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Innovation – Our Theory of Action

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Nanotechnology at AIST

Research Hot Line

UPDATE FROM THE CUTTING EDGE (Oct.-Dec. 2006)

In Brief

Innovation – Our Theory of Action

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From Analysis to Action – A Statement from the Front Lines of Research

Everywhere you go these days, people are talking about innovation. This phenomenon seems to have arisen quite suddenly. Of course, the term innovation has been familiar to economists and other specialists ever since the advent of Schumpeter, but suddenly the word is on everyone's lips. How does one explain it?

In fact, there is a definite reason: the concept of innovation has become a major point at which the consciousness of the average individual converges with the awareness underlying policy-making decisions within government agencies and other organizations. While this convergence may seem at first glance a curious coincidence, it is an inevitability.

Today we can see the same phenomenon occurring in countries all over the world. Increasingly people feel called on to apply creative ingenuity even in their everyday behavior, so that whether in their work or in their personal lives, they feel constantly beleaguered, unable to enjoy a leisurely, stable existence. At the national level, the state is being called on to use novel, unprecedented ideas to solve ongoing political, economic, and social problems. At both levels, there is a need for "positive change." And what is this change if not the innovation of which Schumpeter spoke?

But why has this process of change, as it applies to every entity from the individual up to the state, assumed the character of something thrust on us almost coercively from the outside, rather than something arising naturally and matched to our pace? What has given rise to this sense of "unavoidable innovation" that characterizes the present? This, too, has a clear and unequivocal cause. The reason is that external circumstances which we once assumed would naturally resolve themselves optimally without our interference, or which we believed ourselves powerless to control, are becoming so threatening that we must control them or risk destruction. The global environment, a blessing so long taken for granted, has become something that we must work to maintain through a wide range of innovative measures. International relations, where it seemed we had broken out of an impasse and were headed for peace, now demand vigorous efforts at reconciliation. Our society and economy, whose future we once optimistically consigned to the ambitions of our young people, now demand policy measures to eliminate structural rigidities. The problems underlying these challenges have grown steadily worse, to the point where they are apparent to everyone, from our national leaders to the average person on the street. We have lost the regulating mechanism whereby serious efforts to address each individual problem as it arose could bring favorable change to the environment, international relations, society, or the economy as a whole. Whereas once we regarded change as the outcome of action, we now see action as necessary to effect change.

That said, to attempt to resolve all these problems at one stroke using a specific theory or methodology would be to relive the nightmare of socialist revolution. The only way to resolve the crises we face is for each individual, within every social class, professional field, and community, to work creatively –and in some cases destructively– to improve the situation in which he or she finds himself or herself. It is not as if we know exactly what needs to be done– on the contrary, it often seems that we have not even the slightest idea. Nonetheless, the majority of people today, strongly aware of the problems we face, share a realization that positive change is necessary, and it is this realization that underlies the constant talk of innovation.

We have no time, under these circumstances, to listen to definitions and analyses of innovation as a social phenomenon.

Each of us must decide what should be done from his or her own standpoint. What we need, therefore, is an approach to innovation as action. What we want to know is what kind of action –political, legislative, policy-making, administrative, entrepreneurial, managerial, educational, scientific, journalistic, artistic– considered in the context of class, field of endeavor, and community, will contribute to positive change. Unfortunately, it is difficult to find ready-made theories that can provide a foundation for our action. Studies of innovation generally center either on analysis of the phenomenon or case studies, and are of no immediate use in our goal of action to effect change.

Under these circumstances, we have no choice but to develop our own action plans. This involves determining what actions on one's own part will contribute to positive change overall and devising a method for taking such action. If possible, moreover, the method devised should be expressed objectively, in such a way that a third party can see and understand. Then our individual action plans can be generalized, take their place within our society –which is to say, become part of our common intellectual property– and boost the vitality of society as a whole. For this, we need discussions of innovation grounded in the real world and originating in the actual context in which innovation takes place. With these ideas in mind, I would like to focus my discussion on innovation at the National Institute of Advanced Industrial Science and Technology, AIST, where I serve as president, but what I say will have application to the wider sci-tech community.

Innovation at AIST

At this point I would like to shift the focus from generalities to the actual research being carried out at AIST. This is a true story of innovation coming straight from the lab, from the front lines where research is conducted. AIST Japan's largest independent administrative research institution, was established in April 2001 through the merger of fifteen research institutes previously within Agency of Industrial Science and Technology. The oldest of these institutions, the Geological Survey of Japan (est. 1882) and the Electrotechnical Laboratory (est. 1891) had very long traditions, growing up along with modern Japan itself. These older institutes covered a wide range of research fields, spanning almost the entire spectrum of science and engineering, including lifescience, and were therefore conducting research focused on technologies relating not only to manufacturing industries but to many service industries as well. AIST began by dissolving all these separate institutes and reorganizing close to 3,000 researchers into 60 new research units irrespective of their original affiliations. These researchers found niches for themselves transcending the boundaries of the old research institutes. Unlike conventional research institutes, which are organized by discipline, AIST's research units were organized around goals relating to the development of industrial technology. Although the individual goals were diverse, ranging from specific technologies to visions for industrial reform, each unit was goal-oriented, focused on making a practical contribution to industry, rather than on a traditional discipline, such as mechanics, electricity, or biology.

The full story of innovation at AIST will be told when the unique benefits AIST research has conferred on industry become apparent. At that time we will also be able to evaluate the organizational reform discussed above. Right now, we are scientists pursuing research in the midst of a reconstituted organization and are in no position to identify and evaluate its effectiveness. Here I hope instead to demonstrate that the new brand of research being conducted within the new organization launched in 2001 deserves to be called innovation, and further that it is playing an important role in spreading the kind of innovation that has become the focus of such keen interest in today's society.

At AIST research takes the form of “Full Research” pursued by fundamentally autonomous research units. Full Research integrates Type I Basic Research (corresponding to basic research in the usual sense of the term), Type II Basic Research, and Product Realization Research, carrying them out simultaneously or successively. The composition and structure of AIST's research units, which consist of anywhere from around 10 to about 200 researchers, vary according to the research goal, but

every unit is involved in Full Research. As a rule, therefore, each unit includes three types of researchers to carry out Type I, Type II, and Product Realization Research.

Researchers involved in Type I Research are what people today generally call basic researchers, and even though they are working within the context of Full Research, no particular restrictions are placed on what they do. As with basic research in the narrow sense of the word, the researcher, motivated by curiosity regarding unknown or unexplained phenomena, attempts to establish the place of such phenomena within the explainable world. This includes not only natural but also social and human phenomena. The current state of science as a systematic body of knowledge is said to be the product of research driven by this sort of inquiry.

This body of knowledge is made up of numerous fields or domains organized according to a hierarchy. Domains are linked to one another vertically in this hierarchy, through logical inclusive relationships. However, one rarely sees any attempt to establish the horizontal relationship between domains that exists at the same level. For example, the word entropy is used in both thermodynamics and information theory, but the real phenomena to which the word refers in each case are completely unrelated, even though the underlying idea may be similar. To borrow a concept from paradigm theory, we might call the fields mutually incommensurable.[1] Due to relaxed conditions that do not demand mutual commensurability between fields, science today is characterized by the creation of multiple knowledge domains, within which new knowledge continued to be generated in abundance.

Type II Basic Research is a unique type of research that springs inevitably from the fact that the systematic bodies of knowledge generated by Type I Basic Research are mutually incommensurable at the same level. The approach which I have just mentioned as characteristic of contemporary science –the generation of domain-specific knowledge after the creation of incommensurable domains– is a convenient way of building knowledge efficiently. However, because it does not require that the knowledge-building process be explicit, this method offers no systematic means of recovering the commensurability between different domains.

The purpose of AIST is to generate new scientific knowledge, combine it with the raw materials of existing knowledge to build usable expertise and offer it to society. We know from experience that we cannot build functional knowledge with real-world social value if we confine our work to a single, discrete, calculable field. That is why it is necessary to integrate knowledge from multiple domains. And in attempting to do so, we come up against the incommensurability between these domains.

For example, the idea of using semiconductors as components was quite revolutionary. However, the idea by itself had no practical value to society. Even after researchers had proceeded from the idea to successful laboratory experiments, it offered no social value. It was only after selecting specific materials and designing and manufacturing them for actual use –in short, making practical application possible by integrating knowledge from various domains– that we were able to create the basis for the massive industrial shift from the era of the vacuum tube to the age of the semiconductor, and bring about the social change known as the information revolution. That was truly a great innovation.

But technological progress did not stop at that point. After that came the quest for practical value in the form of ever-higher data density. Where data density is concerned, even when it became possible for scientists in a single field to make calculations envisioning the miniaturization of geometrical structures down to the quantum limit, when it came to turning the concept into a practical device, nothing more could be accomplished without expertise from another field–namely, solid state transformation, the key to microprocessing. Furthermore, though solid state transformation theory and solid state quantum mechanics both applied to semiconductors, a practical and effective processing method to improve semiconductor performance did not emerge from the formal unification of the two theories. Progress required empirical work and experimentation predicated on both theories, together with the inspiration of researchers in the laboratory. This, too, demanded the integration of knowledge domains. Nonetheless, we should not call this sort of progress innovation, lest the definition becomes too vague. In other words, as I would define innovation, the act of overcoming the incommensurability of different domains and integrating them is only a necessary condition for innovation, not innovation *per se*. The significance of this restriction will become clear later. Innovation should not be defined by the process but determined on the basis of the results.

Inasmuch as AIST focuses on the kind of Type II Basic Research that integrates expertise from different domains, it seems reasonable to conclude that it holds abundant possibilities for innovation. What, then, is a sufficient conditions for innovation?

The Goals of Innovation

As discussed earlier, our current age seeks change, but change alone will not answer its needs; it must be positive change. In order to hold to an action-oriented approach to innovation even here, we should begin by suggesting the sort of positive changes AIST should pursue. The starting point for our ideas on this subject was the critical problems in our external environment mentioned above.

From this we arrived at an imposing list of goals, including sustainable development, security for all humanity, maintenance of cultural diversity in the midst of economic integration, ensuring law and order in the midst of free movement of people across national borders, and cooperative relations between the advanced industrial world and the developing countries. We seek the sort of change that will contribute to achievement of these goals and reject any change that goes counter to them. As these issues have not in the past been regarded as problems to be addressed directly, each presents difficult and unknown challenges.

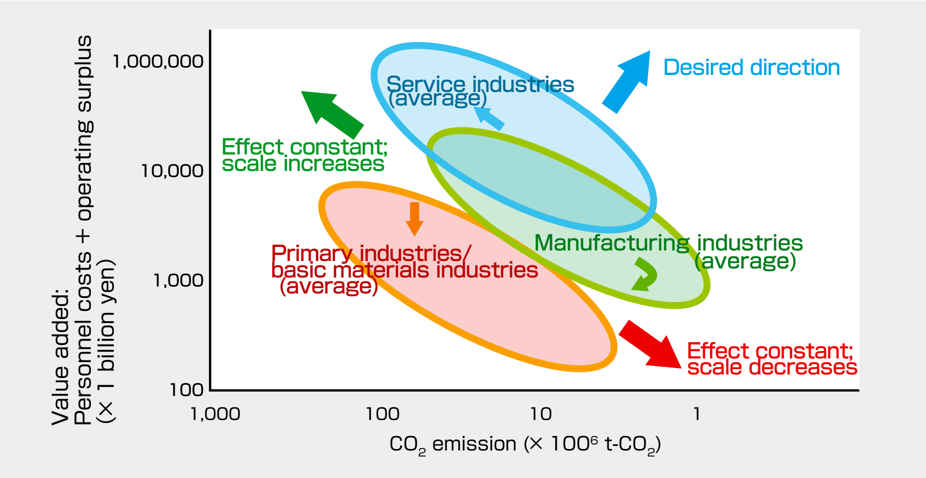


Figure: Relationship between sustainability (inverse of CO_2 emission volume) and developmental benefit (value added: personnel costs + operating surplus)

We have agreed that AIST's purpose is to provide usable technological expertise to industry as a whole, focusing on manufacturing but embracing primary and service industries as well. Accordingly, of the external challenges listed above, sustainable development is one to which AIST can and should make a direct contribution. Sustainable development is development that does not degrade the environment that is the birthright of future generations, and it requires the creation of sustainable industries. However, it is not independent of other issues. A necessary condition for achieving human security is the elimination of poverty, and for that the development of industry is essential. Likewise, for a country to preserve the uniqueness of its own culture even while allowing itself to become integrated into the global economy, it needs innovative ideas to give its own industries a unique profile.

We reached an agreement that all research at AIST should be oriented to the goal of "facilitating a shift in the center of gravity of industry as a whole in the direction of improving sustainability by contributing to the specific industries that are the object of research activities at AIST." For this goal to have practical meaning, we need a quantitative index to help us measure how far current reality is from the goal of sustainability. At this point a somewhat detailed explanation is in order.

What is the center of gravity for industry as a whole? Since our goal is sustainability, we need an index that can express sustainability in quantitative terms. Once we have calculated the sustainability of individual industries, we can calculate the weighted average of all the industries to derive the sustainability of industry as a whole. What is the center of gravity? Sustainable development should be regarded as the comprehensive result of a large number of contributing factors. But since what we seek now is development that can be continued without compromising sustainability, a basic expression of sustainable development should combine sustainability and developmental benefit. If both of these could be expressed quantitatively, then we could make them the axes of a two-dimensional graph and express the sustainability of industry as a point on that graph. That is the center of gravity for industry as a whole, and a shift in the center of gravity toward sustainable development would be expressed by a positive shift along both the sustainability axis and the developmental benefit axis. AIST's goal, then, is for all our research to contribute toward a shift in the center of gravity in this positive direction.

Such a quantitative index is currently under study at AIST,[2] but to illustrate the concept with a simple example, the accompanying figure uses the inverse of CO_2 emission volume to measure sustainability, and value-added as a measure of developmental benefit. The ellipses in the figure show the distribution range for sustainable development in each industrial sector. In each sector, CO_2 emission increases as value-added increases, and this relationship is apparent in the upper-right to lower-left diagonal orientation. This means that at present to boost developmental benefit it is necessary to sacrifice sustainability, and conversely, to improve sustainability we must give up on development–indicating that we are far from the ideal of sustainable industry. For industry to be sustainable, the trend must be in the direction of the arrow at the upper right. We see that by this index service industries are first in terms of sustainability, followed by manufacturing, with primary industries last. But this does not mean that we should simply expand the share of service industries. Other factors determine such shifts. The important point to note is that the small arrows, which indicate the trend for each sector over the decade between 1990 and 2000, are all pointing in a direction unfavorable to sustainable development. This analysis has made us aware that shifting the center of gravity in industrial activities through our basic research is an urgent issue.

So we have set the goal of contributing to a shift in the center of gravity for industry as a whole in the direction of sustainable development, and this will tie in with the individual goal which research unit sets for itself. It is not sufficient for each research unit to aim at changing industry in some way. It is not enough that the results help industry boost profits. The outcome of each "Full Research" project must be research results whose utilization induces the relevant industries to shift their center of gravity toward greater sustainability. This is the goal of Full Research, which is conceived with such an outcome in mind.

In our view, shifting the center of gravity of industry as a whole toward sustainability qualifies as innovation. It means bringing a fundamental positive change to industry –which has "progressed" in the opposite direction ever since the Industrial Revolution– and also to broad sectors of society. This is innovation worthy of the name.

As indicated above, I believe the sufficient condition for defining innovation in the true sense of the word is that it brings this type of fundamental change to broad sectors of society. This is no doubt the original sense in which the word was used, and if we do not adhere to such a definition, we end up calling every minor improvement or contrivance that comes along "innovation," and the word becomes largely meaningless. Of course, we must not forget that small improvements or contrivances are often necessary components of major innovations. These we may call "innovative elements."

Promoting Innovation

On the basis of the foregoing definition, let us now attempt to determine what we need to do in order to innovate. It is true, of course, that in the absence of a clear definition of innovation, the discussion up until now has lacked precision, but this is typical of communications from the field, and it is a useful characteristic. Those who insist on precision can take the foregoing discussion as a whole as a definition.

As I suggested above, Full Research is a necessary condition for innovation at AIST. To begin with, this is the form scientific research must take if it is to remain connected with society, and without this, although we may achieve elements of innovation, there is no possibility of fulfilling a sufficient condition for true innovation. Under the rubric of Full Research, Type II Basic Research is a particularly important key to innovation. Because it requires that one simultaneously make use of knowledge from multiple domains, it comes up against incommensurability and making it impossible to pursue systematic research activities. When that happens, one has no choice but to "muddle through" following fuzzy procedures that can neither be explained nor taught to others, involving hunches, experience, inspiration, brainstorms, and errors leading to chance discoveries. A change of pace or setting and contact with people in other fields are said to facilitate this process. This is probably because, by temporarily leaving the confines of the expertise and modes of thinking specific to one's own field, one opens one's thinking to the possibility of new directions.

This phenomenon has been pointed out frequently in analytical writings regarding the creative process in general, not just innovation. Richard Lester, who has published a fascinating book on the subject, explains the phenomenon using examples that anyone can understand.[3] Lester says that innovation is triggered by the process of interpretation. Interpretation is necessary when people who use different linguistic systems –in other words, people in different professions– get together. The free discussion that goes on between such people gives rise to new ideas. For example, the idea for designer jeans was born from the integration of knowledge possessed by people who rarely had a chance to meet with one another under ordinary conditions, including a textile engineer, the manager of a second-hand clothing store, a fashion designer, and a commercial laundry service provider for hospitals and hotels. Such integration becomes possible when people who use different languages make themselves understood to one another–in other words, it is made possible by interpretation. The result, as Roland Barthes might put it, essentially and broadly altered the social monopoly of fashion.[4] This is innovation.

However, for those of us working in a research institute, just to understand this process is not sufficient. Even if we were to succeed at Type II Basic Research and create something of social value by overcoming the challenge of incommensurability through collaboration among people who speak different "languages" – that is, researchers from different disciplines– or through the efforts of a single researcher involved in multiple disciplines, we would still have the responsibility of elucidating how such success can be achieved by explaining logically how collaborated during that process, how collaboration was possible, and the process of integration between different fields that was involved.

