation method. We are also working to establish international standards for CNT assessment methods. Furthermore, we have started research on graphene which is considered as a new promising nanocarbon material.

Within TIA-CNT, we are developing these basic technologies and as the implementation of open innovation, we are sharing results with internal and external research groups, inviting the participation of corporations to conduct application development using these basic technologies, and initiating applied research and development.

Deputy Director, Nanotube Research Center
Motoo YUMURA

For inquiries about this article : Nanotube Research Center http://unit.aist.go.jp/ntrc/cie/index.html

Super Growth Method

About the super growth method

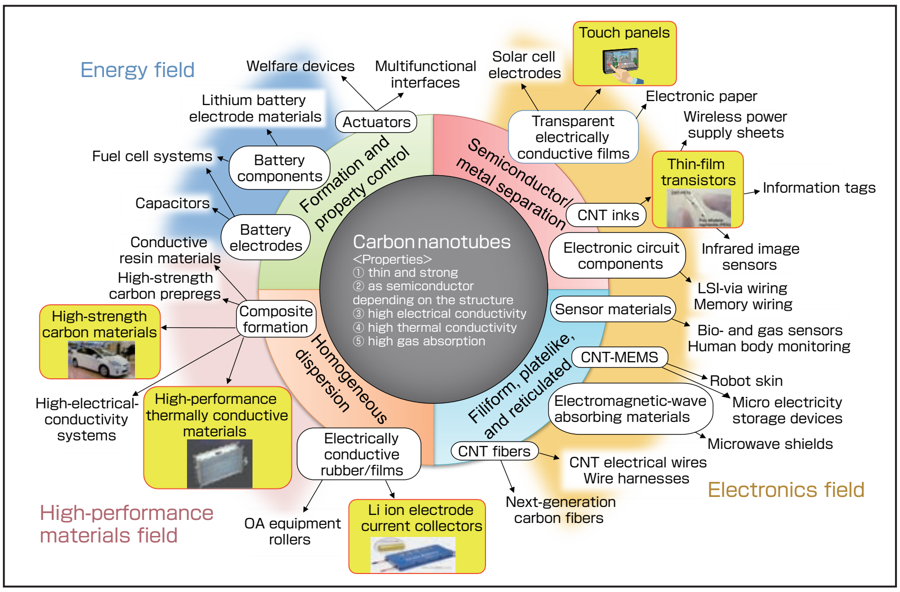
The super growth method, developed at AIST in 2004, is a new synthesis technology for CNTs [1][2]. The addition of an infinitesimal quantity of water (ppm order) to the usual CNT synthetic ambient increases the lifetime of the catalyst from several seconds to several tens of minutes. This allows a mass synthesis of SWCNTs from a small amount of catalyst, with a time-efficiency 3,000 times higher than the conventional approach.

Development of mass-synthesis technologies with the super growth method

We have partnered with Zeon Corporation under the "Carbon Nanotube Capacitor Development Project" being implemented by NEDO to develop mass-production technologies utilizing the super growth method with a goal of the industrial production of SWCNTs at an unprecedented scale and price. Thanks to the efforts of many individuals, the research project has progressed smoothly and we have achieved continuous synthesis, large-area synthesis, moist catalyst development, metal substrate development, and substrate reuse technology development. A pilot plant combining these technologies finally started operation in 2011, and we aim to provide kilogram-scale SWCNTs for the first time in the world at a practical cost.

Application development with the super growth method

We have provided CNTs synthesized using the super growth method to more than 200 research institutes so far. As a result, a variety of new applications have been developed including CNT rubber with electrical conductivity 500 times higher than that of conventional electrically conductive rubber materials[3][4], a fast-moving actuator operable with two AA-size batteries[5], a CNT aluminum composite material with thermal conductivity three times higher than that of aluminum, an extremely black-body-like CNT material that can absorb more than 98% of light across the ultraviolet an far-infrared regions[6], a capacitor operable at a high voltage of 4 V[7], a viscoelastic material that maintains silicone-rubber-like softness and firmness at a stable level over a temperature range of –140 to 600 ℃ [8], and a CNT strain sensor that detects human motion[9]. A unique property of super growth CNTs is that they are fiber materials with the largest specific surface area among currently existing fiber materials. It is essential to utilize this property at a maximum in our application development.



Various potential applications of CNTs

The future of the super growth method

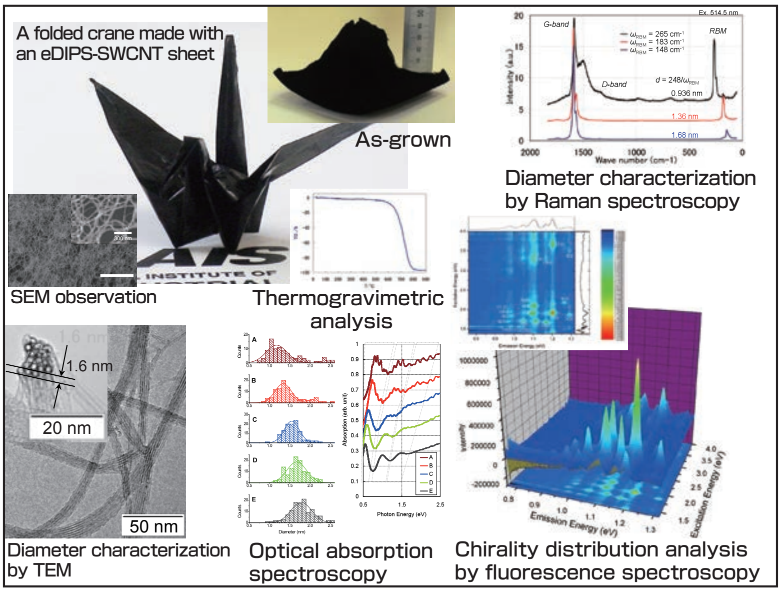
Wide application of SWCNTs in our daily life, summarized by the phrase, "Carbon nanotubes here, there, and everywhere," is what I envision for our future (see figure). I am determined to continue our vigorous research so that one day, when visiting my aged mother and finding her holding a product developed through the application of super growth CNTs, I can say to her, "You know what? That contains carbon nanotubes that we developed!"

Nanotube Research Center
Kenji HATA

References

[1] *Science*. 306, 1362-1365 (2004), [2] *Nature Nanotechnology*. 1, 131-136 (2006), [3] *Science*, 321, 1468 (2008), [4] *Nature Materials*, 8 (6), 494-499 (2009), [5] *Advanced Materials*, 21, 1582-1585 (2009), [6] *PNAS*, 106 (15), 6044-6047 (2009), [7] *Nature Materials*, 5, 987-994 (2006), [8] *Science*, 330 (6009), 1364-1368 (2010), [9] *Nature Nanotechnology*, in print.

The eDIPS Method



Diameter distributions and basic properties of eDIPS-SWCNTs

Introduction

A carrier mobility that makes the processing speed of electronic devices 10 times faster than that of silicon devices, a tensile strength 20 times greater than that of steel yet with about half the mass density of aluminum, and a thermal conductivity 10 times higher than that of copper are just a few of the excellent properties possessed by SWCNTs. Because of these properties, SWCNTs have become one of the most prominent materials in nanotechnology with expectations for their application in a wide range of fields, and active research on them is already underway. It is thought that the potential of SWCNTs can be reached only when their diameters are precisely controlled and high crystallinity is attained. However, a production technology that overcomes both of these challenges, which is essential to the realization of the properties described above, has not yet been developed. We are developing the enhanced direct injection pyrolytic synthesis (eDIPS) method aiming at the establishment of SWCNTs not merely as alternative materials but as extreme materials for unprecedented usages that can be accomplished only by utilizing their specific properties and mass-production of them.

About the eDIPS method

The chemical vapor deposition (CVD) method that is the high-purity, high-yield, and low-cost production method of SWCNTs can be categorized into two types. The substrate CVD method involves growing SWCNTs from metal catalyst particle-coated substrates or carriers, while the other, called the gas-phase CVD method, grows SWCNTs from metal catalyst particles floating in a gas phase without the use of substrates. The latter method is more suitable for the synthesis of highly crystalline SWCNTs, because a higher reaction temperature can be set. The gas-phase CVD method is a promising mass-production technology that can continuously produce SWCNTs, and our eDIPS method, which we began developing in 2005, is classified as a variation of the gas-phase CVD method.

