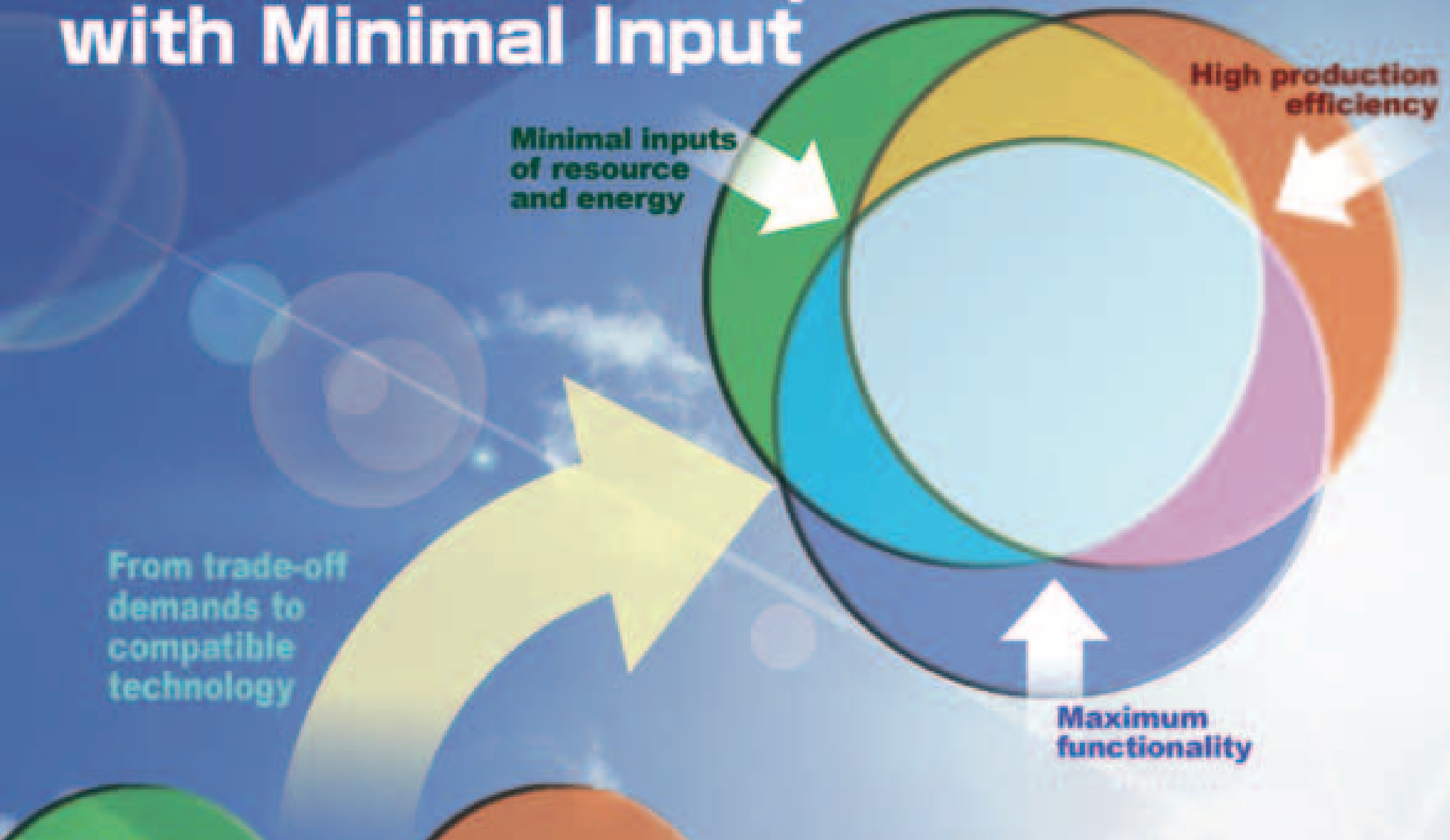
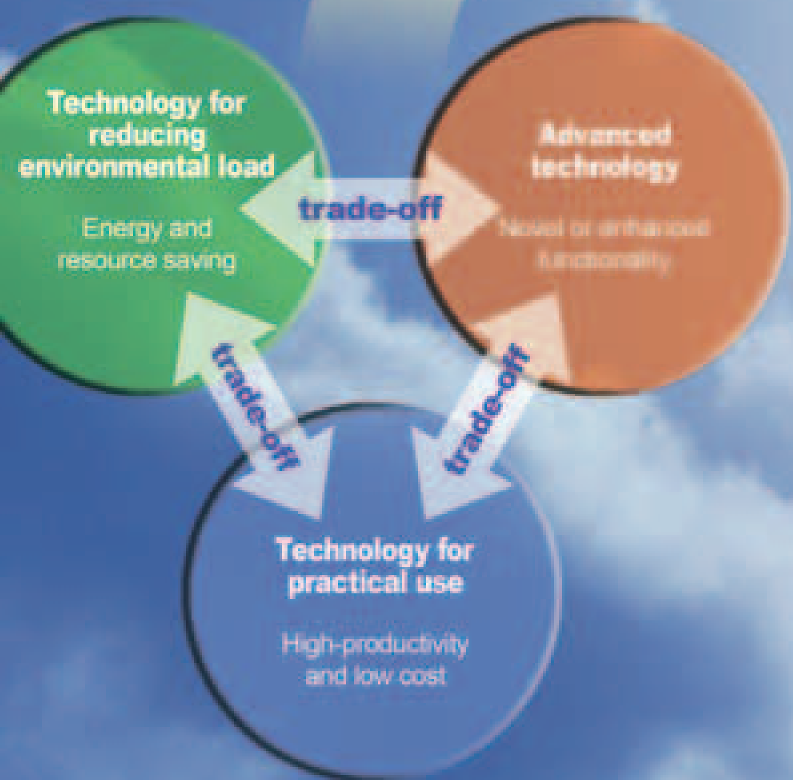
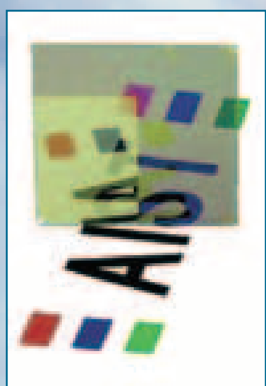
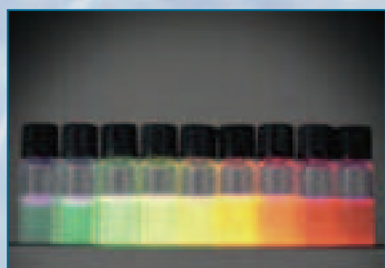
Materials & Manufacturing Technologies in AIST