As I have thus far used the word integration with regard to such successes without providing any explanation, let us consider a few examples. The first is an early experience of mine that predates AIST. I was affiliated with the Department of Precision Engineering in the Faculty of Engineering at the University of Tokyo back in 1964, when a departmental reorganization was carried out (the department became the Department of Precision Mechanical Engineering). At that time the department developed the slogan “kiden-ittai”(mechanical and electrical as one) and adopted it as its guiding principle. The idea emerged out of concern that people were beginning to question the *raison d'être* of our department, wedged between the huge Mechanical Engineering and Electrical Engineering departments within the Faculty of Engineering. So, we made an effort to integrate mechanical and electrical engineering both in teaching and in research. We were not able to create a formal academic discipline, but we did pioneer a new field in the sense that we produced engineers who understood both fields. Now, however, we have something called mechatronics. This was originally a Japanese concept, for which Tetsuro Mori, a senior engineer of Yasukawa Electric Corporation, coined a pseudo-English term in 1969, although it has since become a common noun understood the world over (and as a name it is vastly superior to kiden-ittai). But mechatronics was more than just a word. Soon, more and more equipment was being built from designs in which mechanics and electronics were inextricably linked, until such equipment became the norm. A distinct field of technology had taken shape. I can recall even now how hard the faculty in the Department of Precision Mechanical Engineering worked to abide by the department's taboo against identifying oneself as a “mechanical man” or an “electrical man” (terms engineering experts used to stress the different mentality of engineers in different fields). And since one never associated with people from other departments back in those days, all we could do was diligently read papers on mechanical and electrical engineering.

This case reveals a number of important features of the integration process. First, people define themselves as researchers unconfined by traditional specializations (and this in itself is a momentous step, as it exposes them to the danger of ostracism by the academic community to which they belong). Next, they read published research in multiple fields and form a “provisional field” in their own minds. However, this provisional field is less consistent than established fields. In this case it embraced a mixture of concepts from mechanical engineering, such as involute, sectional secondary moment, and enthalpy, and concepts from electrical engineering, such as impedance, curl, and keep-out zone, which could not be applied to both fields or related to one another. Even if you abstract them and arrive at a common mathematical expression, applying them to the real world is a different matter, and they are useless when it comes to building something practical. So, you repeatedly apply your abstract model to the real-world configuration, and discover the ways in which your inconsistent knowledge corresponds to the real world, which is by nature consistent, and in the process you work out your overall product design. This sort of improvisation is an acrobatic feat demanding great skill and experience. But through this process one grasps the correspondence between the knowledge system and reality as it applies to that particular problem, even though one may not initially be able to explain it. At that point one gains recognition as an engineer who has mastered a provisional field, in this case mechatronics. (In engineering, one of the conditions for defining a field is that the correspondence between a group of concepts and the reality to which they are applied has been clearly demonstrated.) In this way, mechatronics was able to improve the functional possibilities of mechanical products, expand the market for such products, and effect a major change in the way machines are utilized in our society. Thus we can say with justification that mechatronics was an innovation, and further, we can identify in it a distinctive knowledge-building process, as described above.

What about the aforementioned case of designer jeans? One episode in this drama occurred when a fashion designer toured a commercial laundry facility, happened to come across a process in which stones were used to scrub material, and realized that this method could be used to create a new fashion. Here, the “interpretation” of a process for removing dirt as a process for achieving a new kind of design gave rise to new possibilities in the realm of fashion. In this case, since neither fashion nor laundry was a systematized knowledge domain, integration could take place more easily, through free and intuitive interpretation. Nonetheless, here, too, it was necessary to go back and forth in a dialogue between methodology and the practical reality. In this we can see how the example of fashion jeans and that of mechatronics shared a similar knowledge-building process.

At AIST, we have recently launched a multidisciplinary project called GEO Grid, involving collaboration between geologists and people in the field of grid research. Existing GIS data and other information compiled largely by geoinformation researchers, as well as geological information gathered by traditional means, have accumulated in various parts of the world in forms specific to each region, but this project will make it possible to integrate such information with real-time satellite geodata, access the information one needs from a grid system, and make use of it for a wide range of applications in such diverse fields as resource exploration, agriculture, the environment, and disaster prevention. In this project, we are integrating advanced data processing technology and grid technology so that information that was mutually incoherent, not only between fields but from region to region, can be utilized in a unified, integrated manner. This is an innovation that will revolutionize the utilization of geoinformation–in this case, using a system that will be developed by increasing the level of abstraction of the information and creating a common data set based on grid technology. In other words, we overcome incommensurability by temporarily concealing the content of the requisite knowledge and creating an abstract realm.

Another fascinating example is the process by which research into material properties leads to new devices and other practical technology. At the early stages of research, a new material is only a laboratory substance, not something that would stand up to practical use. It only becomes a practical technology when it is supported by performance stability, a usable form, the processing technology for manufacturing it, and so forth. All this requires a vast amount of expertise, regarding not only the physical properties related to the material's intended function but also mechanical and transformation properties, corrosion resistance, interaction with other substances, etc. In these cases one generally strives to ensure the independence of each property in design and finds a solution by reducing the potential issues to that of boundary constraints.

Thus we have seen a variety of methods that are used to resolve incommensurability in situations where one must simultaneously incorporate knowledge from different fields, whose relationship is unknown: creating a provisional field and gradually defining the correspondence between it and the real world; establishing a relationship between unlike things through interpretation; increasing the level of abstraction to create a relationship; and striving for independence to reduce potential conflicts to a boundary problem. We can see that these methods are based on the integration of domains that is a necessary condition for innovation.

Now, Type II Research embodies this aspect of innovation inasmuch as it deals with the integration of different domains. But we need to recognize that while the integration process has fundamental similarities regardless of the context, in practice it is carried out in a variety of ways. Accordingly, while we anticipate eventually assigning a single standard method to Type II Basic Research, for now we have no choice but to continue to seek innovation on an *ad hoc* basis for any given topic, out of a variety of possible approaches. For AIST, the goal of this process is to provide technology that can contribute to shifting industry's center of gravity toward sustainability. The research that will create such technology is what we call "Full Research." But what must AIST do to ensure that such technology reaches society and industry and truly brings about innovation? This is the urgent task for AIST at the present time.

Innovation Architect

Almost six years have passed since AIST was established. Thanks to the Full Research that has been carried out during this time, each research unit has accumulated basic technological expertise waiting to be used by industry. Of course, this Full Research was built on the foundation of knowledge accumulated over more than a century under the former AIST. However, it is Type II Research whose progress has been most remarkable since the Agency was reconstituted as New AIST. What made that progress possible was the establishment of an organizational structure that facilitates dialogue among researchers across disciplinary boundaries. Our next challenge is to determine what needs to be done to ensure that the expertise we have accumulated, now awaiting application, is actually put to use in industry.

At AIST, we have already formulated and implemented measures for promoting greater industrial application of the results of our Full Research. To foster linkages with industry, we have put in place mechanisms for comprehensive partnerships and matching funds for joint research, and have established the Collaboration Department that is moving forward with these programs. Particularly noteworthy is the Industrial Transformation Initiative launched in 2005. Under this system, which seeks to create brand-new industries based on the results of AIST research, we are carrying out Product Realization Research in partnership with a number of businesses. Research projects going on right now are focused on such topics as closed "plant factories" for the production of pharmaceutical substances, a services-focused knowledge-recycling architecture, a user-friendly open robot architecture, and risk in industrial products. And to lay the groundwork for such partnerships, we created a system for funding research into high-tech manufacturing, intellectual property integration, and other topics to further promote the deployment of Full Research in industry. Furthermore, at the AIST Innovation Center for Startups, we are beginning to yield positive results in terms of accelerating the process of converting basic knowledge into practical technology and launching venture businesses by targeting technologies with the potential to shift industry's center of mass toward sustainability –even research at a stage that would not ordinarily be considered advanced enough to form the basis of a venture business– and financing a task force consisting of researchers and talented managers, whom we hire on a contract basis, to commercialize the technology and launch it into society in the form of a venture business. These policies, most of them dating from the First Medium-Term Plan, have been largely successful, and we are developing them further.

AIST's Innovation Hub strategy is a plan to widen the circle of innovation throughout Japan as a whole, with these programs as a foundation.[5] For this purpose, the methods I have just described must be implemented *vis-à-vis* a wide range of industries. In addition, when we apply ourselves to implementing them, we must keep the following important point in mind, one that has been pointed out many times before but still bears repeating: the vital role of people in such partnerships. Practically speaking, to forge a successful partnership, a researcher with results to share must meet a businessperson who has need of those results. That involves luck. And, in fact, we have often been obliged to wait a long time before such good fortune struck. On consideration, it stands to reason that to effectively accomplish the task of translating the results of AIST research into practical industrial technology, we must not only fully understand the content of the research and its significance but also know the real requirements of industry. However, as our society is organized today, researchers and businesspeople move in different circles. Consequently, even if the businessperson we seek exists, the probability of finding that person is low.

We have decided, accordingly, to establish a key post at AIST to be filled by a person with these abilities and inclinations, and to give that position the name of "Innovation Architect."[6] At the same time, we have instituted a program to nurture people with such capabilities.

This decision resolved a question that has long plagued me: Why is architecture the only field with people who perform the role of an architect? In architecture you have the people who supply various building technologies in the form of materials, parts, interior furnishings and fittings, etc. as well as providers of such services as strength calculation. The client who is building a house must do so on the basis of all these elements. However, the client never communicates directly with the people who provide these technologies. It is the architect who provides the missing link. The architect is thoroughly conversant in construction technology and also fully understands the style of living sought by the client whose house it will be. With these things in mind, the architect designs a unique home. The chances that the client understands the construction technology are very slim. And it is difficult for providers of building technology to understand the specific style of living sought by each of their clients. But the architect acts as an interpreter between the builders and the client. In addition, the architect has a unique talent for artistic synthesis. Armed with these capabilities, the architect determines an aesthetically pleasing architectural style in keeping with the built environment, while at the same time conveying to the technology providers the client's practical needs. The architect is thus a pivotal person who takes the lead in guiding the progress of a new building. However, it is difficult to find anyone who fills such a role outside the realm of architecture *per se*. For this reason, while users of knowledge are not able to select and use the optimum technological resources on the basis of a comprehensive, in-depth understanding of all of the usable knowledge, developers of new knowledge face considerable risk. In areas where progress is very fast, such as information technology, there is often wasted investment in terms of both use and development.

How does this pertain to the present issue, that is, partnerships between AIST and industry? In the sense that industry takes the expertise gained from cutting-edge research at the institute and uses it to make products, the framework is analogous to architecture. The sci-tech expertise gained from cutting-edge research corresponds to the architectural technology that advances almost daily, and the industries that use the sci-tech expertise to produce finished products correspond to the client who builds a home using that building technology. The industries that use scientific knowledge may know more about the technology they are using than the client building a home, but inasmuch as today's industries must deal with a wide range of knowledge outside that directly pertaining to their own field of endeavor, they are in a similar position. More important still is the current lack of an adequate mechanism for requesting basic research to generate the kind of knowledge that can meet industry's real needs.

Herein lies the need for an architect to bridge the gap between industry and research institutes. Now, AIST has an innovation architect who is ready apply himself to this task.

Notes

1. Kuhn, Thomas: The Structure of Scientific Revolutions (Chicago: University of Chicago Press, 1962).
2. AIST's Committee on Industrial Science and Technology for Sustainability (Chair, Koji Masuda), established in July 2005.
3. Lester, Richard K. and Piore, Michael: Innovation–The Missing Dimension, (Cambridge: Harvard University Press, 2004).
4. Barthes, Roland: Système de la Mode, (Paris: Editions de Seuil, Paris, 1967).
5. National Institute of Advanced Science and Technology, AIST Second-Phase Research Strategy (chapter 3, "Innovation Hub Strategy"), April 2005.
6. On December 1, 2006, the position of AIST innovation architect was established and AIST's first innovation architect appointed.

Nanotechnology at AIST

Toward innovation and a society of sustainable development

New developments in nanotechnology research

To the global development in nanotechnology research have been added the social acceptance and standardization of nanotechnology, and a large trend encompassing these aspects is in the process of taking shape. In Japan as well, the Third Science and Technology Basic Plan in line with these trends started as of this fiscal year. In the Plan, nanotechnology/materials research area is clearly recognized as a priority field to be promoted, showing the increasing anticipation for its contribution to industrial technology.

Research strategies and nanotechnology

To achieve the Second Medium Term Plan, AIST formulated research strategies which respond to the diverse expectations of society through limited research resources, and disclosed the future directions of its research. Nanotechnology research at AIST is mainly implemented in the area of nanotechnology/materials/manufacturing. The core concept of research strategies in this area is “minimal manufacturing,” which works to construct “a technological and cyclic system which generates the maximum function through use of minimal resources and input of minimal energy (production cost/environmental load), and which also controls wastes to a minimum.” In the concept, nanotechnology plays a key role as a leading-edge technology. Nanotechnology research at AIST is not limited to the research area mentioned above, but also contributes as an important basic technology to the fields of life sciences, information and communications/electronics, and environment/energy.

World-leading efforts at AIST

AIST has been leading programs such as the Nanotechnology Program of the Ministry of Economy, Trade and Industry, carrying on from the outcomes of our world-pioneering Atom Technology Project. Presently, many projects within this Program are in their final stages. AIST also participates in many undertakings of the Nanotech Research and Development of Nanodevices for Practical Utilization of Nanotechnology project kicked off in 2005, as the central research institution.

Needless to say, nanotechnology is a basic technology that breaks new ground for science and technology, and is also relevant to many existing industrial technologies, extending their reach or depth, and is thus expected to prove useful in resolving various issues of today’s society. Meanwhile, there is a concern over the possibility of unexpected negative results being yielded, as the objects of our research become nanomaterials and such of a size domain which has been hitherto unventured. AIST is thus actively engaged in research from a risk control perspective, in order to foster the healthy development of nanotechnology. We have started research on methods for safety testing of nanoparticles as of FY 2005, targeting future international standardization.

In closing, we hope that This feature article offers the readers some understanding of AIST’s nanotechnology-related efforts.

Research Coordinator
Kazuo Igarashi

Figure. From Atom Technology Project to Nanotechnology Research at AIST

Catch a glimpse of nanotechnology R&D in the world

Technology Information Department
Mizuki Sekiya, Junko Takahashi, Kouichi Miyamoto, Shigeyuki Sekine

What is happening in the nanotechnology research and development now? In this short column, we briefly introduce research trend of nanotechnology in the U.S., Europe and Asia.

USA

The U.S. is strategically advancing research and development in nanotechnology (NT) led by the National Nanotechnology Initiative (NNI), a comprehensive NT research and development framework. US maintains its position as the global leader in NT, showing dramatic increase in related patents as well as investment which accounts for about a quarter of the global total. Meanwhile, the U.S. is concerned over the tight competition in research and development with Japan and Europe, as well as its narrowing lead against countries such as South Korea and China. The NNI strategic plan for 2006-2010, announced in 2004, sets forth its policies that further strengthen research and development, human resource development and industrialization of NT for maintaining competitiveness of the nation.

Based upon such a situation, the total budget of NNI, despite the tight financing policy of the Bush administration, is 1.275 billion dollars (request for FY2007), which is more than twice the figure at the time of NNI's launch.

It attracts a great deal of interest that how to balance research and development of NT applications with research on environment, health and safety (EHS) implications as one of the investment issues facing NNI. There have been some cases where safety-related research is implemented even in programs which are not included in the budget category of research on EHS, reflecting increasing concerns over the safety of nanomaterials.

In reflection of current situation, the Green Nanotechnology Initiative led by the U.S. Environmental Protection Agency attracts attention as it focuses on the research and development of eco-friendly and less stressful on human health technologies using NT.

Europe

In May 2004, EU published "Towards a European Strategy for Nanotechnology" in which it identified the issues to be faced in order for EU to lead the world in NT. Among these, returning the outcomes of research and development to society through industrialization was recognized as a priority. In response, in June 2005, "Nanosciences and nanotechnologies: An action plan for Europe 2005-2009" was announced, indicating the action plans for Europe to lead the world in R&D and innovations in nanoscience/NT.

In the EU summit meeting held on March 24, 2006, the new Lisbon Strategy which aims for economic growth and job creation was adopted. It targets raising the present research and development investment, which is sum of public funds and corporate spendings, from current level of 1.9% to 3% of GDP in the EU, by the year 2010. In addition, the founding of the European Institute of Technology (EIT), to be responsible for the promotion of development across EU of leading-edge technologies such as NT environmental technologies, was agreed upon.

In January 2006, EU's Sixth Framework Programme (FP6, 2002-2006) announced the nanoscience/NT roadmap for up to year 2015, and FP7 (2007-2013, 50.5 billion euros in 7 years) stipulates that "Knowledge is Europe's best resource." NT-related topics listed in FP7 include nanoelectronics, integrated microsystems/nanosystems and downsized integration as the essential technologies for "Nanosciences, Nanotechnologies, Materials and New Production Technologies" (3.4 billion euros) and "Information and Communication Technology" (9.1 billion euros).

In the UK, keeping a distance from EU, the Department of Trade and Industry announced in 2004 the Science and Innovation Investment Framework 2004-2014, in which the budget plan (2005-2007) identifies NT as a basic technology to underpin other fields.

Asia

In Asia, NT research and development as well as fostering NT industries are implemented distinctively per region, and Japanese cooperation is anticipated. AIST sponsors the Asia Nano Forum in which it establishes networks and holds international conferences to allow relevant parties to discuss standardization, societal implications, and human resources development in NT.

In China, research bases are established in the Chinese Academy of Sciences and Peking University, etc., where substantial national funds are being invested. In addition, NT bases have been established in Beijing and Shanghai for promoting NT spin-offs new businesses and technology transfers.

South Korea established a 10-year plan to promote NT in 2001, investing heavily in research and development. Although patenting and new businesses in NT are showing rapid growth, basic research and bio fields are considered still rather weak.