One of the characteristics of the eDIPS method is the fact that it permits the reaction to be optimized through the simultaneous use of two or more types of carbon sources with different decomposition properties. This discovery made possible the diameter-controlled synthesis of SWCNTs in a wider diameter range[1], which had otherwise been difficult to accomplish. Our recent research revealed the most effective chemical species to act as a carbon precursor[2][3], which is a key aspect in reaction control in the eDIPS method. We are working to enhance reaction controllability and the precision of SWCNT structure synthesized by eDIPS.

The future for high-quality eDIPS-SWCNTs

We have been presenting various types of SWCNTs that are synthesized by the eDIPS method, as well as their basic properties, to a wide range of users (see figure)[4][5]. In our recent studies, we have expanded our development activities to length-based classification technology[6], metal/semiconductor separation technology, and material processing technologies[7][8] in an attempt to establish the foundations for developing applications of eDIPS-synthesized SWCNTs. Extreme materials that utilize the full potential of SWCNTs can be realized through the eDIPS method, which gives us unlimited potential in the area of application exploration.

Nanotube Research Center

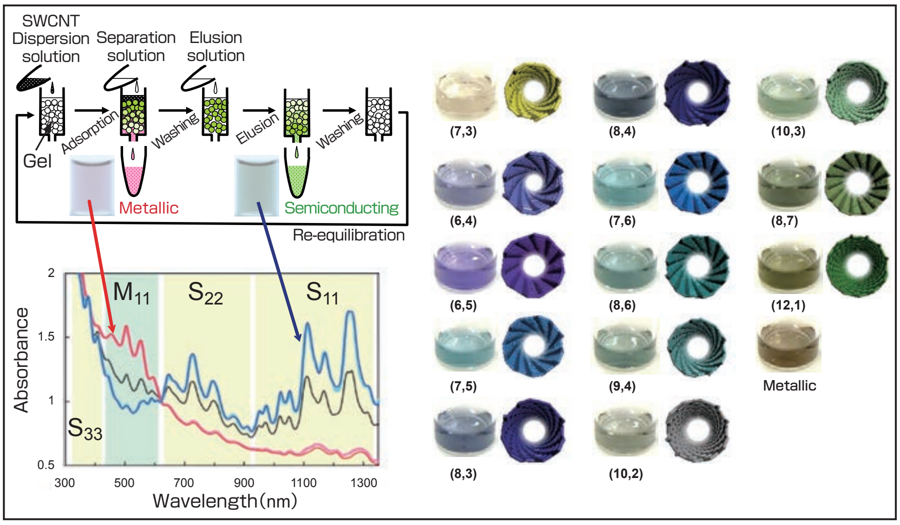
Takeshi SAITO

References

[1] *Journal of Nanoscience and Nanotechnology*, 8, 6153-6157 (2008), [2] *Chemical Communications*, 8, 3422-3424 (2009), [3] *Chemistry of Materials*, 22, 6035-6043 (2010), [4] *Applied Physics Express*, 2, 095006 (2009), [5] *Journal of Physical Chemistry C*, 114, 10077-10081 (2010), [6] *ACS NANO*, 4, 3606-3610 (2010), [7] *Carbon*, 48, 1977-1984 (2010), [8] *Nanoscale*, 3, 1904-1909 (2011).

For inquiries about this article : Nanotube Research Center http://unit.aist.go.jp/ntrc/cie/index.html

Innovative Separation and Purification Technologies for CNTs



Upper left: Schematic illustration of the separation of metallic and semiconducting SWCNTs using gel-packed column chromatography
Lower left: Absorption spectra of the separated metallic/semiconducting SWCNTs
M_{11} shows the absorption band of the metallic SWCNTs, while S_{11} and S_{22} indicate the absorption bands of the semiconducting SWCNTs. The figure shows that the two types of SWCNTs are clearly separated.
Right: Chirality-separated semiconducting SWCNTs
The numbers in parentheses indicate the indexes of the structures.

Metallic and semiconducting single-wall CNTs

Single-wall carbon nanotubes (SWCNTs) have many excellent properties for electronics materials, including extremely high electron/hole mobility like that of graphene, the ability to control band gap by altering diameters, and nanometer-scale size achieved without processing. SWCNTs are promising next-generation semiconductor materials; however, their synthesis yields a mixture of two types of SWCNTs: metallic and semiconducting. The structural differences between these two types are extremely small, which makes the synthesis of each SWCNT difficult. Hence, applications as an electronic material require the separation of metallic and semiconducting SWCNTs after synthesis. At AIST, we have developed a novel separation method using a gel, and are focusing on the development of applications of SWCNTs to be used as electronics materials.

Separation of metallic and semiconducting SWCNTs using gel column

At AIST, we have discovered a unique interaction between semiconducting SWCNTs and agarose gel, and by utilizing this interaction, have succeeded in the development of a novel separation technology that makes possible the high-purity separation of metallic and semiconducting SWCNTs by pouring a SWCNT dispersion solution onto the gel[1]. The poured SWCNTs are completely separated by this process, without any loss of material. We use an inexpensive surfactant, sodium lauryl sulfate, which is also used in daily commodities such as toothpastes, as the dispersant, and the gel used for the separation is a safe natural material extracted from agar. This technique permits extremely low-cost separation, because the gel can be used repeatedly without being consumed and the process can be easily automated. Thin films produced with metallic SWCNTs separated by our technique showed consistently high electrical conductivity in a changing environment. It was confirmed that semiconducting SWCNTs operate as high-performance thin-film transistors fabricated by a simple coating method.

Ultimate separation technologies toward industrialization

Even among semiconducting SWCNTs, slight changes in the arrangement of atoms cause the band gaps to differ, yielding a semiconducting SWCNT mixture with different chiralities–analogous to a mixture of different species of semiconducting materials such as silicon, germanium, and selenium–hindering the full exploitation of intrinsically high-performance SWCNTs. Complete chirality separation of SWCNTs has been difficult up to now. At AIST, however, we have succeeded in the development of a groundbreaking separation technology, similar to the metal/semiconductor separation technique, that realizes high-purity chirality separation by pouring a dispersion solution onto gel[2]. We are planning to deepen our collaborations with industry, and aim to advance these separation technologies and put our SWCNTs into practical use in the next 10 years.

Nanosystem Research Institute
Hiromichi KATAURA

References

[1] T. Tanaka *et al*.: *Appl. Phys. Express* 2, 125002 (2009).
[2] H. Liu *et al*.: *Nat. Commun*. 2, 309 (2011).

Production of functionalized CNTs and International Standardization of CNT characterization methods

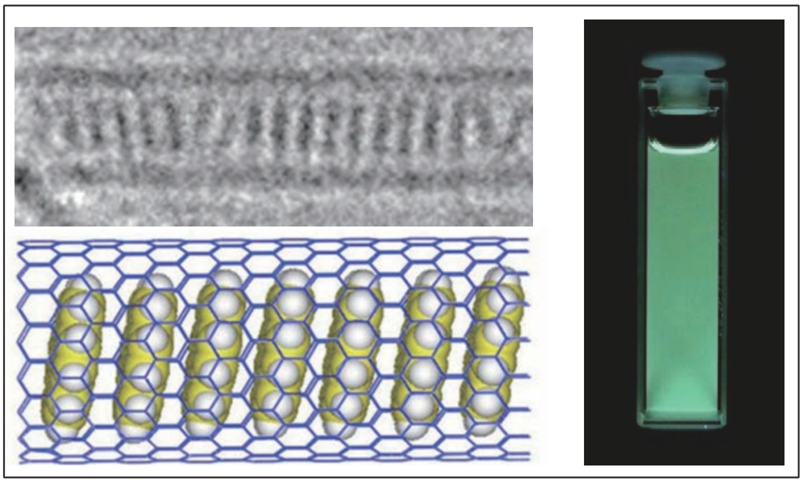
One-dimensional coronene columns with CNTs as templates

One of the most efficient bottom-up approaches in nanotechnology is a technique for synthesizing nanostructures that involves the self-assembled organization of molecules through weak noncovalent interactions.