Taiwan launched a 6 year plan in 2003. In addition to research and development and fostering industry, it is also enthusiastically tackling the issues of human resources development and societal implications of NT.

India kicked off a nanotechnology initiative in 2001, which promotes priority support for research and development, strengthening of infrastructure, human resources development, and coordination between industry and academia.

Singapore promotes research and development that is beneficial to existing industries, focusing on electronics, science, bio and medicine.

In Australia, the Commonwealth Scientific and Industrial Research Organization (CSIRO) is focusing on materials and bio within NT.

Bottom-Up Nanotechnology

Potential of bottom-up nanotechnology

The limit to top-down product fabrication?

Moore’s Law was proposed in 1965 by Gordon Moore, co-founder of Intel Corporation, regarding the miniaturization trend in semiconductor chips. Stating that “the number of transistors integrated on a chip doubles every two years,” it beautifully characterized the progress of semiconductor microfabrication technology over the following 40 years. Presently, the size of mass production level transistors has reached the neighborhood of 50 nm, already plunging into the nanotechnology realm. Moore’s Law is believed to hold for a while yet to come.

How far will top-down type technologies, in which materials are processed to fabricate microscopic objects, continue to make progress in the future? Although processing precision is expected to reach 20 nm within the next 10 years, high technical and economic hurdles are expected to be encountered in its practical application. The cost for new construction of a sophisticated semiconductor production line is as high as several hundred billion yen. The economic hurdles which are anticipated to expend the investment capacity of corporations to an extensive degree pose difficult structural issues – not limited to semiconductors, but also applicable to liquid crystal displays and such – which are common to other leading-edge technology industries.

The potential of bottom-up nanotechnology

Nanotechnology embodies two potential directions for development. The first is the increasingly radical direction of rushing ahead to the bitter end in the road of top-down technology which it has followed up to present, and the other is the road of fundamentally resolving the issues encompassed in the former, or in other words, the direction headed for bottom-up type technologies. The technology for spontaneously building a structure comparable in complexity to a semiconductor chip, based upon the chemical bonding and intermolecular forces intrinsic to atoms and molecules and without depending upon the artificial manipulation of processing, is what we call bottom-up nanotechnology.

The ideal form of bottom-up technology would be for the target objects, be them transistors or PCs, to come into being naturally, upon our simply mixing the required materials together, much as living organisms synthesize protein and lipid molecules from DNA to autonomously create cells and organs. It constitutes the ultimate on-demand technology which requires no large industrial plant, but in which the required objects are cumulated at the required position at the required time. Furthermore, it is not executed by someone looking at a blueprint, but by the substances themselves, autonomously and in parallel in various places.

While this ideal may yet be a distant dream, the natural world is utterly full of such bottom-up activities, beginning with living organisms. Bottom-up nanotechnology, which understands and imitates nature’s laws of creation, is anticipated to play a leading role in a sustainable society. As it seeks miniaturization and higher performance while at the same time realizing the ultimate in resource and energy conservation, it is even capable of detouring around the economic hurdles of top-down type technologies.

The minimal manufacturing for which AIST’s nanotechnology aims is precisely the realization of such a technology.

Nanotechnology Research Institute
Hiroshi Yokoyama

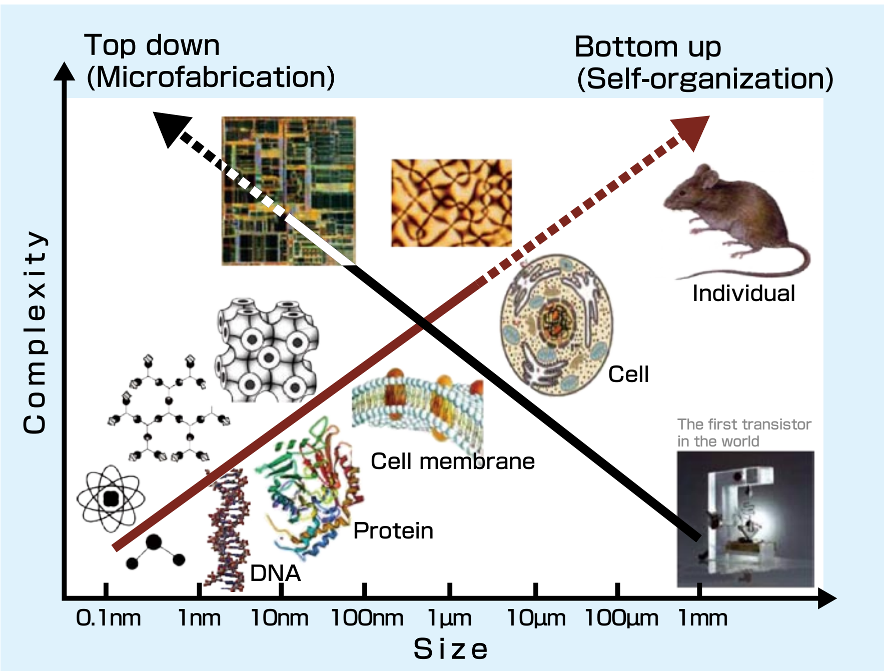


Figure. Limits to top-down product fabrication, and the potential of bottom-up nanotechnology

Synthesis and nanobio applications of organic nanotubes

From microchips to nanochips

The degree of integration of computer chips is increasing steadily every year, owing to progress in semiconductor microfabrication technologies.

Likewise, miniaturization advances in the separators and devices with hollow cylinder constructions indispensable to separation analysis of chemical substances. Recently, high-sensitivity analysis at a femtomole level (a level of 10^8-10^{10} converted to number of molecules) has become possible using a microchip having a channel structure of diameter approximately 100 µm (Figure, left).

However, it is extremely difficult to prepare a space to confine just one molecule inside for ultramicroanalysis. Thus the miniaturization and integration of analytical devices requires technological reform from a completely different perspective.

Utilizing the self-assembly of molecules

We are working on development of hollow cylinder structures (organic nanotubes) which exploit the phenomenon where amphiphilic molecules possessing both hydrophilic and hydrophobic groups in a single molecule spontaneously aggregate in water (molecular self-assembly).

Recently, we succeeded in achieving mass production of organic nanotubes using solvents in the amount of only one thousandth or less compared to the conventional amounts required for molecular self-assembly. In addition, we designed and synthesized a new “wedge-shaped lipid molecule” possessing two hydrophilic groups of different size (Figure, right top). Through molecular self-assembly in water, we are able to create nanotubes of either of the two distinct diameters of approximately 20 nm and 80 nm.

Results of in-depth structure analysis on this nanotube reveal that it is an organic nanochannel possessing asymmetric inner and outer surfaces, of hydroxyl groups covering the outside surface and amino groups covering the inside surface.

Further, we partially imparted a positive charge to the amino groups of the organic nanotube in aqueous solution, and successfully demonstrated for the first time in the world that we could encapsulate spherical proteins (diameter 12 nm) and polymeric nanoparticles (diameter 20 nm) possessing negative charge within the hollow cylinder (Figure, right bottom).

As described above, we are advancing research utilizing molecular bottom-up technologies, on miniaturization and integration of analytical devices using hollow cylinder structures of 10-100 nm, as well as their nanobio applications utilizing encapsulation, separation, sustained-release and sensing functions.

Nanoarchitectonics Research Center
Toshimi Shimizu

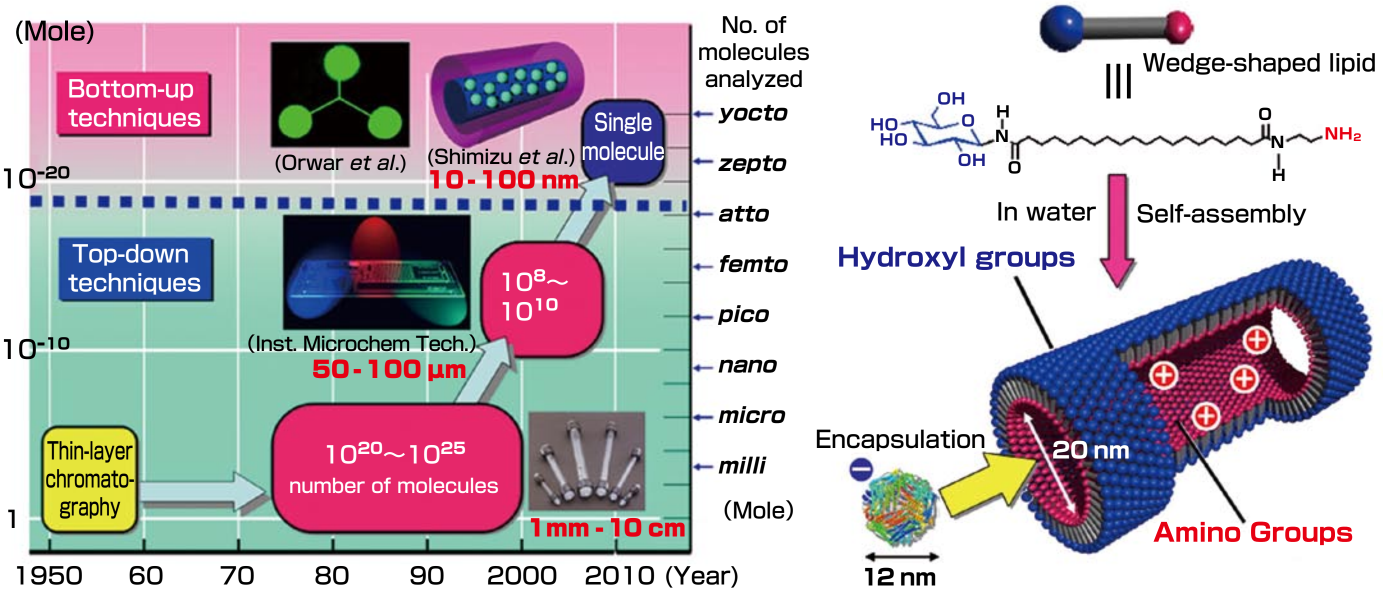


Figure. Chronological transition of miniaturization of hollow cylinder spaces, and the organic nanochannel consisting of molecules

New developments in synthesis technology of carbon nanotubes

AIST, led by its Research Center for Advanced Carbon Materials, is working to develop synthesis technologies targeting industrial application of the carbon nanotube.

Direct injection pyrolytic synthesis method

Single-walled carbon nanotubes (SWNTs) supplied by conventional mass production techniques do not satisfy the requisites as industrial materials in terms of quality, and thus require post-treatment such as purification or modification on the part of the users.

By precisely controlling the reaction conditions in the direct injection pyrolytic synthesis method (DIPS method), a synthesis method of SWNT, we have succeeded in developing a synthesis technique showing dramatically improved purity and crystallinity (graphitization) of the product, reduced impurity concentration and structural defects at a tenth or lower compared to conventional mass production techniques, as well as a catalytic efficiency of roughly 100-fold.

Use of this high-quality SWNT enables us to spin high-strength fiber SWNT wires as well as prepare mesh sheets of SWNT (Photo 1) for cell culture purposes, without use of surface treatment or binders. Furthermore, in addition to the quality (purity and graphitization) being improved dramatically, the SWNT diameter can be controlled with a precision to the 0.1nm level.

Supergrowth technology

We have discovered a completely novel growth mode (we call it supergrowth) which occurs upon addition of a minimal amount of moisture to the regular carbon nanotube synthesis atmosphere. Not only does this supergrowth technique allow ultra high-efficiency synthesis of about 1,500 times in time efficiency, but it also yields SWNT of an ultra high purity of 99.98% in the unpurified state, thus achieving a major breakthrough in synthesis.

Using this supergrowth technique, we have become the first to succeed in preparation of a patterned vertical array structure of SWNTs (Photo 2). The industrial value of this technology is immeasurable. In addition, the technique has also brought about a great new leap forward in development of applications of the SWNTs in bio and electronics fields, and is thus anticipated to sustain the future industry of Japan in diverse ways.

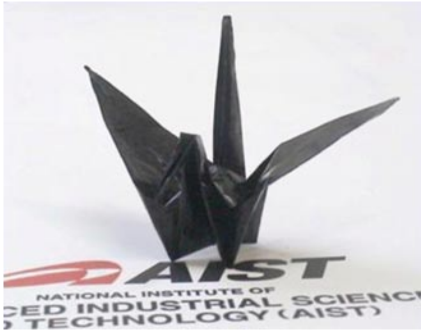


Photo 1. A folded-paper crane made using a high quality SWNT sheet

Research Center for
Advanced Carbon Materials
Motoo Yumura

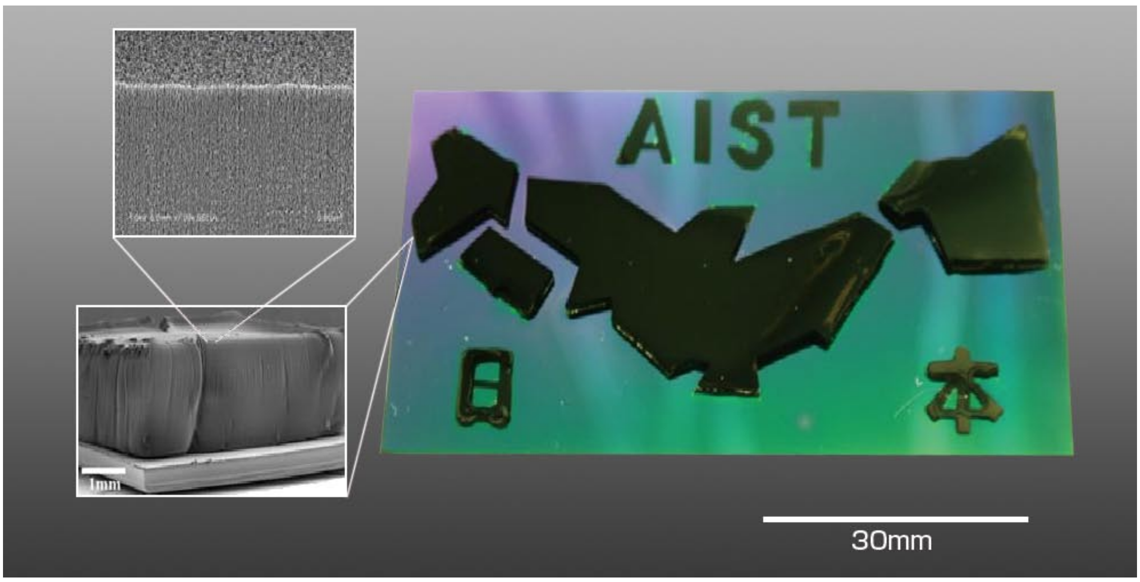


Photo 2. Carbon nanotubes which 'sustain Japan' (map of Japan made using vertically arranged SWNTs)

Structural evaluation technique for nanocarbon materials

A distinguishing feature of nanocarbon materials is their diversity of structure and physical properties. Meanwhile, without performing definite structural determination of individual nanocarbon materials at an atomic level, we are not able to predict the properties accurately. Hence, the establishment of a detailed structural analysis technique enabling quality control at an atomic level is essential to the industrialization of nanocarbon materials.

We aimed to develop an evaluation technique for exhaustively determining the structure of carbon nanotubes (CNTs) in particular.

Determination of optical isomers

The chiral index which describes the helicity of a CNT is the most important factor in determining the electrical properties of the nanotube. However, analysis of the chiral index alone is not sufficient to determine the inter-layer relationships of multilayer nanotubes. Even once the chiral index is determined, there exist optical isomers, so a double-walled carbon nanotube (DWNT) as shown in Figure 1 could potentially consist of any of four different structural isomers. Therefore, in order to completely determine the structure of the DWNT, a technique for discriminating the direction of the winding of the graphene sheet (a single layer in the graphite structure) is required, in addition to the chiral indices. We have developed a method for determining a unique structure among these four isomers, by carefully tilting the sample within an electron microscope using the measurement principle shown in Figure 2.

Direct observation of individual functional groups of fullerene derivatives (C_{60}-C_3NH_7)

The chemical modification of fullerenes is of high interest in the fields of physics and chemistry. However, direct observation of a single modified fullerene at a molecular level had not been achieved up to present. We succeeded in directly observing the C_{60}-C_3NH_7 molecule inserted in the single-walled carbon nanotube (SWNT), using high resolution electron microscopy (HRTEM) (Figure 3).

Further, as a result of the analysis of the nitrogen chemical state contained in the functional group by using electron energy loss spectroscopy (EELS), we have found that there is a strong interaction between the functional group of fullerene and SWNT.

Through development of an ultra high-sensitivity electron microscope system, we are taking on the challenge of structural analysis of new carbonaceous substances at an atomic level, which has been conventionally difficult. The atomic structure of a nanocarbon material is the most important factor to determine its physical properties, thus our achievements mentioned above which enable the precise properties prospections are expected to contribute to the expanding market of nanocarbon application in a large way.

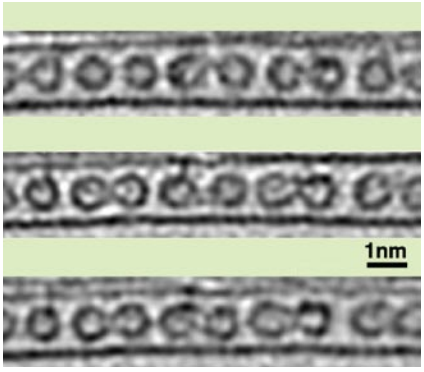


Figure 3. HRTEM image of (C_{60}-C_3NH_7) in SWNT, imaged continuously at 2-second intervals

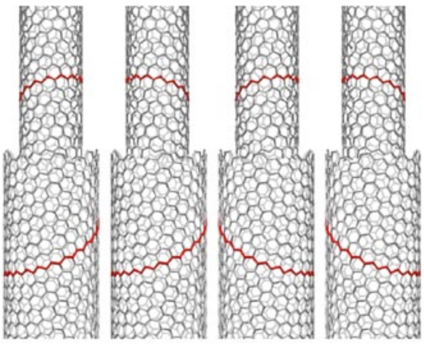


Figure 1. Optical isomers of DWNT

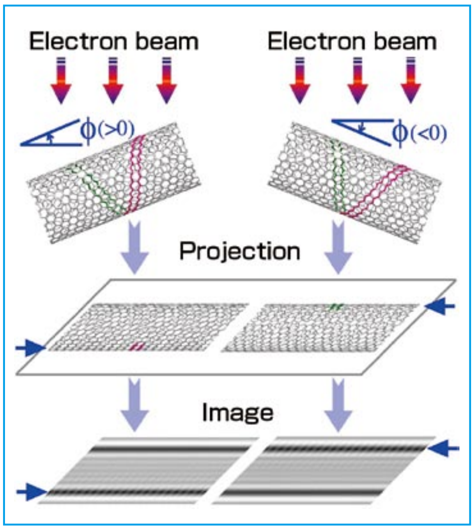


Figure 2. Discrimination of clockwise/anticlockwise winding of carbon nanotubes by sample tilting method

Research Center for Advanced Carbon Materials
Zheng Liu
Kazutomo Suenaga

Beyond silicon technology

In the spring of 2006, the news that "a notebook PC equipped with flash memory instead of a magnetic hard disk is to be released" was announced in successive press releases. As yet, we are not able to imagine that use of the magnetic hard disk as an ultra-high capacity information-recording medium for servers would ever become obsolete. At any rate, however, the role distinctions in PCs establishing that "information processing by semiconductors" and "information recording by magnetic devices" are becoming a thing of the past, owing to progress in silicon technology. Besides the above, we are recently encountering flash memories used in all sorts of personal items, such as the recording media for cell phones and digital cameras.

As you may be aware, this memory, having a high capacity and low bit cost with a recent eye on high speed as well, has been developed through leading-edge silicon technology which controls structures in the nanometer level. In this sense, we could be wondering what all the fuss is over 'nanoelectronics' now.

Meanwhile, no matter how far the performance of silicon technology is enhanced through ultra-miniaturization technologies, it will reach its limit some day. Regarding the flash memory mentioned above, if nanometer-size fabrication progresses at the current rate, concerns are arising that an inevitable operating limit will be reached around the year 2010.

At AIST, we are already advancing research and development in nanoelectronics, which goes beyond silicon technology, in an effort to avoid sudden confusion at such a time. The objects of our research and development can be roughly classified into "those that show characteristics exceeding silicon devices" and "those of a principle of operation differing from silicon devices." A representative example of the former is the development of materials and devices using silicon carbide and diamond semiconductors, which have high thermal conductivity and are superior in performance to silicon in uses requiring power. Below I would like to focus on and introduce typical examples of the latter type (the former is presented in page 19 of this feature article).

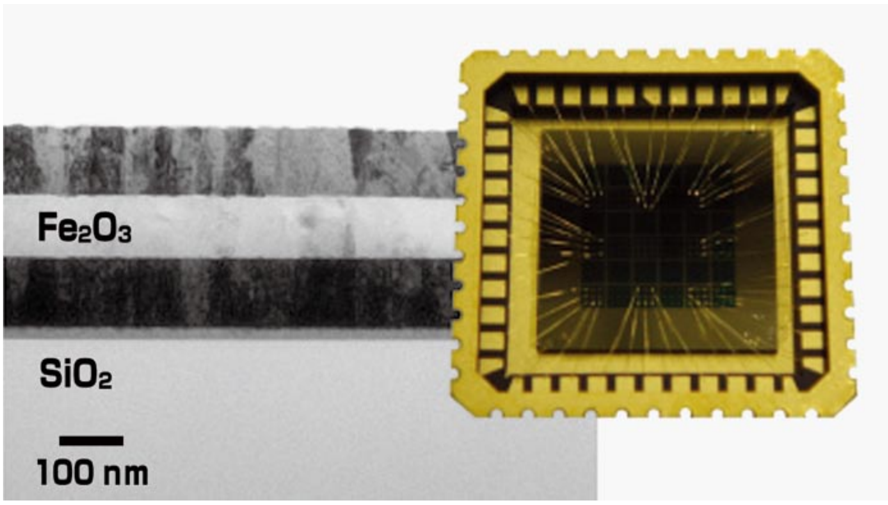


Figure 1. Cross sectional transmission electron microscope image of resistance random access memory structure consisting of iron oxide (left), and the prototype memory device of the same (right)

Nanoelectronics using functional oxides

One of the reasons that silicon technology has shown such great success can be attributed to our success in developing the technology to form silicon dioxide (SiO_2), an oxide of high insulation properties, flatly on an atomic level. However, in the realm of single digit nanometers, even this superior insulator is unable to head off the leakage of electrons. Such is the reason behind the active research into gate dielectrics using new oxides having high dielectric constants.

Meanwhile, some oxides, when applied with an electric field, for example, demonstrate significant change in electrical conductivity. At the Nanotechnology Research Institute at AIST, we are conducting research on characterization of such functional oxides also targeting application to memory, in partnership with the Correlated Electron Research Center.

Figure 1 is a photograph of a device used to demonstrate the functioning of a resistance random access memory, using iron oxides having roughly the same composition as the iron sand found at your feet. Of the future-generation candidates under research and development as nonvolatile memories that maintain data records without supply of electric power, such a resistance random access memory, in particular, is regarded as extremely promising from various perspectives including good compatibility with silicon technology and a high-intensity change of signal.

Now, the other major reason why silicon technology has been so successful is that nanofabrication technologies, or various etching technologies, in particular, were successfully developed. For example, the selective milling (or etching) of only the Si in SiO_2 can be achieved through vapor-phase etching using an appropriate reactive gas. In the following section, I would like to discuss developments in this etching process.

Nano spin-electronics

Whereas in existing electronics, devices are operated by controlling the flow and quantity of electrons, another research under way now works to develop devices based upon a new principle using spin, the other degree of freedom of electrons. Spin is sometimes likened to the rotating movement of electrons, and clockwise and anticlockwise rotations are defined as "up" and "down" spins, respectively. A familiar image is offered by the permanent magnet. Roughly stated, if the spins are aligned in one direction, magnetization occurs. New devices can be designed exploiting properties such as the magnetization being nonvolatile, or the spin inversion being of ultra-high speed.

A representative example of a familiar spin electronics device already in use around us is the data read head of hard disks. In the near future, we are likely to see practical application of a magnetic random access memory consisting of a film stack of ferromagnetic metals and insulators. If so, is a nanofabrication process such as that which led silicon technology to success being developed to allow such practical application?

The answer is No. Owing to the background that process development, while being an aggregation of technical know-how, has not been treated as a science, there are no existing systematic research and development technologies for it.

At the AIST Nanotechnology Research Institute, we are conducting development of a reactive ion etching process, in preparation for the upcoming ultra-fine fabrication of spin electronics devices. In addition, with the aid of computer simulation, we are also developing techniques for speedily advancing such research and development.

Figure 2 shows the cross section of the structure of a ferromagnetic alloy, called NiFe, etched using plasma of mixed gases consisting mainly of methane gases, observed using a scanning electron microscope. We were able to increase the selectivity against the Ti metal mask to almost infinity. The technique is anticipated for future use in nanofabrication of ferromagnetic metals.

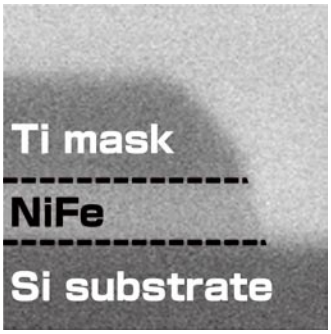


Figure 2. Cross sectional scanning electron microscope image of structure of NiFe (Permalloy) processed by reactive ion etching using Ti (titanium) masking (black dotted line has been added to show boundaries between materials)

Nanotechnology Research Institute
Hiroyuki Akinaga

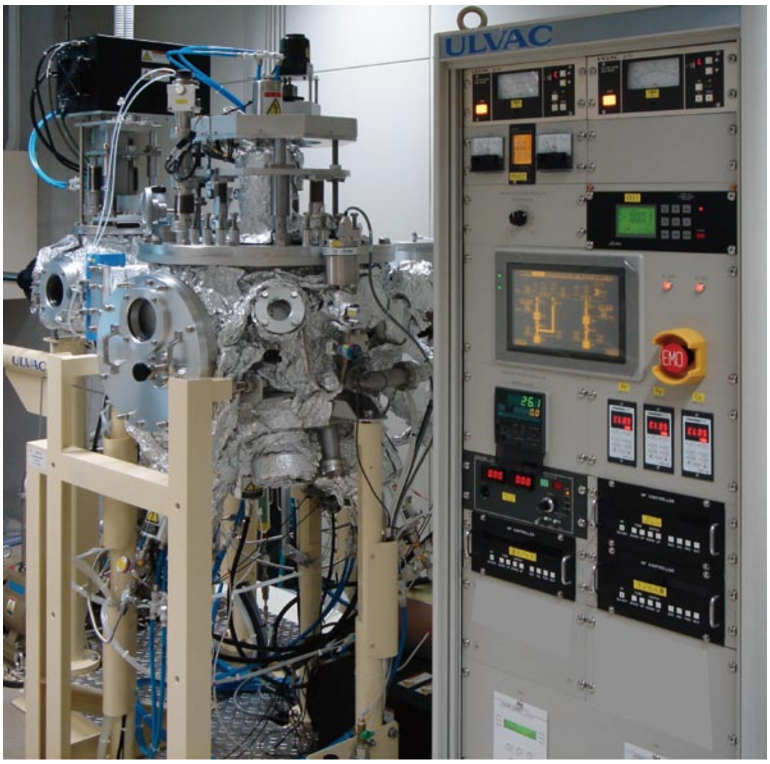


Photo. Sputtering system equipped with radical oxidation source for fabricating thin film of a transition metal oxide (the function of transition metal oxides changes largely depending upon the oxidation state, thus establishment of the thin-film deposition know-how is essential in the development of memory)

Advanced Device Materials

Correlated electron materials and electronics applications

What are correlated electron materials?

Semiconductor electronics centering on silicon technology can be considered the upholding force behind the household electric appliances to information and communications equipment of today. Owing to nanotechnology which miniaturizes to the level of 10 nm, semiconductors are becoming increasingly high-density and high-capacity. In such a nanometer-scale size, however, other physical phenomena may appear, leading to concerns that devices will not have conventional functionalities any more. Correlated electron materials are examples of electronic materials which have the potential of breaking through this limit.

In a simplified view, the semiconductor device may be thought to have device functionalities by controlling each individual electron among a small number of electrons (minority carriers). In correlated electron materials, on the other hand, a large number of electrons are strongly interacting with each other, forming the electronic phase.

Under certain environments, the correlated electron material behaves like an insulator with its electrons unable to move. By applying a small external stimulus, it makes a transition to a metallic phase in which its electrons move freely. This phase switching can be as fast as one picosecond or less and the gigantic phase-response of electrons can be realized. The fundamental concept of correlated electron technology is to utilize the outputs associated with changes in correlated electron phases, and to develop this phenomenon into new electronic technology.

Examples of correlated electron materials are transition metal oxides having perovskite structures, including the high-temperature superconducting copper oxides, and manganese oxides which demonstrate colossal magneto-resistance (CMR) effect. In addition, organic charge-transfer complex crystals are also correlated electron materials. Here, we would like to introduce typical examples which are expected to evolve into strongly-correlated electronics in the future.

Towards strongly-correlated electronics

A phenomenon has been discovered in which, by attaching metal electrodes to both sides of perovskite manganese oxide films and applying a pulse voltage, it switches from high resistance to low resistance at high speed. As this low-resistance state is stored until the following reverse bias voltage pulse is applied, it is expected for future application to large-scale high-speed nonvolatile memory (Figure 1).

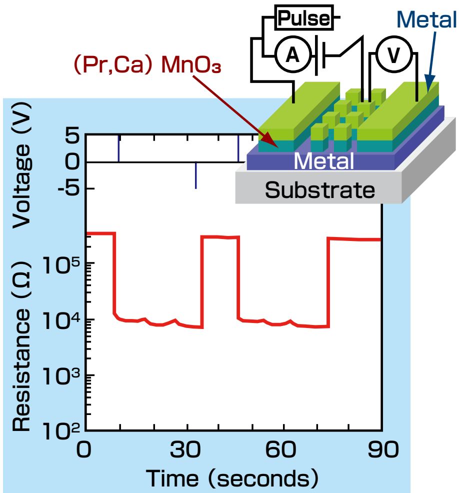


Figure 1. Colossal electro-resistance (CER) memory effect of perovskite manganese oxide

Ferroelectrics are important device materials which are widely used for electronic applications such as nonvolatile memories and piezoelectric elements with polar inversion. Recently, we have succeeded in development of new organic ferroelectrics having a huge dielectric constant even at room temperature (Figure 2). These organic ferroelectrics have been desired for the future organic electronics which can realize the excellent functions flexibly in lightweight materials.

In addition, we have discovered that irradiating laser light on perovskite cobalt oxides and manganese oxides causes them to make an extremely high-speed (sub-picosecond) transition from the insulator to metallic phases. They are thus expected for use in devices of ultrafast optical switching or magnetic switching by light irradiation.

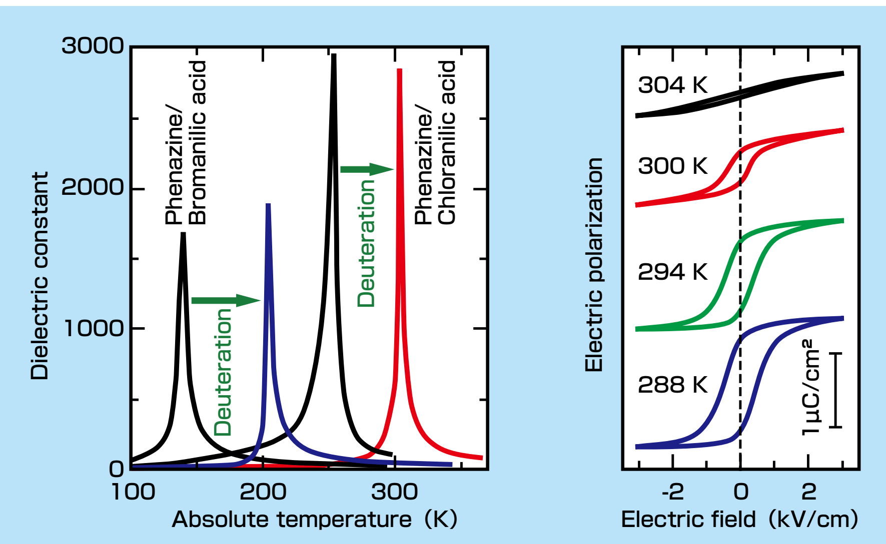


Figure 2. Dielectric property of a new organic ferroelectric material in which 2 species of π-electron molecules are bounded by strong hydrogen bonding

Correlated Electron Research Center
Hiroshi Akoh

Toward electronic application of diamond

Although diamond is popular to us as a jewel, it is a quite unique material with many excellent characteristics. Owing to progress in the synthetic methods of vapor-phase deposition, diamonds are now available not only in particle, but also in sheets and thin films, thus their application may be expected so widely. Current status of research and development to use diamond as an electronics material for devices is active to contribute in environment, bio technology, measurement technology, etc.

Diamond devices?

The advantage of diamond may be recognized as to have the prime characteristics such as the highest hardness, the highest thermal conductivity, optical transmittance, excellent semiconducting characteristics, etc. Thus, it is anticipated to be developed for wide-range applications. Recent progress of the technology to process diamond in nm scale has expanded the range of devices fabrication. In addition, it has also been revealed that atomic level control of the surface significantly affects on the surface properties, making diamond applicable to uses such as sensors. Followings are the introduction of the devices which are under development in Diamond Research Center (DRC).

Semiconductor devices: Some physical properties of diamond are regarded as the ultimate among semiconductor materials, and diamond is a candidate as the post-silicon material. Owing to its expected device characteristics of high-temperature operation and high breakdown voltage, it is regarded as the material best suited for high power applications. However, there still remain many basic issues to be developed, such as high-quality epitaxial layer, doping, and control of interface, in order for it to prevail in the competition with materials preceding it such as silicon carbide (SiC) and gallium nitride (GaN).

Electron emitting device: Diamond has negative electron affinity under certain surface states and is a material which can emit electrons easily. Many attempts were carried out to show the potential of as an electron source with low turn-on voltage, high-current and low-temperature operations. Also, diamond is considered to be good material as secondary electron emitting.

Biosensor: Diamond can immobilize biological materials, such as DNA, protein, etc. on the surface, which may be modified into various characteristics. Diamond has a wide electrochemical potential window and biocompatibility. It is anticipated for use in various biosensors using these characteristics, and further, use within the body is not a dream thanks to its biocompatibility.

Development of research at AIST

DRC is researching toward the applications mentioned above. For example, we are working on improvement of breakdown voltage of Schottky junctions, on the surface structures that allow low-voltage electron emission and on the sensor detecting bio materials. In particular, an ion sensitive field effect transistor (ISFET) type pH sensor (Figure 1) using single crystal diamond was developed, and has succeeded in achieving high sensitivity (Figure 2). In addition to developing the device itself, we are doing some basic studies on the characterization and the surface modification of diamond, including immobilization of DNA. Further, we are working as well on manufacturing technologies for large single crystals wafer which looks very important material in electric application. Already, we have succeeded in growing a single crystal up to 10 mm in thickness using a chemical vapor deposition, and hope to make progress to single crystals in the inch size in the future.

As described above, we will develop realistic devices and transfer our research results in industry and promoting the wide use of diamond devices in various application fields.