The inside of single-wall CNTs (SWCNTs) provides an excellent space for such aggregated molecules. We have recently succeeded in building one-dimensional nanostructures consisting of coronene, a type of planar π-conjugated molecule that self-assembles in a columnar shape inside SWCNTs and forms a homogeneous molecular arrangement[1]. Such a structural arrangement is different from that of any other coronene crystals ever reported. In addition, we have observed strong fluorescence from the embedded coronene, even though the emissions of embedded molecules are usually quenched by an interaction with SWCNTs.

Interestingly, the observed fluorescent spectrum differs significantly from that of solid coronene reported to date. This suggests that the one-dimensional coronene crystals formed inside the SWCNTs have an electronic structure unique to a one-dimensional array structure that is different from that of molecules (zero-dimensional) or crystals (three-dimensional).

The use of SWCNTs as templates as described above makes it possible to synthesize new one-dimensional nanostructures. Such synthesized nanostructures are protected by CNTs, providing excellent durability against strain, heat, and light, and offering the potential for application in areas such as nanophotonics, molecular probes, and electrode materials in the future.



Transmission electron microscope image of one-dimensional coronene crystal formed inside SWCNT (upper left), its schematic (lower left), and a fluorescent picture of the aqueous solution

International standardization of CNT characterization methods

The need for standardization in the field of nanotechnology has been widely recognized now that industrial applications are being discussed. Movements for standardization have been active in the United States, Europe, Japan, and China since 2004, and a technical committee (TC229) has been established in the International Organization for Standardization (ISO) to deal with subjects related to nanotechnology.

As CNTs are a primary nanomaterial, more efforts for international standardization have been put into CNT-related subjects than for other nanomaterials. WG2, a working group in TC229 that deals with measurement and characterization, has published a technical specification for characterization of single-wall carbon nanotubes using near infrared photoluminescence spectroscopy (ISO/TS 10867:2010)[2]. The objective of this standard is to determine the chiral indices of the semiconducting SWCNTs in a sample, as well as their relative emission intensities, which makes it possible to estimate the molecular structures and diameter distributions of SWCNTs in a sample. With AIST taking the lead in such standardization efforts, we are contributing to the preservation and securing of Japan's predominance in the field of nanotechnology.

Nanotube Research Center
Toshiya OKAZAKI

References
[1] T. Okazaki *et al.*: *Angew. Chem. Int. Ed.*, 50, 4853-4857 (2011).
[2] ISO/TS 10867, (Sept. 15, 2010).

For inquiries about this article : Nanotube Research Center http://unit.aist.go.jp/ntrc/cie/index.html

Low-Temperature Synthesis of Graphene by Microwave Plasma CVD

Transparent conducting films (TCFs) have become highly important core materials used in LCDs, touch panels, solar cells, and other applications. Currently, indium tin oxide (ITO), which contains a rare metal, indium, is used in nearly all TCFs, and the development of alternative materials in order to prevent rising costs and supplement an unstable supply has become a necessity.

Graphene is a one-atom-thick sheet, composed of carbon atoms. Optical transparency over a broad wavelength, ranging from visible to infrared light, and high electrical conductivity are superb properties of graphene from an application point of view, and it is hoped that graphene-based TCFs will become an alternative to ITO-based TCFs.

Graphene was discovered by Dr. Andre Geim and Dr. Konstantin Novoselov of the University of Manchester in 2004, by attaching a piece of adhesive tape to a piece of graphite and peeling it off. The amount of graphene that could be obtained by this method was extremely limited, and it is apparent that a method of graphene synthesis applicable to the continuous large-area production was essential in order for it to be adapted for industrial use. Consequently, a chemical vapor deposition (CVD) method, which produces graphene on the surface of nickel and copper by pyrolyzing carbon-containing methane gas, was developed. This has made large-scale synthesis of graphene possible and increased the potential for industrial applications; however, the fact that this method requires the pyrolysis of methane gas to occur at 1000 °C makes continuous production difficult, and this remains a problem to be solved.

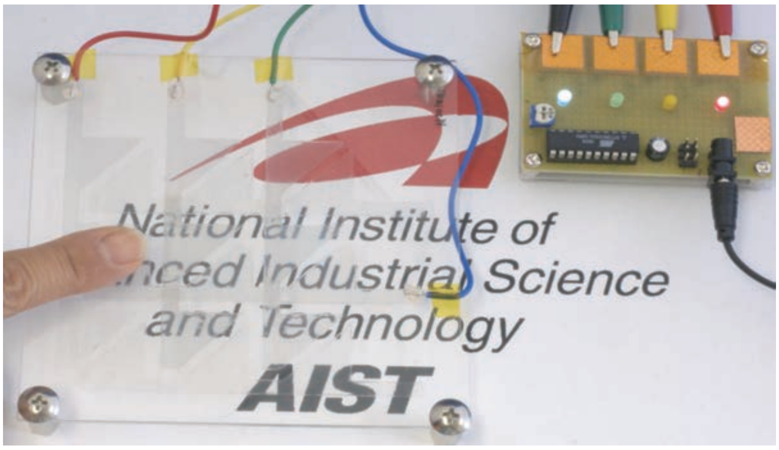


Fig. 1 Electrostatic capacity-type touch panel with graphene synthesized by microwave plasma CVD[1]

Fig. 2 A1-size (594×841 mm) transparent graphene sheet synthesized by microwave plasma CVD

At the Nanotube Research Center, we have been working on technologies for low-temperature, large-area synthesis of nanocrystalline diamond thin films by applying our unique microwave plasma CVD equipment and method, and have been making efforts to modify this method for application to low-temperature, large-area CVD synthesis of graphene. We have succeeded in the synthesis of large-area graphene up to the size of A3 paper at a low temperature of 300 °C. We are now able to produce graphene-based TCFs that have a visible light transmittance of about 80 % and sheet resistance of 1 to 2 kΩ/sq. We have fabricated a test model of an electrostatic capacity-type touch panel by applying the graphene-based TCFs, and confirmed its performance (Figure 1). Figure 2 shows an A1-size graphene transparent sheet that was fabricated by connecting four A3-size sheets. We have been working on the development of roll-to-roll deposition technologies for graphene by improving our current method.

Nanotube Research Center
Masataka HASEGAWA

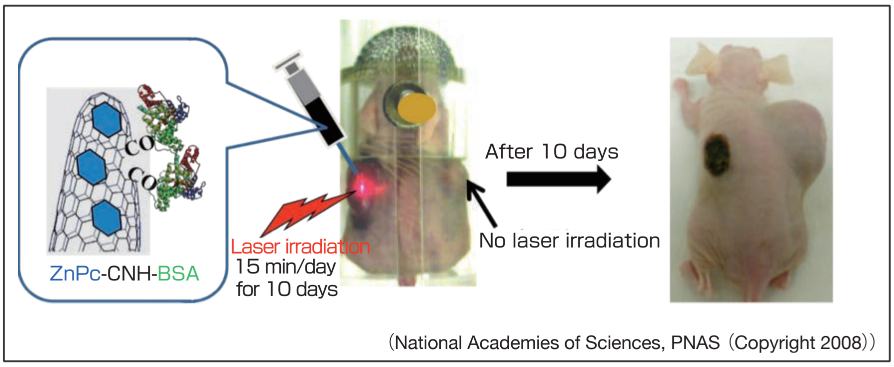
Reference

[1] J. Kim *et al*.: *Appl. Phys. Lett.* 98, 091502 (2011)

Medical Applications of Carbon Nanotubes

Introduction

Recent advances in medical care are the result of research in the fields of medicine, pharmacology, and biology in conjunction with research in other areas of science and engineering. Among these advances, the development of chemical materials has held an important position. Many new materials are currently in clinical use including special surgical fibers, dialysis filters, and alloys used as a bone substitute. Meanwhile, research in the area of nanometer-scale substances has progressed over the past 20 years, and advances have taken place in disease treatment technologies such as liposomes, which function as a carrier of a drug delivery system (DDS), delivering drugs selectively to an affected area inside the body. There have been many discoveries of nanometer-scale substances with structures and properties different from those of conventional substances. Among these substances, CNTs have received considerable attention in applied research because of their high utility. Investigation of medical applications of CNTs began about 10 years ago, especially in the area of applied research of DDSs. This is because CNTs, unlike conventional carriers in DDSs, can be chemically modified in a variety of ways, and their use as a carrier is expected to increase the efficiency of targeted antitumor agent delivery and make gene therapies less complicated. In addition, CNTs absorb near-infrared light that can easily penetrate living tissues, which makes it possible to apply them to photodynamic therapy (PDT). CNTs also emit near-infrared light, allowing their utilization as a light-emitting probe within the living body, which is an advantage that conventional carriers do not have. Apart from their use as DDSs, CNTs exhibit potential as a probe that can visualize cancer cells.