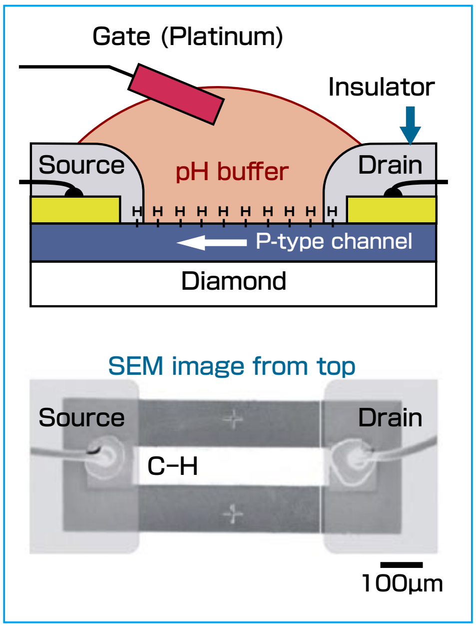


Figure 1. Schematic diagram of diamond pH sensor and SEM image

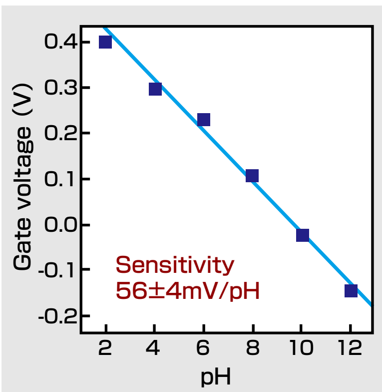


Figure 2. Sensitivity characteristics of diamond pH sensor

Diamond Research Center
Naoji Fujimori

From nanobiotechnology to medical application

Nanobiotechnology, an area of fusion between biology and nanotechnology, has recently been attracting attention and making rapid progress.

AIST, led by its Nanotechnology Research Institute, is actively advancing research on applications to medicine utilizing such technology. Below, I would like to introduce some representative examples.

Target-oriented drug delivery system

Winning the battle against cancer is one of the greatest issues of 21st century medicine. Drug delivery systems (DDS) which are capable of delivering anticancer drugs selectively and intensively to the affected area are commanding high interest as the trump card in this battle.

We have focused our attention on the cell-recognition function of sugar chains to advance development of a DDS that will launch a missile attack against cancer cells.

DDSs known up to now relied solely on the sustained release of drugs captured within the vesicles. They were passive, showing little or no recognition action for the affected area, whereas AIST's sugar chain type drug delivery system has demonstrated high selectivity for the affected area in the results of recent animal experiments.

Development of a cell culture dish using the nanopillar sheet

It is possible to make fine structures in the nanoscale on the resin on a substrate using nanoimprinting technology. The result is called a nanopillar sheet. The Nanotechnology Research Institute, in a corporate joint research effort, has discovered that the nanopillar sheet can be used as a novel type cell culture dish.

The nanopillar sheet, as shown in Figure 1, consists of column-shaped nanopillars arranged at equal spacing, upon which living cells can be cultured. The cells contact the heads of the nanopillars and multiply by division supported on top of the nanopillars.

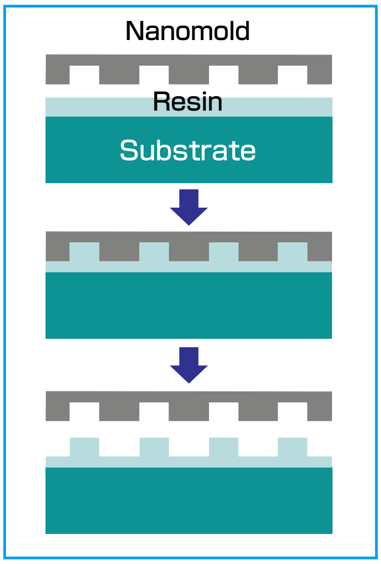
In regular cell culture dishes, passage (subculture) of the cultured cells is performed by stripping the cells by means such as enzyme treatment, as the cells are strongly adhered to the dish. The nanopillar sheet, however, has the features of allowing cells to be collected simply by pipetting, and of readily allowing the formation of spheroids. Therefore, it is attracting attention as a novel cell culture dish with characteristics which makes it applicable to fields such as regenerative medicine.

Development of technologies for restructuring living tissue

Techniques available for restructuring lost tissue include transplanting biomedical tissue to the affected area or culturing the materials and stem cells (cells which constitute the seeds of all cells) in vitro and then transplanting them to the diseased area for regeneration (regenerative medicine: tissue engineering). A method is also available in which growth factors are adsorbed onto a material to induce cell regeneration through sustained release within the living body.

Based upon such techniques, we are undertaking research aimed mainly at regeneration of hard tissue (bones and cartilage, as well as teeth).

Let us start from the tip of the head. Complete regeneration of the cranial bone is not possible using the medical material apatite which is used in cranial bone formation in cranial nerve surgery. In an effort to remedy this situation, we are advancing research aiming at complete regeneration of the cranial bone. We adsorbed FGF, a growth factor having a bone formation stimulatory effect, onto the medical material and transplanted it to the affected area to activate the surrounding



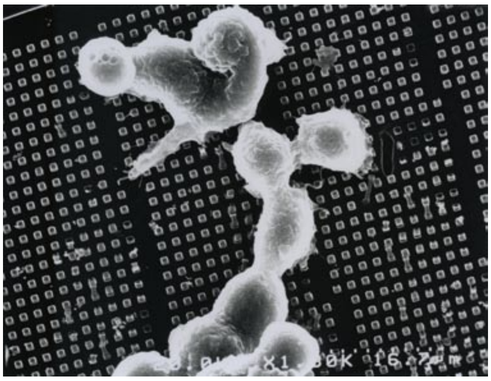


Figure 1. Method for preparation of nanopillar sheet using nanoimprinting technology (left) and electron microscope photograph of HeLa cells cultured upon nanopillars (diameter 0.5 μm) (right)

cells by sustained release of FGF, thereby promoting bone formation.

Next, periodontal disease, which affects anybody with increasing age, is a disease in which the alveolar bone supporting the teeth is dissolved and the teeth become increasingly unstable. Through joint research with a university, we have discovered that a protein found in the teeth called a phosphophoryn bonds with collagen to form nanoapatite, thereby becoming capable of bone regeneration (Photo). Currently, we are advancing development of the materials to be used in treatment of diseases such as periodontal disease using this material.

Osteoarthritis which is a chondropathy of the knee and hip joint is a serious issue of the aging society, affecting large numbers of patients. Cartilage is not readily substituted by biomaterials, thus requires regenerative treatment using autologous cells. However, cell culture of cartilage is difficult. We have already succeeded in constructing transplantable large-scale cartilage tissue from bone marrow cells, which have a large content of stem cells, using a RWV bioreactor. This bioreactor enables culturing in a state where the tissue is floating as if in a microgravity environment (space environment), using rotation of a cylindrical vessel. We are thus advancing research aiming for clinical application.

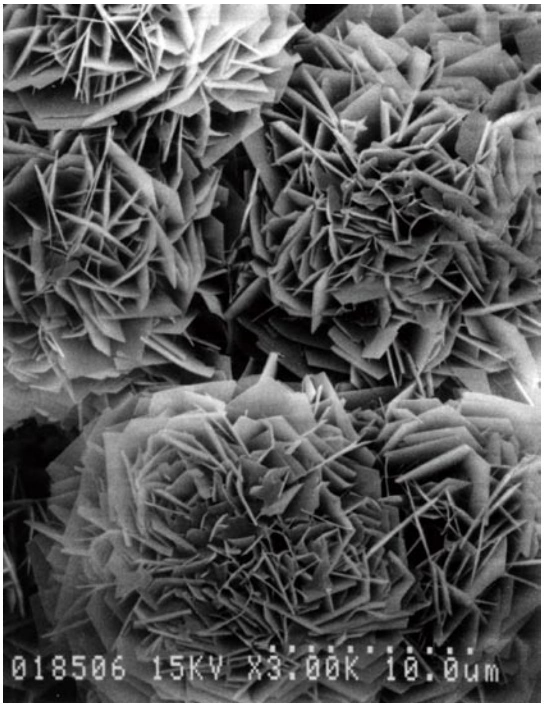


Photo. Electron microscope image of calcification by a phosphophoryn applied on agarose beads (Robust growth of apatite crystal was observed)

As hydroxyapatite, the principle component of bone, has the properties of bonding with bone and adsorbing many biomolecules in the body, it is considered for use not only as a material for artificial bone, but in wide-ranging applications. We are working on developing scaffolds for artificial bone and tissue regeneration as well as biomaterials for percutaneous devices and such, by forming apatite layers, having various compositions and structures, on the surface of polymeric materials. Conventional percutaneous devices were troubled by a high incidence of bacterial infection due to insufficient adhesion of the device to the epithelium at the contact surface, which allowed bacterial penetration. We are therefore working to develop an anti-infective percutaneous device by combining signal molecules, such as cell-adhesion agents to enhance attachment to the epithelium and antibacterial agents to kill bacteria, with apatite and polymeric materials (Figure 2).

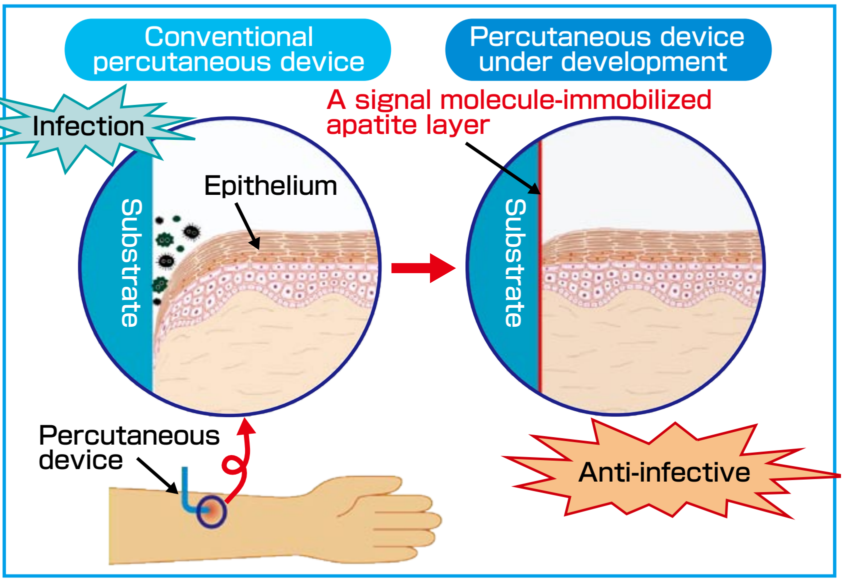


Figure 2. Development of anti-infective percutaneous device using a signal molecule-immobilized apatite layer

Nanotechnology Research Institute
Toshimasa Uemura

Nanoenvironment technology

VOC sensors using organic-inorganic nanohybrids

A new concept

Volatile organic compounds (VOC) are the substances responsible for sick house syndrome. A compact sensor capable of on-the-spot measurement of the type and concentration of VOC in the atmosphere is in demand as a means to adequately control these chemical substances. We are tackling this issue through the approach of organic-inorganic nanohybridization.

Materials consisting of a hybridization of organic and inorganic component on a nano level can be anticipated to demonstrate completely new properties, instead of just a combination of the properties of both. We have proposed a new concept for applying organic-inorganic nanohybrids to VOC sensors (Figure, left).

The concept aims to enhance the potential of the material itself by allocating the functions required in a gas sensor material, of molecular recognition and signal conversion, separately to the organic compound and the inorganic compound. A higher selectivity towards VOC could be expected compared to semiconductors using the typical conventional material of a metal oxide.

VOC gas selectivity

In order to actualize the concept mentioned above, we focused attention on intercalation type nanohybrids, consisting of layer structured molybdenum oxide (MoO_3) with organic component inserted between the layers. In the material, alternating inorganic and organic layers are stacked at crystal lattice level, each playing a distinct role. It has been revealed that the $(PANI)_xMoO_3$ thin film element – consisting of polyaniline (PANI) inserted between the layers of molybdenum oxide – demonstrates excellent selectivity, responding to formaldehyde and acetaldehyde by a reversible change in resistance, but not to toluene or xylene, etc.

A further interesting point is the diversity of possible combinations of organic component with molybdenum oxide. By changing the combination, gas selectivity may potentially be controlled. Thus, we prepared a $(PoANIS)_xMoO_3$ thin film element by inserting polyorthoanisidine (PoANIS), a polyaniline derivative, and compared the sensor characteristics to the $(PANI)_xMoO_3$ (Figure, right). While the $(PANI)_xMoO_3$ showed a higher response sensitivity (rate of resistance change) to formaldehyde than to acetaldehyde, $(PoANIS)_xMoO_3$ inversely showed a higher sensitivity to acetaldehyde. PoANIS shows a higher solubility in acetaldehyde compared to PANI, which is believed to be the reason for the high sensitivity of $(PoANIS)_xMoO_3$ to acetaldehyde. Unquestionably, the organic component is fulfilling its role of molecular recognition. This result is important from a practical standpoint as well. It signifies that, by arithmetic processing of the two different signals from the device, independent measurement of formaldehyde and acetaldehyde is possible. We are currently working on applying these results to devices.

Advanced Manufacturing Research Institute
Ichiro Matsubara

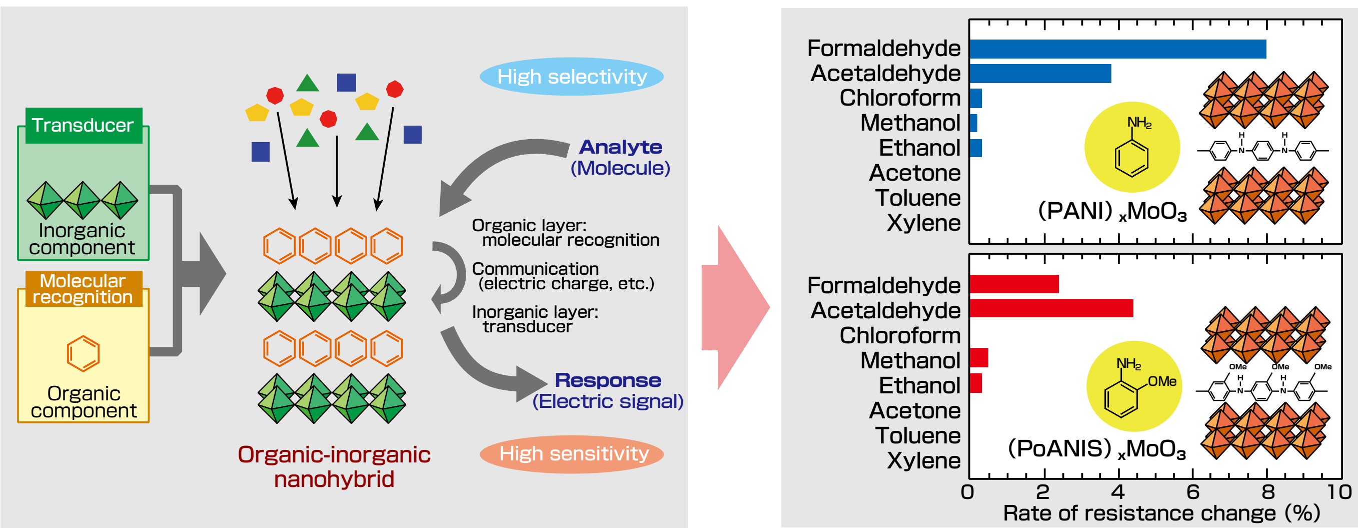


Figure. The concept of the organic-inorganic nanohybrid sensor, and response sensitivity to VOC of the organic/molybdenum oxide thin film element prepared

Development of a photocatalyst utilizing nanotechnology

Unconscious nanotechnology

Titanium oxide (TiO_2), which possesses photocatalytic functions, such as purification of air and water, antifouling (self-cleaning), and antibacterial properties, has been used since long ago as a pigment in all things white. Having a high absorbency of UV light, titanium oxide is also used in cosmetic products.

Practical application of titanium oxide as a photocatalyst began in the 1990s. It was found that titanium oxide particles of 20 nm diameter or smaller are highly active. The reasons are believed to be an expansion of surface area due to fine-graining, and shortening of the travel distance to the surface, of electrons and positive holes generated by light absorption. Photocatalysts may be the first nanoparticles to be used in our familiar surroundings.

Enhancement of performance utilizing nanotechnology

Enhanced adsorption: The effect of photocatalysts is believed attributable to the action of active oxygen species such as OH radicals which are generated on the surface upon light irradiation. In order to remove environmental pollutants, first of all, the substances must come into contact with the photocatalyst surface, which is where adsorption ability becomes a factor. At night, without light, the photocatalyst is not functioning, but if it can hold on to the contaminants using adsorption, it will be able to dispose of them at dawn.

Micro-mesopore silica material which is cast using polymers adsorbs volatile organic compounds (VOCs) in large amounts. As it also shows fast adsorption-desorption cycle, we are now studying to support photocatalysts on it (Figure A).

Enhanced selectivity: As OH radicals have a high oxidative ability, they indiscriminatingly attack nearby organic matter. If they were to destroy only the desired targets, treatment efficiency would be improved. Therefore, we are trying to achieve selectivity for specific substances by controlling factors such as surface fine structure, acidity, and hydrophilicity. We have confirmed that the surface made hydrophobic by addition of a carbon layer or modification by alkylsilane (Figure B) successfully enhances VOC degradation efficiency. In addition, we are investigating preparation of a specific structure called a nanopod (Figure C).

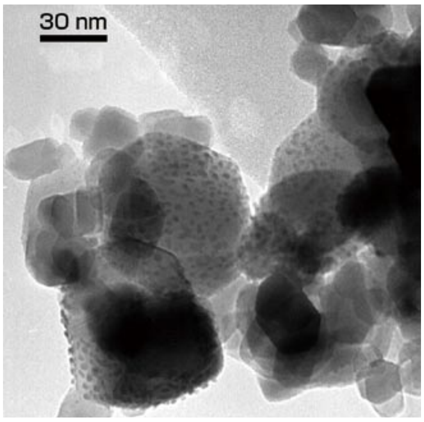


Photo. Palladium-supporting titanium oxide prepared by photodeposition

By using photodeposition exploiting the fact that it is a photocatalyst, it is capable of supporting highly dispersed nanosized metal particles. Using palladium-supporting titanium oxide (Photo), complete oxidation of vinyl chloride becomes possible, and with the silver (Ag)-supporting titanium oxide, stable nitrous oxide can be successfully decomposed. By inverting this configuration, new functions may also be anticipated (Figure D).

Enhanced photonic efficiency: Electron-positive hole charge separation is improved with support of metals, as is light use efficiency. However, in order to achieve efficient functioning of titanium oxide indoors as well, response to visible light is essential. The most effective doping at present has been achieved through treatment of titanium oxide under an ammonia atmosphere. By calcinating a titanium complex containing nitrogen, AIST has succeeded in increasing the uniform nitrogen concentration within the photocatalyst to enhance activity.

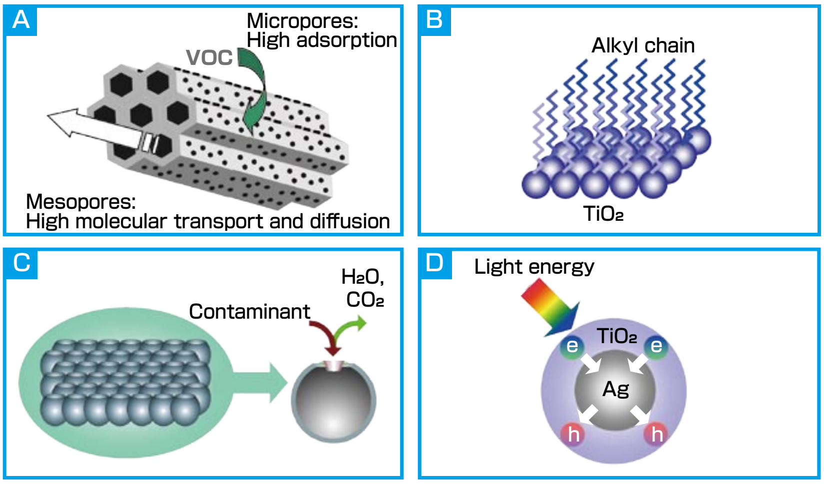


Figure. Enhancing photocatalyst performance through three-dimensional structure control
A: Utilization of micro-mesopore silica adsorbent
B: Enhancement of selectivity through surface modification (this example: improvement of VOC degradation activity by hydrophobization)
C: Nanopod possessing molecular recognition function (aggregation of TiO_2 hollow particles)
D: Photocatalyst of core-shell structure (the inverse of metal-support; aims to enhance efficiency of active oxygen generation and electron storage)

Research Institute for Environmental Management Technology
Koji Takeuchi

A high-performance capacitor using singled-walled carbon nanotubes

Electric double layer capacitor

The electric double layer capacitor has high power (high output), is maintenance-free (high cycle life) and is highly safe. A new market is presently developing for its use as a power source in rapid preheating, as its capability of rapid discharge eliminates the necessity for standby power, thereby making energy saving possible in various equipments.

The capacitor is capable of rapid charge and discharge compared to the lithium ion secondary battery but also has the disadvantage of a small capacity of stored energy. The greatest challenge in capacitor development is to increase the stored energy, or in other words, realize a high energy density, but we have already reached the limit using the current activated carbon electrodes. Consequently, the development of capacitors using carbon nanotubes (CNTs) as electrodes is anticipated.

The potential of CNT electrodes

In order to achieve high energy density, it is essential that the electrode surface area be large. Using “supergrowth technology,” an innovative CNT growth technique (details are introduced in page 6 of this pamphlet), it is possible to prepare long single-walled nanotubes in a high-density vertical array (Figure 1), which we have named the “CNT forest.” The CNT forest possesses a large surface area unparalleled by any of the existing CNTs. Breakthrough improvements in energy density can be achieved by using it as a capacitor electrode. Further, as it does not have the contact resistance seen in activated carbon electrodes prepared by powder molding, the internal resistance of the cell ascribable to electrode material is minimized (Figure 2). This indicates that it has excellent charge/discharge characteristics as a charge storage device and is thus capable of achieving a high power density.

The project and its anticipated economic ripple effects

The “Carbon Nanotube Capacitor Development Project” was launched in FY2006, led by AIST. Although there are high hopes for CNT capacitors as they show high performance, their manufacturing cost must be drastically reduced in order to allow practical application. Development of a mass synthesis technology for CNT is indispensable to that end. This project works to develop a mass synthesis technology for CNT forests, as well as to develop a high energy density capacitor using the CNT forest.

Electric double layer capacitors of high energy density are anticipated for energy-saving uses in diverse fields, from the compact types in portable devices, to the medium-sized types in power supplies for preheating copy machines and printers. In addition, there is an extremely large market potential for large-scale types, as regenerative power sources in automobiles and railways, as well as power sources in hybrid vehicles which require high-power charge storage devices. They are thus anticipated to contribute to energy conservation in a large way.

Research Center for
Advanced Carbon Materials
Motoo Yumura

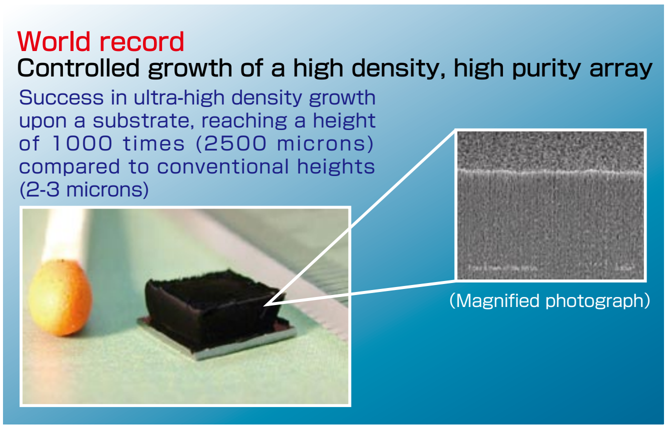


Figure 1. CNT forest (Kenji Hata et al., Science 306 (2004) pp.1362)

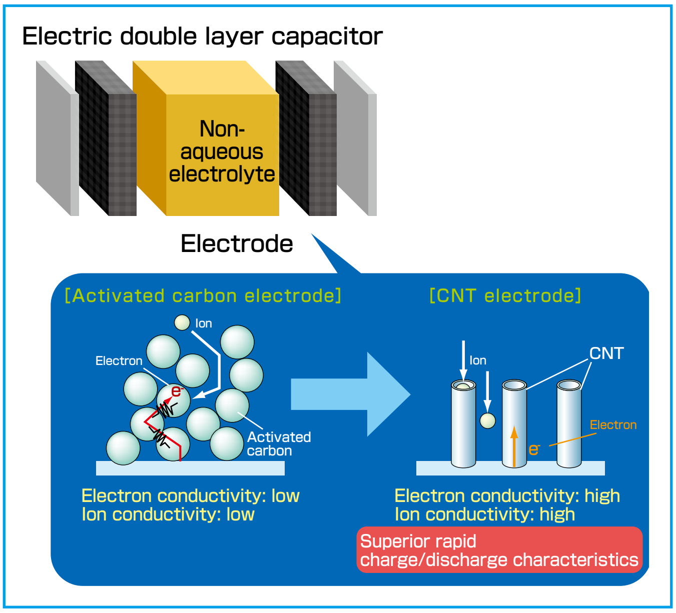


Figure 2. Comparison of activated electrode and CNT electrode

Lithium ion secondary battery utilizing nanostructures

With the progress in electric vehicles and mobile electronic products such as cell phones, increasingly high energy capacity and high power are demanded of lithium ion secondary batteries. In response to such demands, we have been attempting to apply active materials possessing nanostructures to the electrode of the lithium ion secondary battery.

Enhanced energy capacity and high power through increased surface area

When materials are made smaller to sizes in the nano-order, they exhibit properties differing from those of their bulk form. The same result has been also observed when applying nanosize active materials to the electrode of the lithium ion secondary battery. For example, it had been known that insertion/extraction of the lithium ion into/from anatase type titanium dioxide (TiO_2) is possible, but insertion/extraction of the lithium ion into/from the rutile type TiO_2 is nearly impossible. However, if the size of the rutile type TiO_2 becomes as small as 15 nm, insertion/extraction of the lithium ion becomes possible, and the charge/discharge capacity reaches as high as 365 mAh/g. Further, regarding anatase type TiO_2 as well, the theoretical capacity in bulk is about 167 mAh/g, but in nanoparticles of 6 nm, the charge/discharge capacity increases to 360 mAh/g. In this way, even conventional active materials show significant increases in charge/discharge capacity when made smaller to the nanosize, owing to the effect of increased surface area.

Enhanced performance due to increased surface area is also apparent in the power characteristics. The 6 nm anatase type TiO_2 nanoparticle achieves a high charge/discharge capacity of 240 mAh/g even at the high rate (rate = speed of charge/discharge) of 10A/g. Further, using the nanoporous crystalline TiO_2 which possesses the same high surface area as this nanoparticle, increased charge/discharge capacity and improved power characteristics (about 380 mAh/g at the low rate of 0.1 A/g, and about 260 mAh/g at the high rate of 10 Ah/g) have been observed. The improvement in power characteristics is enabled by the lithium ion and electrolyte being able to move easily into the nanopores (Figure 1). In the case of nanoparticles, likewise, there are nano-order pores between the particles.

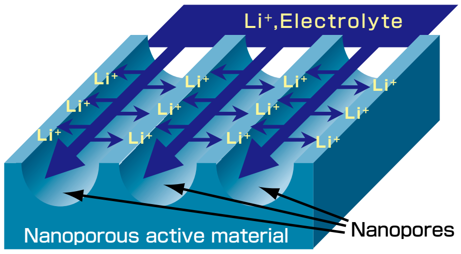


Figure 1. Image of diffusion path of lithium ions (Li^+) through nanopores of a nanoporous active material

Achieving further high power through construction of conductive paths

Oxidation-reduction by ions and electrons is involved in the charge and discharge of secondary batteries, not limited to lithium ion secondary batteries. In order to realize high power (charge/discharge in a short period of time), it is necessary to establish an efficient diffusion path for lithium ions to the active material, as well as an electronic conductive path for the electrons. Therefore, we have constructed a complex consisting of electrically conductive metal wire coated with an active material having a nanoporous structure, at a thickness of about several hundred nm. With the metal wire acting as the conductive path for electrons and the nanopores serving as the diffusion path for the lithium ions, each fulfills its own role (Figure 2).

In NiO/Ni systems, we have already achieved a charge/discharge capacity of about 800 mAh/g against the active material, even at the high rate of 10A/g. Presently, we are attempting to increase energy capacity and high power of the lithium ion battery by coating active materials possessing nanoporous structures on the surface of electrically conductive nanowires and nanotubes.

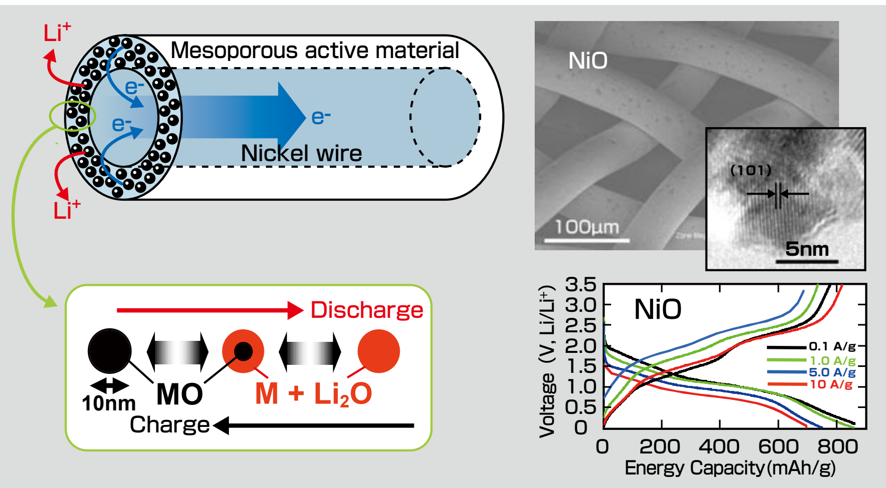


Figure 2. Achievement of both an electron conduction path and an ion diffusion path by structuring nanoporous active material on metal wire

Energy Technology Research Institute
Haoshen Zhou

Public Acceptance of Nanotechnology

From responsible research and development to innovation in nanotechnology

The challenge for a new methodology of technological development

The process of any new technology being accepted into society is accompanied by various obstacles and difficulties, no matter how superb the technology. Nanotechnology, for which high prospects are anticipated, is no exception, and its public acceptance is in fact making extremely slow progress.

What moral lessons have we learnt from our research and development in science and technology up to now and from the history of the public acceptance of such technologies, and how must we put these lessons to good use in the research and development of nanotechnology? The challenge of achieving a new methodology for technological development, which starts with considerations for societal impacts and public acceptance from the stages of research and development, is about to begin for nanotechnology.

Movements in research of the societal implication of nanotechnology

The U.S. government held its first workshop regarding societal implication in September, 2000, and since, has allocated roughly 10% of the nanotechnology budget to research regarding societal implication. A feature of this allocation is that it includes not only risk-related research, but also many development topics of core technologies whose public acceptance is not easy, reflecting the government's efforts to place emphasis on return of research and development investments as a result of the lesson learnt from the case of genetically modified organisms (GMOs). This basic stance is reflected in the systemization of functions in Woodrow Wilson International Center for Scholars (WWICS) for research of public acceptance of emerging technologies, as well as in programs such as the "Green nanotechnology Initiative" led by the Environmental Protection Agency (EPA).

EU as well, is undertaking comprehensive initiatives related to societal imlication, beginning with risk evaluation of nanoparticles. Further, of growing interest are efforts by the UK which is advancing its own public acceptance initiatives. In response to the report compiled by the Royal Society and the Royal Academy of Engineering in July, 2004, the British government established an inter-ministry collaborative system for research and policy formulation regarding the societal implication of nanotechnology in February of the following year. At the same time, it established frameworks for dialogue and debate in order to reflect public opinion in the system, and supports such activities in terms of funding as well.

Such initiatives regarding societal issues were slow to develop in Japan, owing to various reasons such as subconscious negative awarenesses, stemming from the misinterpretation that risk = Kiken (danger), that hampered development of risk-based discussions, and the negative effects remaining from the government's vertical administrative structure, of promotion-oriented factions rivaling restriction-oriented factions. The situation in Japan only began to change significantly from 2004.

From an open forum to a project

We have held open forums since August 5, 2004, with the objective of availing a place for information sharing in Japan regarding this issue and for creating a network. We have been working upon the basic stance of approaching both the risks and the benefits of nanotechnology, objectively and correctly. At the Keidanren hall on February 1, 2005, Japan's first comprehensive symposium regarding the societal impacts of nanotechnology was held, by AIST, the National Institute for Materials Science, the National Institute for Environmental Studies, and the National Institute of Health Sciences of the Ministry of Health, Labour and Welfare, and backed by relevant ministries.

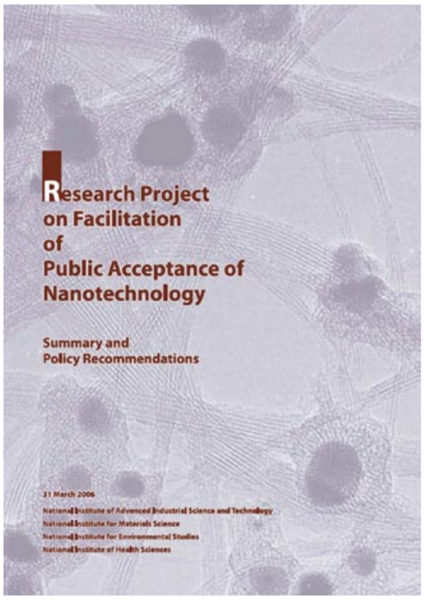


Photo 1. Summary and Policy Recommendations on Public Acceptance of Nanotechnology

The framework of coordination between these four public research institutes is carried on in "Research Project on Facilitation of Public Acceptance of Nanotechnology," a project in the FY2005 Project for Special Coordination Funds for Promoting Science and Technology of the Ministry of Education, Culture, Sports, Science and Technology. In the project, 70 participants conducted investigations aiming to make policy recommendations regarding issues such as risk management, environmental impact, health impact, and ethical/social issues. On February 1, 2006, the international symposium "Exploring the Small World: Role of Public Research Institutes" was held, and the results of investigative research by the project were reported.

The policy proposals compiled by the project regarding responsible research and development of nanotechnology were reflected in the strategies for the field of nanotechnology/materials in Japan's Third Science and Technology Basic Plan for 2006-2010 by the Council for Science and Technology Policy. Specifically, standardization of nanotechnology, risk control measures, outreach activities, literacy enhancement, and education/

human resources development are indicated, among others, as the issues to be tackled by various ministries. An example of materialization of the above is the launch of activities of the NEDO-sponsored new research and development project "Risk Assessment & Management of Manufactured Nanomaterialas" led by Dr. Junko Nakanishi, Director of the Research Center for Chemical Risk Management at AIST.

Turning social issues into a driving force for creation of innovation

In 2005, the year we launched the project mentioned above, AIST also launched projects for risk management of nanoparticles and standardization of nanotechnology. The prompt actions taken by AIST in response to expectations of private-sector corporations and the government since then have evolved significantly, and AIST has already become a global leader regarding social acceptance of nanotechnology.

Attempts to position the issues, such as societal impact and public acceptance encompassing risk management and standardization, in the stages of research and development constitute an original research and development strategy of AIST, aimed at creation of innovation from core technologies. At the same time, AIST is expected to generate large outcomes which are required in the runup to full scale development of nanotechnology. These include the streamlining of various relevant laws, industrial standardization, and development of social platforms including risk governance. Consideration for the issues such as standardization and risk management during the process of core technology development is truly the driving force behind the creation of innovation from AIST.

Responsible research and development and public acceptance

From June 26 to 28, 2006, at the Gakushikaikan, we held the Second International Dialogue on Responsible Research and Development of Nanotechnology, in which about 90 participants gathered from 21 countries as well as Taiwan and EU, to carry out discussions regarding the following five topics: environment health and safety issues, ethical legal and societal issues, education and capacity building, developing country issues, and nanotechnology standardization setting.