ZnPc-CNH-BSA was directly injected into a subcutaneously transplanted tumor and laser irradiated (670 nm) for 15 minutes per day. After 10 days, the tumor disappeared (left flank). The black mark where the tumor was previously located is a scar from the laser. The tumor that received no laser irradiation grew larger (right flank).

Research findings

The Nanotube Research Center has demonstrated that carbon nanohorns (CNHs), a variety of CNTs, make it possible to realize double phototherapy–namely, photodynamic therapy (PDT) plus photohyperthermia therapy (PHT)–and has shown the high effectiveness of the therapy in cancer treatment through animal tests. More specifically, we fabricated a complex (ZnPc-CNH-BSA) by loading a PHT agent (zinc phthalocyanine: ZnPc) into CNHs and attaching a protein, bovine serum albumin (BSA), to the CNHs. When the ZnPc-CNH-BSA was directly injected into subcutaneously transplanted tumors in mice and laser irradiated, we observed that the double phototherapy, PDT and PHT, caused the tumor to disappear within about 10 days (see figure).

In the medical applications of CNTs, there is the need to elucidate the toxic effects and in vivo distribution of CNT materials. Rigid rod-like CNTs of about a micrometer in length and 100 mm or more in diameter raise concerns with respect to toxicity. However, CNTs of less than 100 nm in length and non-rigid rod CNTs of a few nm in diameter have been shown to have low toxicity. Furthermore, CNTs that are small in size and are adequately chemically modified can be excreted from the body. The Nanotube Research Center has been studying the safety of CNHs, and we have found no acute toxic effects so far in either cell experiments or animal experiments.

Prospects for the future

Our research on medical applications of CNTs involves the investigation of interactions between CNTs and the body, since CNTs are a new material. In the future, we hope to find unique medical applications of CNTs with advancements in the research, thereby contributing to the progress of medicine.

Nanotube Research Center
Masako YUDASAKA

For inquiries about this article : Nanotube Research Center http://unit.aist.go.jp/ntrc/cie/index.html

Mass Production and Industrial Application of Organic Nanotubes

Introduction

Organic nanotubes (ONTs), which form through self-assembly of molecules, are materials that can be manufactured in both resource- and energy-conserving ways, and have been attracting attention due to their potential for contributing to both life innovation and green innovation.

AIST developed a method for the mass synthesis of glucose-type ONTs and glycylglycine-type ONTs in 2006. Since then, the focus of our research has expanded to the practical application of ONTs across various fields, including health foods, medicine, the environment, and energy.

In addition, in 2008 we developed a technology to mass-synthesize metal-complex-type ONTs (metal-ONTs) by utilizing the molecules that compose glycylglycine-type ONTs along with metal ions. Our research and development of metal-ONTs have concentrated on organic nanotube catalysts that can contribute to reduction of the environmental load.

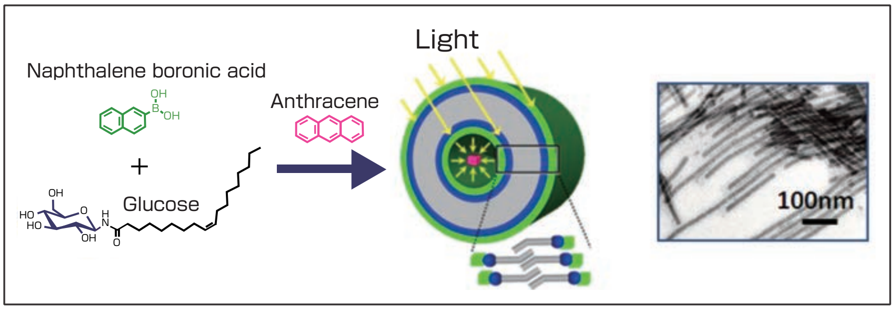


Fig. 1 Synthetic route of dye-ONTs with dye inclusion, a schematic of their light-harvesting function, and a transmission electron microscope image

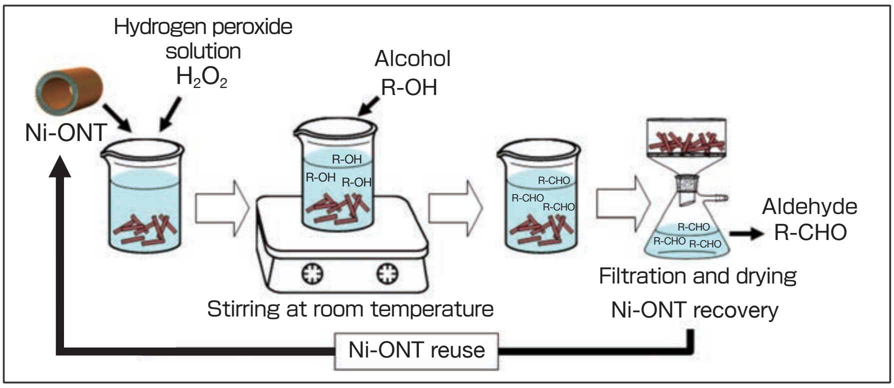


Fig. 2 Oxidation reaction process of alcohol using Ni-ONT catalyst

Development of light-harvesting materials with dye-conjugated ONTs

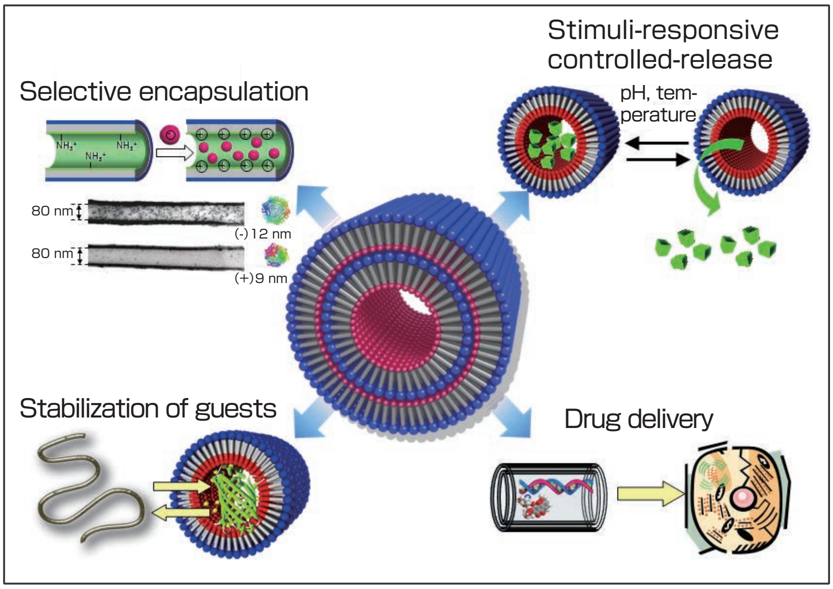
We have succeeded in the synthesis of dye-ONT complexes (dye-ONTs) by dehydrative ester condensation of glucose and naphthalene boronic acid. Observations using a transmission electron microscope revealed that coupling with dye reduces the inside diameter of dye-ONTs to about one-fifth of its original size. In addition, it was found that the surface of dye-ONTs becomes hydrophobic as a result of the coupling with dye, making the dye-ONTs well-dispersed in organic solvents such as chloroform and toluene. We also evaluated the functionality of dye-ONTs through fluorescence measurements, and found that photo-excited energy efficiently transferred to another type of dye, anthracene, which was contained in a hollow cylinder (light-harvesting function) (Fig. 1). We are currently conducting research and development of a new photosensitized material utilizing this light-harvesting function.