In the keynote lecture, AIST's President Hiroyuki Yoshikawa raised the point that it is important to maintain harmony instead of mutual exclusion in the maturation of both technology and society. The fundamental concept of this harmony is that we, the researchers, are required not to simply indicate the benefits offered by nanotechnology, but to form a societal consensus regarding the degree of the unavoidable risks that can be accepted, based upon a neutral assessment of risks and benefits. The responsibility of the researchers is to advance this assessment scientifically and link it to the research and development of core technologies, in order to implement responsible research and development. In doing so, we may lead core technologies, without imposing, to harmonious creation of innovation. This is what one of the participants described as "responsible innovation."

The future society opened up by nanotechnology

Not only does nanotechnology improve our lives by dramatically advancing existing technologies, but it constitutes a new technology that will also prove useful in resolving various issues facing society today, such as energy and food. However, looking at reality, according to statistics of the World Bank, we find that half of the world's population of 6.5 billion has no access to clean water and suffers poverty with no prospects for the future. In Japan as well, as we advance technological developments only prioritizing economics effects, we are seeing a widening of the social divide, the resulting strain of which is beginning to cause social instability.

In order to realize our common dream of a sustainable future society filled with the benefits of science and technology, we need to establish a new methodology for research and development of nanotechnology encompassing the perspective of social acceptance, and execute it responsibly as well as reform the awareness of researchers.

Technology Information Department
Masafumi Ata

Photo 2. The Second International Dialogue on Responsible Research and Development of Nanotechnology

Research Hot Line

UPDATE FROM THE CUTTING EDGE

Oct.-Dec. 2006

The abstracts of the recent research information appearing in the Vol.6 No.10-12 of "AIST TODAY" are introduced, classified by research area. For inquiry about the full article, please contact the author via e-mail.

Information Technology & Electronics

Inter-domain Advance Reservation of Coordinated Network and Computing Resources over the Pacific

To provide a stable service using resources such as computers and storages connected to a network, it is important to have a guaranteed bandwidth on the network. The G-lambda project, which AIST, KDDI R&D labs, NTT and NICT are promoting, in cooperation with the US Enlightened computing project, successfully conducted an experiment in which bandwidth between Japan and the US and computing resources in Japan and the US were simultaneously reserved and the applications were executed. This was the first experiment carried out at such scale in the world.

Figure : Map view of activated resources

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AIST TODAY Vol.6, No.12
p.18-19 (2006)

A Portable High-speed DNA Analysis Device

A micromachined fluorescence detector has been developed in which an optical interference filter is monolithically integrated and patterned on an amorphous silicon photodiode. The detector can be combined with an excitation light source and the limit of detection is as low as 7 nM of fluorescein concentration. We have also succeeded in the separation and detection of DNA fragments with a high speed, a high sensitivity and a high separation efficiency, using a compact device combining the micromachined fluorescence detector and a microfluidic electrophoresis chip (Figure). This technology will constitute a basic platform to realize compact diagnostic devices, enabling high-speed point-of-care analysis of DNA, RNA, proteins, saccharide chains, etc.

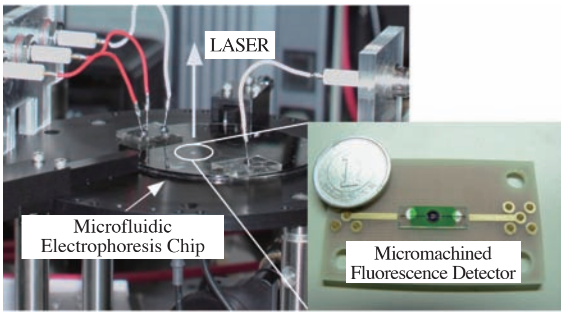

Figure : A portable high-speed DNA analysis device incorporating the micro fluorescence detector.

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AIST TODAY Vol.6, No.12
p.20-21 (2006)

Massive Synthesis of Organic Nanotubes

We have newly designed and synthesized amphiphilic molecules, and have developed a technique for the synthesis of various organic nanotubes of 40-200 nm in inner diameter, 70-500 nm in outer diameter, and several to hundreds µm in length by self-assembling them in organic solvents. This method needs less than one thousandth of the solvent used by conventional methods, enabling mass-production of organic nanotubes (Figure). Since they have excellent dispersibility in water, unlike carbon nanotubes, and can encapsulate guest substances of over 10 nm in size, such as proteins and nucleic acids, they are expected to be applied in various fields such as medicine, health, and nanobio-technologies.

Figure : (Left) white powders (100g) consisting of organic nanotubes (mean outer diameter : 80nm, and mean inner diameter : 60nm), and (right) a scanning electron micrograph of the organic nanotubes.

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AIST TODAY Vol.6, No.10
p.20-23 (2006)

Establishment of a Technique for Production of High-performance Thin Films with Laser Irradiation

By combining a metalorganic deposition (MOD) method with an excimer-laser annealing technique, we have developed a novel process, excimer-laser-assisted MOD (ELAMOD), to produce high-*Tc* oxide superconducting films ($YBa_2Cu_3O_7$: YBCO). The process realized the improvement of film characteristics as well as the enhancement of film production efficiency. In the production of epitaxial YBCO thin films, we have achieved critical current densities, *Jc*, of over six million A/cm^2, which is of the world's highest class. This value is comparable to or greater than those of superconducting thin films produced by high-cost physical processes. Our process enables the cost reduction and mass production of thin film devices, long tapes, large-area devices, etc.

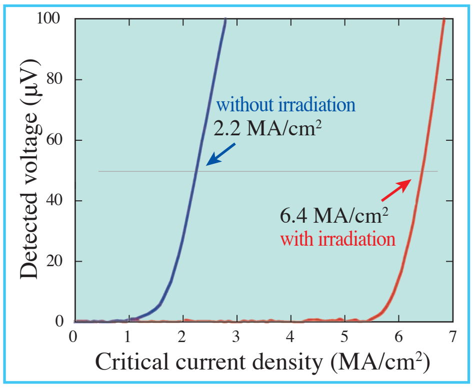

Figure : Performance gain by laser irradiation

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AIST TODAY Vol.6, No.11 p.12-15 (2006)

Development of a Liquid Crystalline Organic Semiconductor Forming a Helical Structure

Cholesteric liquid crystals have been drawing much attention because of their helical structure, which can be applied to circularly polarized emission and optically pumped laser. However, conventional cholesteric liquid crystals are insulators and cannot be applied to electrically pumped devices. We synthesized cholesteric liquid crystals exhibiting semiconductive carrier transport properties. A dimeric cholesteric semiconductor was also synthesized and circularly polarized luminescence was observed.

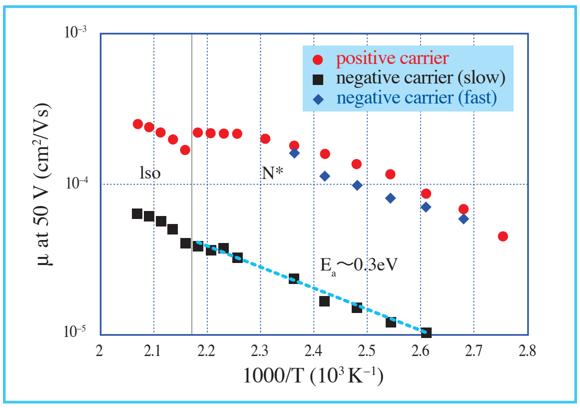

Figure : Temperature dependence of charge transfer mobility

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AIST TODAY Vol.6, No.10 p.26-27 (2006)

Development of a Pipe-type Module for a Power Generating Heat Exchanger

We have developed a pipe-type thermoelectric module for use in heat exchangers that can simultaneously generate steam superheated above 100°C and electricity from the combustion heaters and cooking stoves. Thermoelectric ceramics, which are stable even in extremely hot air, are used to cover stainless steel tubes in electricity generating modules. This cover prevents the contact between flame and the stainless steel tube that acts as a heat exchanger, protecting the metal tube and extending the useful life of the heat exchanger. Control of the flame temperature will suppress the formation of nitrogen oxides (NO_X) or carbon monoxide (CO), which are products of incomplete combustion.

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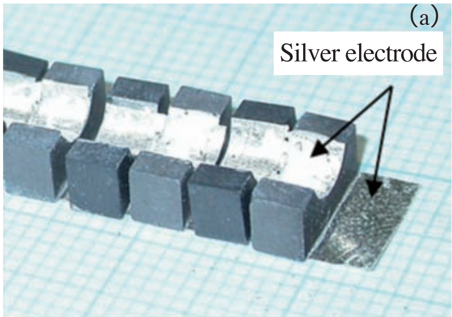
p.28-29 (2006)



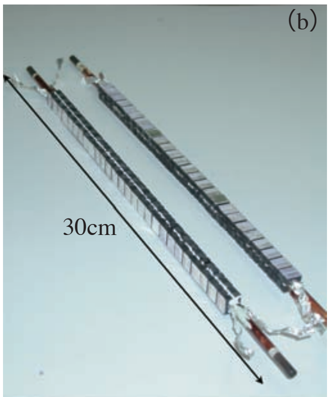


Figure : (a) Elements attached with Ag electrodes
(b) Appearance of the pipe-type module developed

Development of a Nano-scale Dispersion Technique for Immiscible Polymer Blends

We have developed a new polymer-blending technique with a high-shear flow field without any additives. The technique realized nano-scale dispersion of immiscible polymers. The domain sizes of the dispersed polymer phase are over one order smaller than those prepared using conventional methods. Our technique is also considered to be useful for inorganic dispersants such as carbon nanotubes. As no additive is necessary, the technique is also applicable to medicines and cosmetics.

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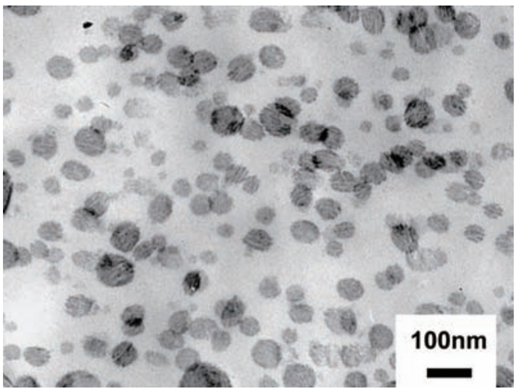

Figure : A transmission electron microscope image of a PVDF/PA11 blend prepared using high-shear processing. PA11 of ten to several tens of nanometers in diameter (round black parts) is homogeneously dispersed densely in the PVDF matrix (white background region).

PVDF : poly (vinylidene fluoride)
PA11 : polyamide 11

A High-performance Catalyst for Purification of Exhaust Gases

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AIST TODAY Vol.6, No.11
p.18-19 (2006)

We have developed a highly porous platinum-alumina cryogel catalyst for exhaust gas purification with high activity and superior thermal stability. The reaction temperature of this catalyst is lower by about 100ºC than that of conventional catalysts, and the thermal resistance has been improved to approximately 200ºC. The advantage of this catalyst, together with the use of low cost aluminum hydroxide as the starting material, and the implementation of a low cost and simple process such as freeze-drying, will lead to the spread of its applications.

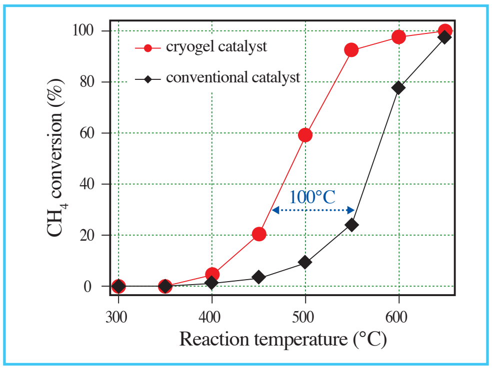

Figure 1: Methane combustion activity on platinum-alumina catalysts.

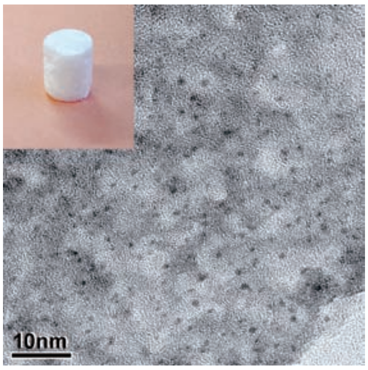

Figure 2: Platinum-alumina cryogel catalyst with 18 mm in diameter and 23 mm in height (upper), and nanoscaled platinum particles in the cryogel. The platinum content is 5wt%; black spots correspond to the platinum particles with ca. 1 nm diameter.

High-efficiency Ultraviolet Light Emission from a Diamond Semiconductor

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AIST TODAY Vol.6, No.12
p.22-23 (2006)

We have succeeded in fabricating a diamond *p-i-n* junction diode. The diode emits high-efficiency deep-ultraviolet (UV) light with the wavelength of shorter than 250 nm by current injection at room temperature. This deep-UV light emission has been realized by using the high density excitonic states in diamond, and can be observed even at 200°C. It is also found that the diode shows high internal quantum efficiency. These results indicate that even indirect transition semiconductors like diamond can emit high-efficiency deep-UV light.

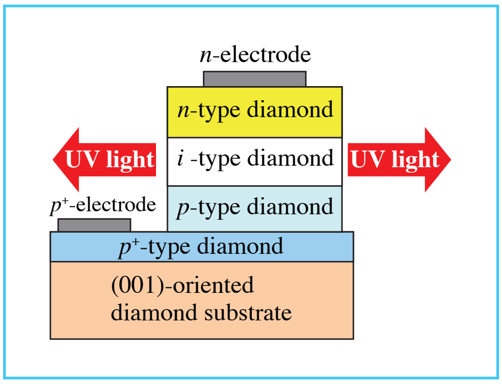

Figure 1: Schematic cross section of diamond *p-i-n* junction diode.

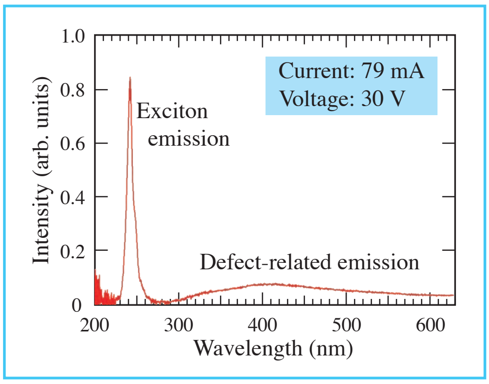

Figure 2: Current injected light emission spectrum at room temperature.

Micro-thermoelectric Hydrogen Sensor

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AIST TODAY Vol.6, No.12
p.24-25 (2006)

We have demonstrated the performance of a newly-designed micro-thermoelectric hydrogen sensor. Integration of thermoelectric thin film of SiGe and ceramic catalyst into a micro hot plate on a thin membrane has improved its performance, allowing for detection of a wide-range concentration of hydrogen in air from 0.5 ppm to 5 v/v %.

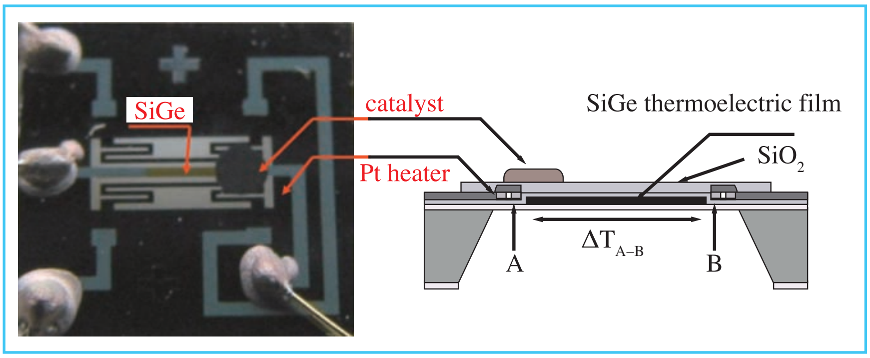

Figure : Left; photograph of micro-thermoelectric hydrogen sensor with the ceramic catalyst deposited on the membrane. Right; schematic of the sensor structures of microheaters.

Microwave-assisted Polyester Synthesis

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p.24-25 (2006)

Rapid synthesis of aliphatic polyesters by direct polycondensation, which does not generate any wastes, is an ideal method for producing polyesters. We report a rapid, environmentally-benign, solvent-free method for synthesis of poly(butylene succinate) (PBS) and poly(lactic acid) (PLA) through microwave irradiation in the presence of tin catalyst. The microwave irradiation accelerated the polymerization rate more than 10 times compared with the conventional heating method. PBS with average molecular weight (M_w) of 29000 and PLA with M_w of 16000 were obtained within 30 minutes.

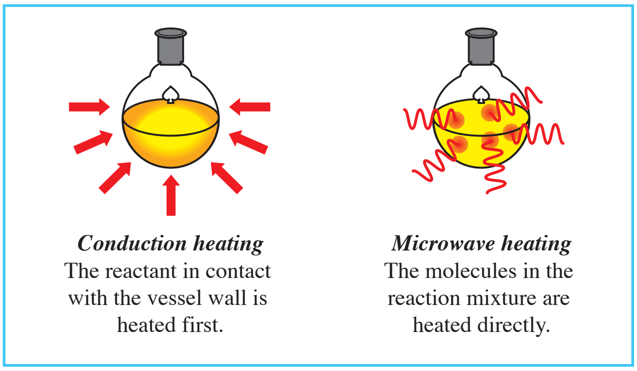

Figure : Schematic of sample heating by conduction versus microwave

Monitoring of Pyrolytic Gas Evolution

A new instrument for evolved gas analysis (EGA) has been developed using a skimmer interface and IA-QMS (Ion Attachment Quadrupole Mass Spectrometer). The skimmer interface is a new interface device between an infrared image furnace and an MS, for sampling of gaseous species produced by pyrolysis. It offers gas sampling with no change and higher sensitivity. The IA-QMS can measure a mass spectrum with no fragmentation during the ionization. As its application to pyrolysis of organic additives for ceramic processing, monitoring of individual polymer pyrolysis has been successfully carried out to pyrolytic gas evolution from mixtures of different polymers.

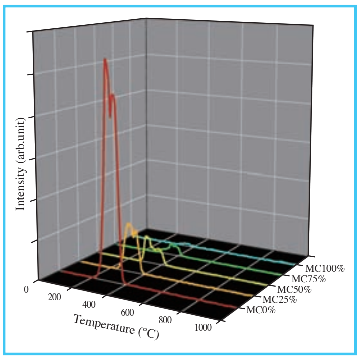

Figure 1: EGA curves of m/z = 77 as a specified indicator of PVA pyrolysis behavior in PVA/MC blended binder.

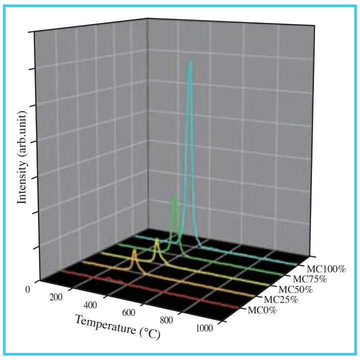

Figure 2: EGA curves of m/z = 81 as a specified indicator of MC pyrolysis behavior in PVA/MC blended binder.

PVA : polyvinyl alcohol
MC : methyl cellulose

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p.20-21 (2006)

Observation Technique of Low-temperature Object by Phase-contrast X-ray Imaging

Nondestructive imaging of air clathrate hydrates

A non-destructive observation and the absolute density analysis method of air clathrate hydrates in ice core were developed. Phase-contrast X-ray CT is considered to be a powerful tool for nondestructive observation due to its high density resolution. We developed a cryochamber and a liquid cell, which enabled low-temperature X-ray CT measurements from –80°C to room temperature. The technique can be applied to the imaging of temperature-induced phase or compositional change of various materials besides various gas hydrates.

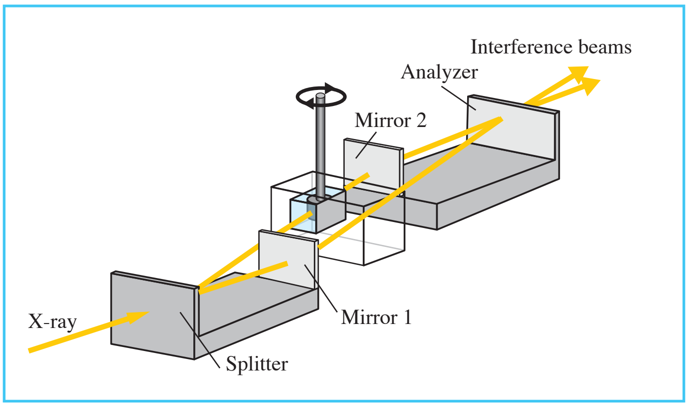

Figure : Measurement principle of a low-temperature phase contrast X-ray CT device

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Development of Cryocooler without Liquid Helium Cryogen

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p.26-27 (2006)

We developed a ^{3}He cryocooler that can reach down to 0.6 K. It consists of a mechanical refrigerator and a closed-cycle ^{3}He Joule-Thomson expansion circuit. Since the cryocooler uses a mechanical refrigerator for pre-cooling, it does not require cumbersome liquid helium as a cryogen. The developed cryocooler can run for over a month with a simple procedure. We are developing a thermometer calibration apparatus on the basis of the developed cryocooler. The cryocooler can also be applied to other general apparatuses that require low temperature environment.

Figure : Photograph of the developed ^{3}He cryocooler.

H. R. H. Princess Sirindhorn of Thailand Visits AIST
AIST Participated in the National Science and Technology Fair 2006 in Thailand

Her Royal Highness Princess Maha Chakri Sirindhorn of the Kingdom of Thailand visited AIST Tsukuba on August 22, 2006. Also known as the "Princess of Technology" or the "Princess of Information Technology," Princess Sirindhorn is well versed in science and technology and highly admired by the Thai people as the intellectual successor to His Majesty the King.

Princess Sirindhorn was accompanied by her niece Khun Sirikittiya Jensen; H.E. Mr. Suvidhya Simaskul, Ambassador of Thailand to Japan, and his wife Mrs. Boontipa Simaskul; Dr. Paritud Bhandhubanyong, Director of the National Metal and Materials Technology Center (MTEC), National Science and Technology Development Agency (NSTDA); and 25 Thai officials.

After being warmly welcomed by the top officials and visiting Thai researchers at AIST Tsukuba, Princess Sirindhorn visited Science Square Tsukuba (SST), the hands-on museum of AIST. At SST she observed a number of state-of-the-art technologies, including standards and measurement technologies, a tactile display system for people with severe visual impairments, a single-crystal TMR device, an electromyogram interface, and an intelligent wheelchair. She then toured the Open Space Laboratory (OSL) Building where she inspected a photovoltaic power generation system and an exploratory humanoid robot.

We at AIST were deeply impressed with the great interest Princess Sirindhorn showed in our technologies, asking many questions and taking notes and pictures herself. We would like to express our sincere gratitude again to Princess Sirindhorn, who took the time to visit us despite her tight schedule. We hope her visit will further promote partnerships in research between AIST and our Thai counterparts.

In fact, Princess Sirindhorn's visit to AIST Tsukuba reflected the recent growth of such partnerships, although it was arranged while Princess Sirindhorn was in Japan to attend an international conference jointly organized by United Nations University and the United Nations Educational, Scientific and Cultural Organization (UNESCO). In June 2001, AIST concluded a specific research cooperation agreement with the National Institute of Metrology Thailand (NIMT). AIST signed a general cooperation agreement in November 2004 with NSTDA and the Thailand Institute of Scientific and Technological Research (TISTR). Based on these agreements, AIST has strengthened its mutually supportive relations with these institutes strategically through workshops and joint R&D. Last year AIST jointly organized the Second Biomass-Asia Workshop in Bangkok with the Thai government and research institutes. In addition, AIST participated in the National Science and Technology Fair of Thailand in 2005 and 2006 and exhibited a number of technologies, including some of the products of joint research with its Thai counterparts.

The annual National Science and Technology Fair is organized by the Thai government as part of its ardent efforts to support S&T promotion and education. The 2006 Fair was held in the Bangkok International Trade and Exhibition Centre (BITEC) for 12 days from August 11 through 22. More than 1 million people in total, which included many primary and middle school students, visited the event.

Princess Sirindhorn toured the venue on the first day of the event. At our booths she inspected our exhibits with much interest. Among them were a minibus powered solely by biodiesel fuel (BDF)—a product of our joint research with NSTDA/TISTR; and our project to develop PARO, a seal-type mental commitment robot (AIST gave PARO to Princess Sirindhorn as a gift last year).

AIST exhibited under seven themes. Some of the products of our joint research with NSTDA and TISTR were presented using boards and videos with Thai translations as well as exhibits. Researchers from NSTDA, TISTR, other institutes, and universities helped us with our exhibition. Thanks in large parts to their help, all of our booths attracted many visitors. The BDF-powered minibus, which had been brought from Japan, carried visitors within the venue every day as a demonstration.

In Thailand as well we held a working-level meeting with researchers and officials of our counterparts on the progress and future prospects for joint research. The participants decided to chart the future course of action at the next round of the Thailand-Japan Collaboration Workshop (AIST-NSTDA-TISTR).

International Workshop on Biochips and Environmental Monitoring

On August 17 and 18, 2006, the Third International Workshop on Biochips and Environmental Monitoring was held at AIST Kansai. The biennial workshop, which was organized this time by the Human Stress Signal Research Center (HSS), focused on the application of OMICS (genomics, proteomics, and metabolomics) technology to environmental stress analysis and its future prospects. A total of 76 researchers participated, including those from the US, Germany, the UK, and South Korea.

It started off with opening remarks by Hitoshi Iwasaki, Deputy Director of HSS and the organizer of the workshop; and Etsuo Niki, Director of HSS. A total of 11 lectures were given on the first day, focusing on genomics and proteomics and covering a wide range of species of animals, plants, microorganisms, etc. Some of the lectures concerned innovative and promising technologies that have already been put to practical application. In addition, young researchers from Japan, South Korea, etc. gave a total of 19 poster presentations.

The second day of the workshop focused on metabolomics, and 5 lectures were given. Researchers in metabolomics have been competing with one another to refine analytical methods, including nuclear magnetic resonance spectroscopy (NMR), gas chromatography-mass spectrometry (GC-MS), and capillary electrophoresis-mass spectrometry (CE-MS).

Among the lecturers were Dr. Oliver Jones doing research at the University of Cambridge under the leadership of Dr. Jules L. Griffin, the leading authority on NMR-based metabolomics analysis; Dr. Tomoyoshi Soga of the Keio University, the top-ranking expert in CE-MS-based metabolomics analysis; and Dr. Wolfram Weckwerth of the Max Planck Institute of Molecular Plant Physiology, who was studying intensively in GC-MS-based metabolomics analysis. The workshop offered an invaluable opportunity to learn about the latest developments in these analytical methods at one time, providing important clues as to the future of these technologies.

The next workshop will be held in South Korea in 2008.

A Delegation of NRC Canada Visits AIST

On September 8, 2006, a delegation of the National Research Council of Canada (NRC Canada) led by its president, Dr. Pierre Coulombe, visited AIST Tsukuba. They were welcomed by AIST Senior Vice-President Kisaburo Kodama and briefed on AIST by Vice-President Masakazu Yamazaki. They then toured some of the research units at AIST Tsukuba: the Energy Technology Research Institute, the Metrology Institute of Japan, the Institute for Human Science and Biomedical Engineering, and the Nanotechnology Research Institute.

NRC is best known for the innovative achievements of its institutes, which include the invention of the pacemaker (1940s) and the cesium beam atomic clock (1960s). It has over 20 research institutes across Canada, with one or more institute in each province. With a staff of some 4,000 and a pool of about 1,200 guest researchers, NRC is similar to AIST in terms of the scale of its human resources.

This visit was made in the context of the increasingly close relations between AIST research units and NRC institutes in recent years. In February 2006 two memoranda of understanding on research cooperation were signed. One was between the Metrology Institute of Japan and the Institute for National Measurement Standards regarding reference materials for the measurement and standardization of nanoparticles. The other involved cooperation in such fields as research projects, human resource development, and industrial applications between the Nanotechnology Research Institute of AIST and the National Institute for Nanotechnology. In July 2006 AIST invited Dr. Bruce Baskerville of NRC Canada to speak as a panelist at the Symposium on Strategic Research Evaluation held at AIST Tokyo Waterfront.

A new field for research cooperation was found. The delegation inspected the achievements of the Advanced Fuel Group, Energy Technology Research Institute, which focuses on the production of cleaner fuels from heavy hydrocarbon resources as well as the high-efficiency conversion and utilization of such resources. After returning home, the delegation contacted AIST for possible research cooperation regarding the large reserves of oil sand in the Province of Alberta, Canada.

We at AIST hope that this visit will further promote cooperative relations with NRC Canada.

AIST Renews the General Research Cooperation Agreement with CNRS of France

AIST and the Centre National de la Recherche Scientifique (CNRS, National Center for Scientific Research) of France have renewed the General Agreement on Comprehensive Research Cooperation. AIST President Hiroyuki Yoshikawa and visiting CNRS President Catherine Bréchignac signed the renewed agreement on November 6, 2006. They agreed that Yoshikawa will visit the CNRS headquarters in Paris in February 2007 to exchange views on innovation management as part of efforts to deepen the partnership between the two organizations. The original agreement was concluded on November 21, 2001, since which time AIST and CNRS have maintained a close partnership.

CNRS is the largest public research organization in France. It employs 12,000 researchers and 14,000 engineers. Its budget accounts for about 14% of the national S&T budget of some 16.8 billion EUR (FY2005). The focal points of its research strategy include: (i) partnership; (ii) diversification; (iii) innovation; and (iv) multi-disciplinarity. CNRS promotes collaborations among government, industry, and academia. As part of such collaborations, many of the CNRS laboratories work in partnership with universities. CNRS is also committed to developing networks of innovation clusters across the country.

The partnership between AIST and CNRS covers many research fields. In robotics, AIST and CNRS operate joint laboratories — one in the Open Space Laboratory (OSL) at AIST Tsukuba, and the other in the Laboratory for Analysis and Architecture of Systems (LAAS) of CNRS in Toulouse, France–under a research cooperation agreement between the Intelligent Systems Research Institute and a CNRS department. In materials research for the development of next-generation optical discs, a specific research cooperation agreement is in place between the Center for Applied Near-Field Optics Research of AIST and CNRS/The University of Montpellier II. In environmental catalysis, a joint workshop involving the Energy Technology Research Institute and three other research units of AIST on the one hand and CNRS's research units and universities in France on the other have resulted in a closer partnership. They have agreed to collaborate on environmental catalyst technologies for the sustainable conservation of atmospheric and hydrospheric environments.

AIST Co-organizes International Conference "Renewable Energy 2006"

From October 9 to 13, 2006 AIST co-organized a major international conference on all kinds of renewable energy titled "Renewable Energy 2006", which was the first of its kind in Japan. The conference was held at Makuhari Messe near Tokyo. Under the slogan "Advanced Technology Paths to Global Sustainability," Renewable Energy 2006 attracted 1,063 participants from 55 countries. The conference saw over 600 research presentations, inviting lively discussions.

AIST performed a variety of activities in addition to making a number of research presentations. For example, AIST organized a special session titled "AIST Session: Energy Vision for Future." In the associated event "1st Renewable Energy International Exhibition," AIST exhibited state-of-the-art technologies in such fields as photovoltaics, biomass, geothermal power, fuel cells, and power electronics. AIST also joined forces with the Agency for Energy Management and Environment (ADEME) of France to organize an expert meeting on low-energy buildings.

The AIST Session started off with a keynote speech on the energy technology outlook for 2100 by Makoto Akai, Principal Research Scientist of the Energy Technology Research Institute, AIST. This was followed by a number of informative lectures on the present state and future prospects of advanced technologies in this field. The lecturers included: Dr. Walter Kohn of the US, a Nobel Laureate in Chemistry (solar power); Dr. John W. Lund of the US (geothermal power); Dr. Ralph P. Overend of Canada (biomass); Dr. Teresa Pontes of Portugal (ocean energy); Dr. Goran Strbac of the UK (energy systems); and Dr. Satoshi Morozumi of NEDO, Japan (energy systems).

AIST booths attracted many visitors in the exhibition. A total of over 20,000 people visited the exhibition as a whole, in which 208 exhibitors participated.

Renewable Energy 2006 was closed with the pledge to further support the R&D and promotion of renewable energy.

Japan-Thailand Collaboration Workshop 2006

On November 14 AIST Tsukuba hosted the Fourth Japan-Thailand Collaboration Workshop 2006. A total of nearly 40 people from Thailand participated, including Dr. Sakarindr Bhumiratana, President of the National Science and Technology Development Agency (NSTDA); and Dr. Nongluck Pankurddee, Governor of the Thailand Institute of Scientific and Technological Research (TISTR). The participants from AIST were Senior Vice-President, Kisaburo Kodama, Vice-President, Masakazu Yamazaki, and many researchers involved in related joint research projects.

Under the general agreements between AIST and NSTDA, and TISTR concluded in November 2004, AIST is working on eight joint research projects. Three of them are New Energy and Industrial Technology Development Organization (NEDO) projects consisting of two "proposal-based" projects and a "leading research" project. The other five projects are funded by the NEDO Grant for International Joint Research.

The 2006 Workshop covered 14 themes. Some of them matched the ongoing joint research projects in such fields as IT, environmental energy, and nanotechnology/materials. The other themes were selected based on requests from the Thai participants, including

biodiesel fuel, the installation and standardization of photovoltaic experiment equipment, photocatalyst-based environmental purification technology, biomass promotion, and the application of IT and robots to the treatment of the disabled.

The fifth workshop will be held in late October 2007, expanding its scope to innovation management as well. AIST will participate in a series of Thailand-related events, including the Asian conference on the GEO Grid and a meeting on the efficacy of the mental commitment robot PARO in treating autistic children, both in Bangkok in March; and the National Science and Technology Fair 2007 in mid August.

On November 15, Dr. Sakarindr and Dr. Nongluck met with President of AIST, Hiroyuki Yoshikawa, in Tokyo. They appreciated the fact that the three organizations had successfully been strengthening cooperative relations. This fact was reflected in the research partnerships and personal exchanges as reviewed in the workshop the day before, as well as a series of recent events like the Biomass-Asia Workshop in December 2005, AIST's participation in the National Science and Technology Fair 2006 in Thailand, and H.R.H. Princess Sirindhorn's visit to AIST. The heads of the three organizations agreed to further strengthen the partnership to produce more tangible outcomes.

AIST-VAST Workshop

On November 20, 2006, AIST Tsukuba held a general workshop with the Vietnamese Academy of Science and Technology (VAST).

This was the third workshop of its kind since the two organizations signed a general agreement on research cooperation in Hanoi in December 2004, when the First AIST-VAST Workshop was held concurrently. The Second Workshop took place in Tsukuba in October 2005. Also, the GEO Grid workshop was held in Hanoi in March 2006.

The present workshop was attended by 44 participants, including VAST Vice-President Nguyen Khoa Son and 13 researchers from Vietnam and the rest from AIST.

They worked on an array of themes regarding environmental management such as wastewater treatment, biomass-related technology, marine geology, the GEO Grid, multilingual processing, and open source software. The participants reviewed the developments in the AIST-VAST partnership since the last workshop.

Vietnam is facing such challenges as worsening environmental pollution, growing energy demand, and lagging infrastructural development while experiencing solid economic growth. The workshop participants agreed that increasingly serious environmental degradation in the Mekong River Delta should be addressed by a combination of environmental monitoring (involving the GEO Grid and marine geology), environmental restoration (water quality improvement,etc.), and biomass technology application. They recognized the importance of the promotion of an Asian GEO Grid with Thailand as well as the development of networks involving multilingual processing and other information technology. Industrial wastewater treatment was another case in point. VAST and AIST agreed to work together more closely with a view to formulating a specific project to address this issue.

They appreciated the growing exchange/network of researchers with the help of the AIST Fellowship and other programs. They also discussed future activity plans. A major issue was how to win so-called "competitive research funds" from Japan. The GEO Grid workshop, scheduled for March 2007 in Bangkok, will expand its scope to include Thailand as well Vietnam.

The Fourth AIST-VAST Workshop was decided to be held in Vietnam the coming autumn. They agreed to work even harder to develop partnerships in various fields until then.

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