Application development of metal-ONTs as a catalyst

Our research and development efforts were based on the possibility that nickel-complex-type ONTs (Ni-ONTs) may work as an efficient catalyst because their structure is composed of a single bilayer membrane with nickel ions exposed on the inner and outer surfaces of the nanotubes. Our findings confirmed that Ni-ONTs function as a catalyst, because the addition of Ni-ONTs and alcohol to an aqueous solution of hydrogen peroxide causes the oxidation reaction to proceed when the solution is stirred without heating, resulting in the selective formation of aldehyde. Ni-ONTs are solid in the aqueous solution and can be recovered and reused by filtration after the reaction (Fig. 2), making them a promising catalyst with a low environmental load that can contribute to green innovation.

Nanotube Research Center
Masumi ASAKAWA

Bio-nanotubes and Their Applications



Conceptual scheme of various bio-nanotube functions

Tubular nanocapsules with distinctive inner and outer surfaces

Organic nanotubes (ONTs), formed by the spontaneous aggregation (self-assembly) of lipid molecules, have a hollow, cylindrical nano-space with an inner diameter ranging from several nanometers to several hundred nanometers. These nano-spaces can be utilized to encapsulate molecules and materials as well as to release them[1]. For these reasons, ONTs are expected to be widely applied across the fields of pharmacology, medicine, chemistry, biotechnology and nanotechnology. We have developed ONTs, also called bio-nanotubes, shown in the center of the figure, characterized by the outer surface of the tube being covered with glucose while the inner surface is covered with amino groups and carboxyl groups. We are currently studying physicochemical properties of the ONTs and also developing fundamental technologies for its practical use, mainly in the life science field.

Protecting biopolymers

Bio-nanotubes have an excellent ability to selectively encapsulate biopolymers such as proteins and DNA and to stably store them (see figure). We studied the thermal stabilities of green fluorescent protein (GFP) encapsulated in bio-nanotubes with three different inner diameters (10, 20, and 80 nm). Our findings revealed that GFP encapsulated in the nanotubes with a 10 nm inner diameter (10 nm nanotubes), which was closest in size to the protein (4 nm), showed almost no denaturation at a high temperature of 90 °C[2]. Such an effect was not observed in the 80 nm nanotubes, and the denaturation conversely progressed in the 20 nm nanotubes. We conjecture that the stabilization effect observed in the 10 nm nanotubes is caused by the confinement of biopolymers in nano-spaces. Bio-nanotubes have a function of releasing drugs in response to external stimuli such as pH and temperature, and they are expected to be utilized as nanocapsules to deliver drugs to body tissues and cells[3].

Aiming toward practical applications

We have been making efforts to produce a variety of bio-nanotubes and to scale up the production of them. We reduced the steps required for the synthetic process to less than half compared with the original process through the structural optimization of raw material lipids and simplification of the purification process, using reprecipitation and filtration. We succeeded in efficiently producing several kinds of bio-nanotubes. By extensively supplying bio-nanotubes to researchers both in academia and industry, we are aiming to accelerate practical applications in various fields through open innovation and collaborative research.

Nanotube Research Center
Mitsutoshi MASUDA

References

[1] N. Kameta *et al.*: *Soft Matter*, 7, 4539 (2011).
[2] N. Kameta *et al.*: *Chem. Eur.*, 16, 4217 (2010).
[3] N. Kameta *et al.*: *Jap. J. Polym. Sci. Tech.*, 67, 560 (2010).

For inquiries about this article : Nanotube Research Center http://unit.aist.go.jp/ntrc/cie/index.html

Observation of Nanocarbon Materials Using Ultra-High-Sensitivity Electron Microscope

Introduction

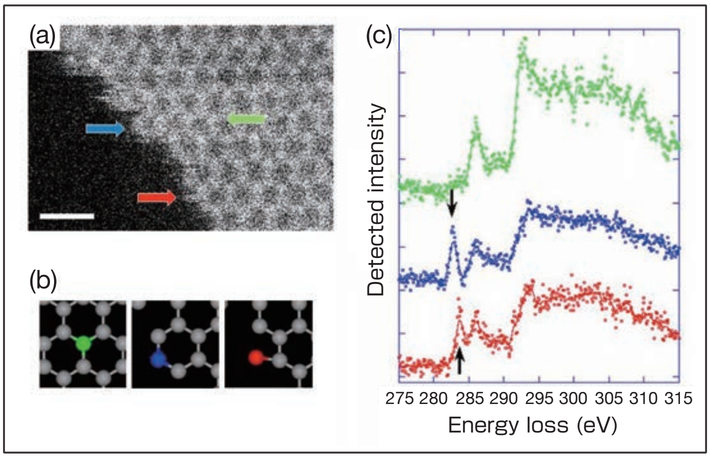
Characterizing the mechanisms and properties of substances is one of the most essential factors in the advancement of today's industrial technologies. A molecule is the smallest unit of a substance that can retain its properties, while an atom is, in general, the smallest unit that cannot be divided any further. Technologies that analyze individual molecules or atoms play a vitally important role in the development of superior equipment and materials with novel functions.

Visualization of chemical reactions at the atomic level

Chemical reactions are diverse, ranging from familiar vital activities such as respiration and digestion to those supporting modern industry such as chemical synthesis and energy conversion. Although we can predict the most reactive part of a molecule to some extent by applying theories, some actual chemical reactions are extremely difficult to predict. One example is the fusion reaction of fullerene molecules, in which different reactions occur simultaneously and various substances are produced.

We successfully controlled and analyzed the reaction of individual fullerene molecules captured inside carbon nanotubes by regulating experimental conditions such as the temperature, concentration, orientation of the molecules, presence of metallic atoms, and energy supplied[1].

Application of this promising technology to organic molecules and biomolecules is expected to advance development across a broad range of areas, including elucidating the reaction mechanisms of individual molecules, which is a key to understanding life, analyzing the dynamics of molecular interactions, and designing molecules based on structural chemistry for the discovery of new drugs.



Single atom spectroscopy of three types of carbon atoms in graphene
(a) an electron microscope image: the scale bar indicates 1 nm.
(b) models of three different types of carbon atoms: coordination numbers of 3 (green), 2 (blue), or 1 (red) in carbon atoms
(c) electron energy-loss spectra of the three carbon atoms indicated by the arrows in (a)

First-time observation of the properties of individual carbon atoms in graphene

The element in nano-scale often displays quite different properties from those of the element in bulk-scale even though it is the same element. The cause of these differences lies in the fact that materials used in nanotechnology are extremely small, and their properties are dominated by specially-conditioned atoms such as those on the surfaces and edges. Conventional analytical methods are only able to identify different types of elements but fail to reveal in detail the differences in electronic states and properties among the same elements.

The Carbon Characterization Team has developed a new electron microscope having the world's highest sensitivity, and confirmed for the first time through a detailed investigation of graphene, which is composed of carbon atoms, that the electronic states of carbon atoms at graphene edges significantly differ from those of normal (bulk) -state carbon atoms[2]. We found that the properties of carbon atoms at graphene edges in turn greatly affect the properties of graphene, to which we must pay great attention when graphene is utilized as an electronic device.

In the future, our research is expected to identify any active sites at the atomic-level in the reactions of the substances, contributing to the development of nanodevices, and the design of new material synthesis.

Nanotube Research Center
Masanori KOSHINO
Kazutomo SUENAGA

References

[1] M. Koshino *et al.*: *Nature Chemistry*, 2, 117-124 (2010).
[2] K. Suenaga and M. Koshino: *Nature*, 468, 1088-1090 (2010).

The abstracts of the recent research information appearing in Vol.11 No.4-6 of "AIST TODAY" are introduced here, classified by research area. For inquiry about the full article, please contact the author via e-mail.

Environment and Energy

The membrane separation technology for refining biobutanol

High concentration butanol recovered from 1 wt% butanol solution

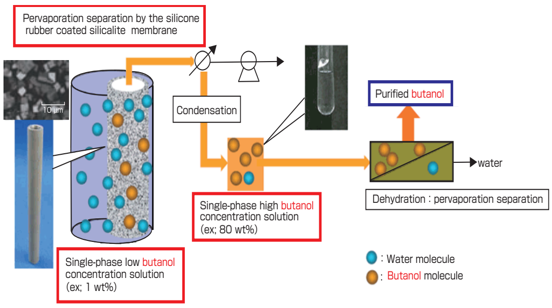
We have developed an energy-saving technology for purifying biobutanol. It uses a kind of zeolite membrane and can recover concentrated 1-butanol (hereinafter referred to as butanol) of at least 80 wt% from dilute (about 1 wt%) aqueous butanol solution. Butanol has a larger calorific value than ethanol. It is expected to be a post-bioethanol fuel, namely a renewable liquid biofuel that is useful in mitigating global warming. A silicalite membrane that has high permselectivity for butanol was synthesized through the optimization of hydrothermal synthesis conditions. The membrane enables the recovery of highly concentrated butanol from low-concentration aqueous solutions of butanol by pervaporation separation. Its use is expected to reduce drastically the energy required to recover butanol by separation membrane methods. Use of this membrane would contribute to the further development of butanol production technologies and effective use of biomass.

Hideyuki NEGISHI

Research Institute for Innovation in Sustainable Chemistry

h-negishi@aist.go.jp

AIST TODAY Vol.11 No.5 p.10 (2011)



Preparation system of purified butanol from low-concentration aqueous solutions of butanol using the novel separation membrane

Life Science and Biotechnology

Discovery of a novel endosymbiotic bacterium inducing body color change of insect

Symbiotic bacterium modifies aphid body color

We discovered a novel symbiotic bacterium of the genus *Rickettsiella* in European natural populations of the pea aphid *Acyrthosiphon pisum*, and demonstrated that the symbiont induces a drastic color change of the host aphids: originally red insects turned into green when infected. Body color is an ecologically important trait, often involved in species recognition, sexual selection, mimicry, aposematism, and crypsis. However, there has been no report on such a phenomenon that the important biological trait, body color, is drastically changed by a symbiotic microorganism. This finding provides a new viewpoint to the ecology and adaptation of insects and other organisms in general.

Ryuichi KOGA
r-koga@aist.go.jp

Takema FUKATSU
t-fukatsu@aist.go.jp

Bioproduction Research Institute

AIST TODAY Vol.11 No.5 p.11 (2011)

The green pea aphid (left) is, although genetically identical to the red aphid (right), infected with a novel symbiont of the genus *Rickettsiella*, which modifies the aphid body color from red to green.

Novel concept of organic photovoltaic cell

Demonstration of photoelectric conversion at near-infrared region (wavelength > 1 μm)

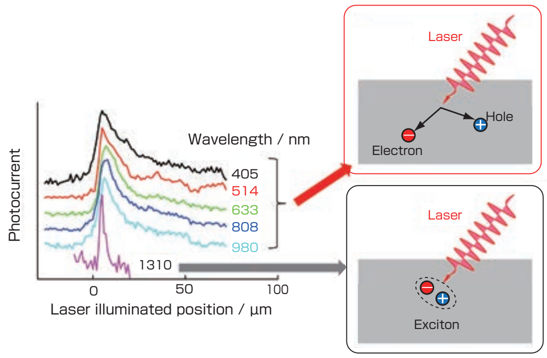
We have substantiated an organic photovoltaic cell (OPC) based on a novel concept where optical absorption due to the charge-transfer between different organic molecules is utilized. Research and development of OPC technologies have currently been conducted worldwide because the technologies are expected to realize light-weight, flexible photovoltaic sheets. In this study, we designed and fabricated a prototypical OPC using a molecular compound composed of two different kinds of organic molecules. It was found that the device presents a photovoltaic effect due to the irradiation of near-infrared light whose wavelength is longer than 1 μm, although such a photoelectric conversion of near-infrared light has been very difficult in conventional OPCs. Furthermore, the lifetime and the diffusion length of excitons or charge carriers in the device were found to be three orders of magnitude longer than those of the conventional OPCs. Based on the concept, we can expect to realize the more efficient conversion from light energy to electric energy.

Tatsuo HASEGAWA
t-hasegawa@aist.go.jp

Jun'ya TSUTSUMI
junya.tsutsumi@aist.go.jp

Flexible Electronics Research Center

AIST TODAY Vol.11 No.5 p.12 (2011)



Decay profiles of high-resolution laser-beam-induced current at different excitation wavelengths

Organic materials that liquefy upon irradiation by light

Novel reusable photoresponsive materials

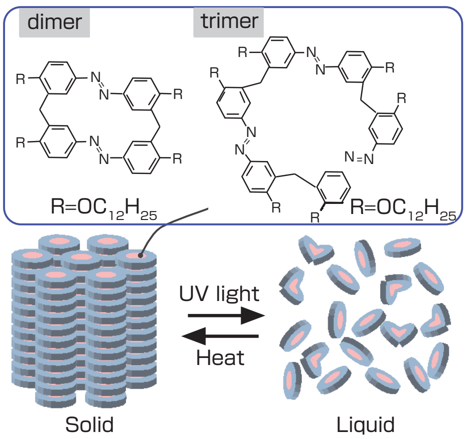
We have developed novel solid organic materials that liquefy upon photo-irradiation. The new materials have a reversible property – they resolidify upon heating – in contrast to conventional light-sensitive polymers. This reversible switching property is induced by photoisomerization of azobenzene. Generally, isomerization of azobenzene and its derivatives readily occurs in solutions, but rarely takes place in their solid state. However, newly synthesized macrocyclic azobenzenes with flexible alkoxy chains exhibit crystal-to-isotropic phase transitions upon irradiation by light. As far as we know, this is the first report of a solid-to-liquid phase transition achieved by photoisomerization rather than heating. Our materials have potential applications to photoresists, photoresponsive adhesives, and other photoresponsive materials.

Yasuo NORIKANE

Electronics and Photonics Research Institute

y-norikane@aist.go.jp

AIST TODAY Vol.11 No.6 p.20 (2011)



Chemical structures of the two newly developed organic compounds (top) and schematic diagram of the phase transitions of the compounds (bottom).

Development of a new oxide material for the negative electrode of lithium-ion batteries

High capacity hydrogen titanium oxide prepared by soft chemical synthesis

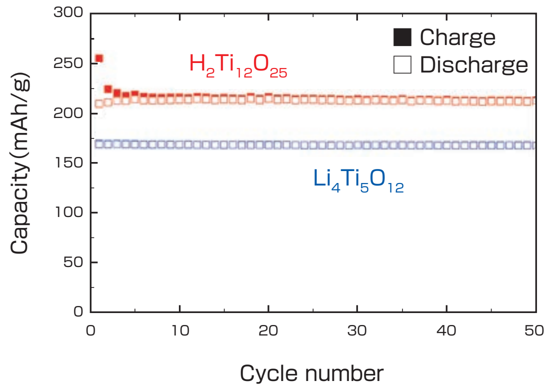
We have developed a new high-capacity hydrogen titanium oxide material ($H_2Ti_{12}O_{25}$) for the negative electrodes of lithium ion secondary batteries in collaboration with Ishihara Sangyo Kaisha, Ltd. (ISK). The developed material exhibits the same voltage (approximately 1.55 V vs. Li/Li^+) as and a higher charge-discharge capacity per mass of oxide (225 mAh/g against 175 mAh/g) than lithium titanate ($Li_4Ti_5O_{12}$) presently used in negative electrodes. In addition, because the hydrogen atoms in the material form a skeletal structure due to hydrogen bonding, the structure of the material is stable, and is not affected by the lithium insertion and extraction reactions during charging and discharging. The new material displayed an excellent charge-discharge cyclic performance equivalent to that of the conventional lithium titanate, while it maintained a high capacity of over 200 mAh/g even after 50 cycles. Accordingly, the developed $H_2Ti_{12}O_{25}$ is expected to be one of the high-voltage oxide negative electrodes in advanced lithium-ion batteries.

Junji AKIMOTO

Advanced Manufacturing Research Institute

j.akimoto@aist.go.jp

AIST TODAY Vol.11 No.4 p.12 (2011)



Charge-discharge cycle characteristics of new titanium oxide ($H_2Ti_{12}O_{25}$) and the conventional lithium titanate ($Li_4Ti_5O_{12}$: LT-017, manufactured by ISK) (counter electrode: metallic lithium; current density: 50 mA/g)

Fabrication method for submicrometer spherical particles

Utilizing instantaneous high temperature generated by laser irradiation

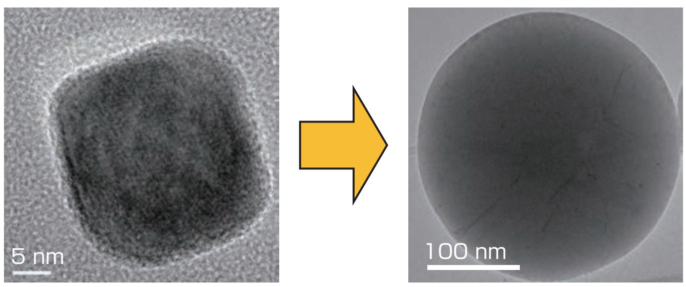
The fabrication of spherical particles has been of great their interest due to their interesting functionalities. Colloidal spheres of dielectric amorphous materials such as polystyrene and SiO_2 are commercially available. Solution-based self-assembly is also an important approach for the fabrication of spherical particles, although most of the particles are structurally unstable spheres composed of nanoparticle aggregates. Our group previously developed a method for reactive fabrication of B_4C submicrometer spheres by pulsed laser irradiation of boron nanoparticles in organic solvent using a focused laser beam with relatively low fluence. Inspired by this work, we have further developed a novel and versatile fabrication method for submicrometer spherical particles utilizing instantaneous high temperature generated by laser irradiation. Submicrometer spherical particles are obtained by unfocused pulsed laser irradiation onto raw CuO nanoparticles (Fig.).

Naoto KOSHIZAKI

Nanosystem Research Institute

koshizaki.naoto@aist.go.jp

AIST TODAY Vol.11 No.4 p.13 (2011)



Morphological change induced by laser irradiation (copper oxide)

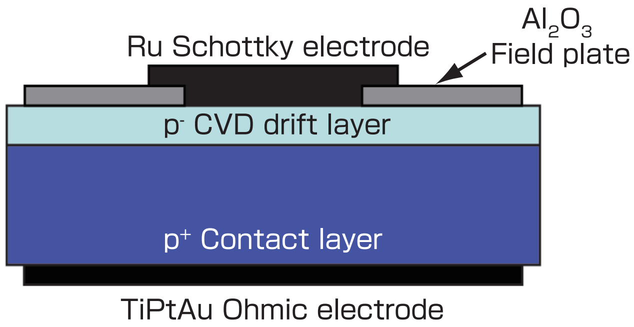
Diamond high voltage Schottky barrier diode (SBD) for next generation power electronics

High speed switching of diamond SBD achieved at 200 °C

We have developed a fast switching, high temperature, high voltage diamond Schottky barrier diode (SBD) for next generation power electronics. Based on the excellent material properties of diamond, a high performance SBD was fabricated on epitaxially grown drift layer with a ruthenium Schottky electrode.

The fabricated diamond SBD shows excellent thermal stability at 400 °C and high blocking voltages (1.8 kV). Switching characteristics of the diamond SBD have been measured at elevated temperature (up to 200 °C) by the double-pulse measurement. Thanks to the unipolar operation and low dielectric constant, the turn-off time is shorter than 20 ns and is constant to the temperature and forward current density. Turn-off time of the diamond SBD is much shorter than the conventional silicon PiN diodes and comparable to silicon carbide SBDs.

Hitoshi UMEZAWA
Diamond Research Laboratory
hitoshi.umezawa@aist.go.jp
AIST TODAY Vol.11 No.4 p.14 (2011)



Cross sectional view of diamond SBD

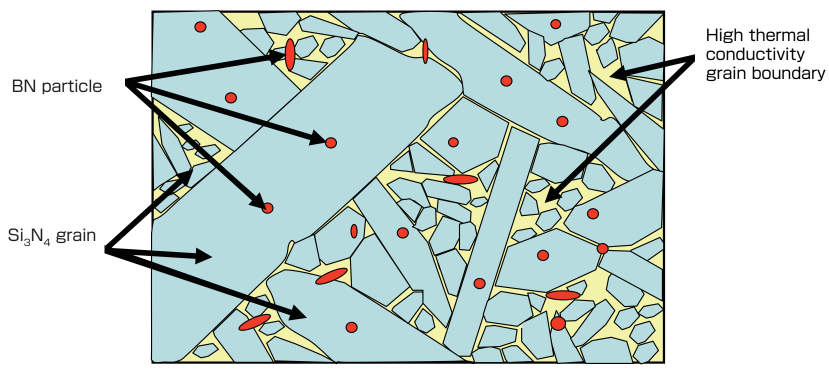
Nanotechnology, Materials and Manufacturing

Development of a silicon nitride ceramic material which maintains strength even under large thermal changes

Dispersion of boron nitride fine particles results in dramatic improvement in resistance to thermal shocks

We have developed a silicon nitride ceramic material which displays significantly higher resistance to thermal shocks and strength at high temperatures than conventional silicon nitride ceramics. Using silicon nitride (Si_3N_4) as a base, the material was developed by forming a grain boundary phase with high thermal conductivity and dispersing almost amorphous nanometer-order particles of boron nitride (BN) in the grain boundary phase. While the strength of conventional silicon nitride ceramics declines at a temperature difference of 1,000 °C, there was almost no deterioration in the strength of the developed material even when heated to 1,400 °C in an electric furnace and dropped into water ten times. In addition, the material displayed the same level of strength in high-temperature bending tests conducted in air at 1,200 °C as at room temperature.

Hideki HYUGA
Advanced Manufacturing Research Institute
h-hyuga@aist.go.jp
AIST TODAY Vol.11 No.5 p.13 (2011)



Microstructure image of the developed material

An ultrasonic flowmeter for accurate measurement of micro-flow rates

Improving-the performance of semiconductor manufacturing equipment and reducing running costs

AIST has developed an ultrasonic flowmeter that can accurately measure micro-flow rates of less than 10 mL/min (error: ±0.1 mL/min) in collaboration with Atsuden and Tokyo Keiso.

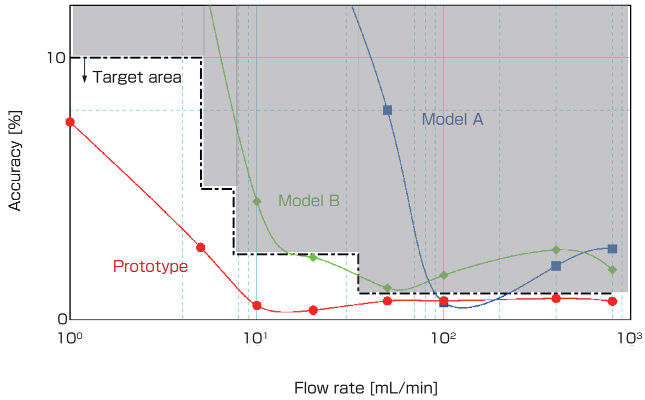
In developing the flowmeter, we examined the fundamental theory of ultrasonic wave (guided wave) propagation, increased the frequency of ultrasonic waves, and optimized the design of the ultrasonic flowmeter. This ultrasonic flowmeter can measure flow rates in the micro-flow rate range that has not been possible with conventional ultrasonic flowmeters. It allows highly accurate control of the liquid chemicals used in semiconductor manufacturing equipment and is expected to contribute to the increased performance, reduced environmental load, and reduced running costs of semiconductor manufacturing equipment.

Harumichi SATO

Advanced Manufacturing Research Institute

h.sato@aist.go.jp

AIST TODAY Vol.11 No.6 p.21 (2011)



Accuracy of flow rate measurement

Development of AC Josephson voltage standards

Approaches for realization of the next-generation quantum AC voltage standards

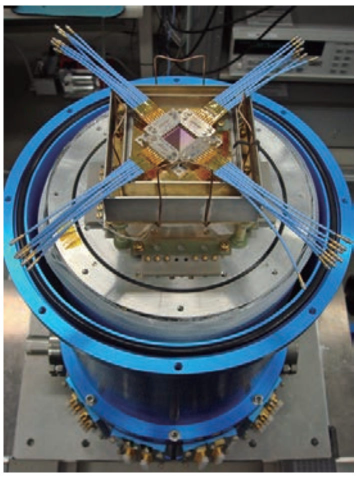
We are developing the next-generation AC voltage standard systems based on the Josephson effect. These systems will enable direct calibration for AC voltage with quantum accuracy, drastically improving the measurement uncertainty in our conventional systems. They are also expected to open new metrological and physical fields such as waveform standard, Johnson noise thermometry, etc. Up to now, many types of methods have been proposed for realizing quantum AC voltage standards. It is important to carefully understand both advantages and disadvantages of each method and put the right method in the right application. This article focuses on some of them and reviews basic mechanisms and characteristics of the methods. The present status and the prospects of our researches in AIST are also reported.

Michitaka MARUYAMA

Metrology Institute of Japan

m-maruyama@aist.go.jp

AIST TODAY Vol.11 No.4 p.15 (2011)



New 4-K cryocooler system with wideband cryo-probes (under development)

Aiming at an ultimate clock
Development of a Sr/Yb optical lattice clock

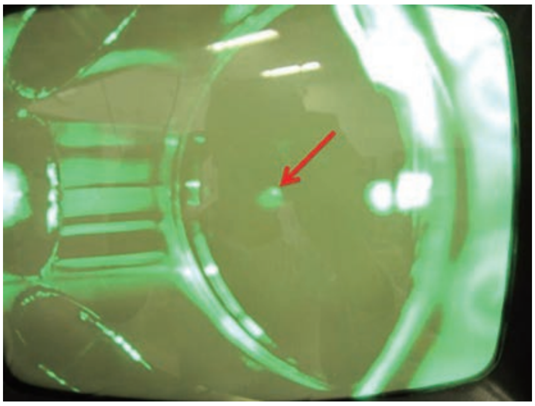
An optical lattice clock is one of the promising candidates for the next generation "SI" second. We developed an Yb optical lattice clock in 2009. The uncertainty of our Yb lattice clock will soon be limited by our cesium fountain clock. In 2009, we therefore started a new project on Sr/Yb dual optical lattice clock project. In this project we aimed to realize an optical lattice clock of Sr and Yb using the same vacuum chamber and to measure the clock transition frequency ratio with unprecedented precision. We believe that this project will strongly support the redefinition of the second using an optical lattice clock scheme.

Daisuke AKAMATSU

Metrology Institute of Japan

d-akamatsu@aist.go.jp

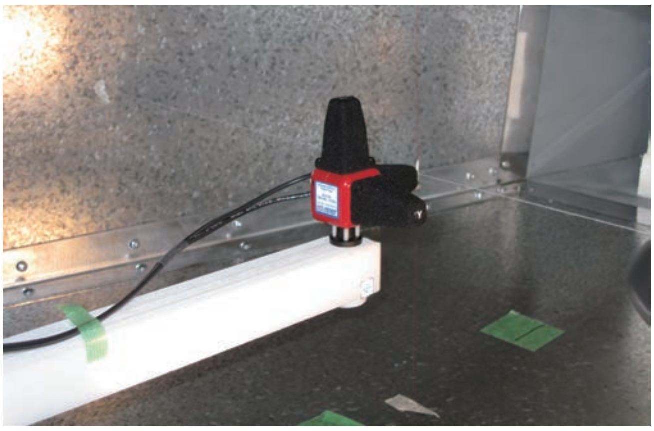
AIST TODAY Vol.11 No.5 p.14 (2011)



Magneto-optically trapped Sr atoms

A compact system generating high-precision electric field
Electric field standards using a waveguide

We are doing research on standard electric field (*E*-field) generation using waveguides. An electrical device should not be influenced by unexpected electromagnetic fields. Ordinary electromagnetic interference tests require uniform *E*-field illumination to the device under test. The *E*-field strength applied to the device should be sufficiently reliable for safety and a field probe employed for the measurements should be properly calibrated against the standard *E*-field strength. Although the standard field generation in an anechoic chamber has an advantage in the frequency band, that in a transverse electromagnetic (TEM) waveguide is still more useful in terms of compactness. In addition to this, generating a strong field in the TEM waveguide requires an amplifier with significant lower gain compared with that in an anechoic chamber.



Standard electric field generation using a waveguide

Takehiro MORIOKA

Metrology Institute of Japan

t-morioka@aist.go.jp

AIST TODAY Vol.11 No.6 p.22 (2011)

MOU concluded with BPPT of Indonesia

From February 24 to 25, 2011, AIST President Tamotsu Nomakuchi visited Jakarta, Indonesia, and with Chairman Marzan Aziz Iskandar of the Agency for the Assessment and Application of Technology (BPPT), he signed a comprehensive memorandum of understanding (MOU) with BPPT. He also gave a lecture at a seminar cosponsored by Japan External Trade Organization and the Economics Research Institute for ASEAN and East Asia where Japanese company affiliates gathered.

BPPT is the largest public research institution in Indonesia under the Indonesian Ministry of Research and Technology Organizational structure and research fields of BPPT are very similar to those of AIST. Having concluded the MOU, the possible collaborative research fields extend over plant biotechnology, nano-bio-technology and medical technology in the fields of life sciences, and production, reformation and standardization of biomass fuels, in addition to environment assessment, life cycle assessment and gasification in the fields of environment and energy, and survey of marine active faults in the field of earth sciences.

In addition, under the MOU with BPPT, an agreement was reached on launching a tripartite collaborative research related to natural rubber with Bridgestone Corporation of Japan. Indonesia is the world's leading producer of natural rubber. Through the collaborative research with the world's leading rubber and tire manufacturing company, Indonesia will engage in the productivity improvement of natural rubber based on biotechnology such as genetic information. It is expected to contribute to the natural rubber industry in Indonesia.

President Nomakuchi introduced a summary of AIST's history and its research fields at the seminar, and spoke on the future of enterprises expressed as "The enterprise is Being-in-the-World", transition of business competition from labor-intensive to knowledge-intensive, and the meaning of the existence of Japanese enterprises abroad supporting the Asian economy. He also spoke of the various collaborations such as raising the level of Asian researchers through human resource development, and collaboration for standardization.

By the conclusion of MOU, we are expecting that it will lead to the building of the foundation for economic growth of the two countries through the strengthened collaboration of public research institutions in science and technology.

BPPT Chairman Marzan (right) and President Nomakuchi after signing MOU

President Nomakuchi speaking at the seminar

Cover Photos

Above: A folded crane made with an eDIPS-SWCNT sheet (p. 10)

Below: Transmission electron microscope image of one-dimensional coronene crystal formed inside SWCNT (left), its schematic (center), and a fluorescent picture of the aqueous solution (right) (p. 12)

AIST TODAY International Edition
2011-3 No.41
Published in September, 2011

AIST NATIONAL INSTITUTE OF ADVANCED INDUSTRIAL SCIENCE AND TECHNOLOGY (AIST)

Website and Publication Office, Public Relations Department
National Institute of Advanced Industrial Science and Technology (AIST)

AIST Tsukuba Central 2, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan
TEL: +81-29-862-6217 FAX: +81-29-862-6212 Email: prpub@m.aist.go.jp URL: http://www.aist.go.jp/index_en.html

AIST11-E00003-1