Get Maximum Output with Minimal Input









Get Maximum Output with Minimal Input

New Approach to Technologies for Materials and Manufacturing

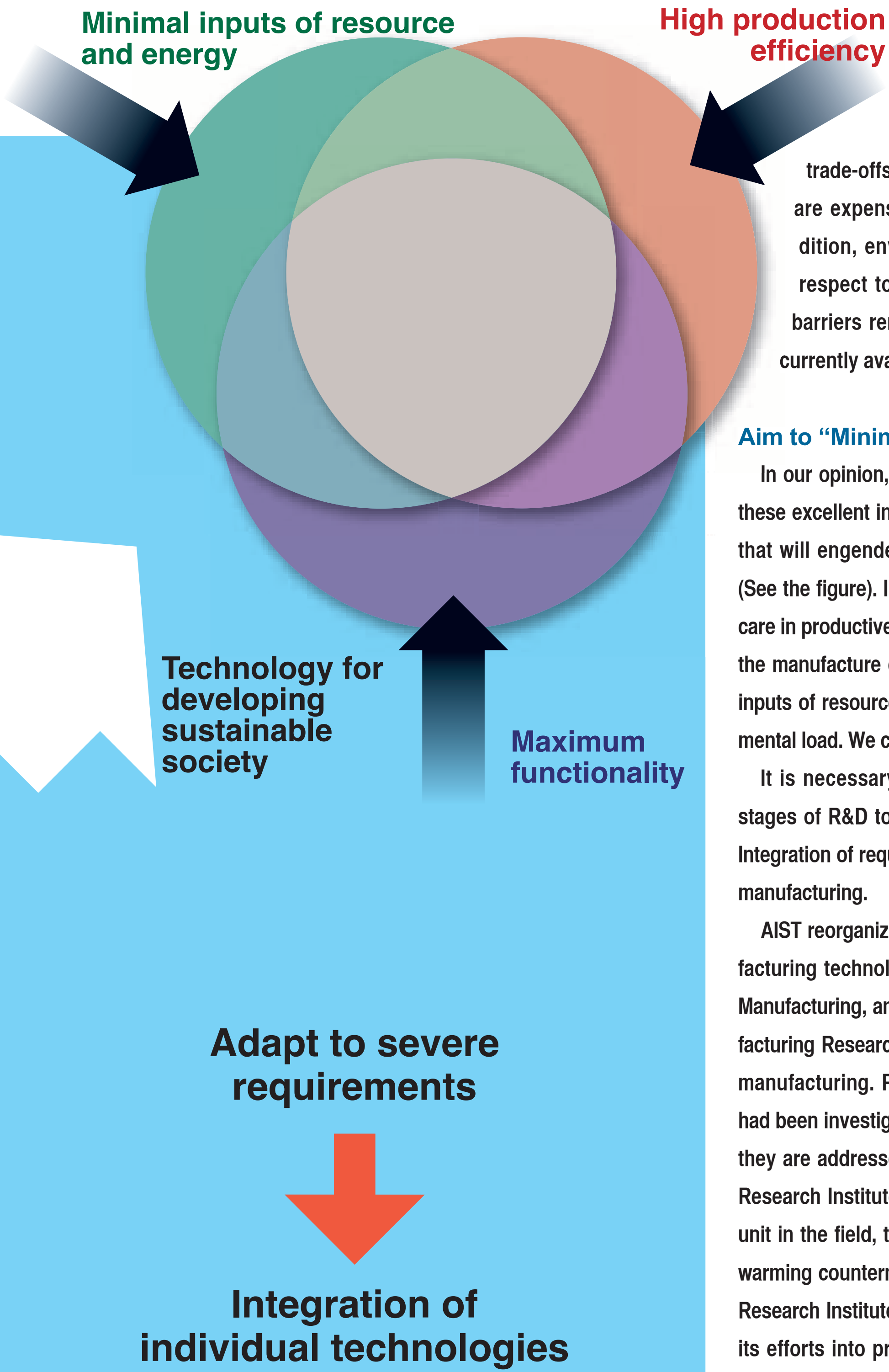
Research Coordinator
Dr. Kazuo IGARASHI

It has been four years since AIST was established. FY2004 marks the final year of its first mid-term plan and the evaluation of progress toward the plan's objectives. This year is also important because it marks the development of the next mid-term plan. At present, we are setting the definite direction of the plan. I will introduce its underlying concept in the fields of Nanotechnology, Materials, and Manufacturing.

For reinforcing materials and manufacturing industries

The international competitiveness of Japanese industries depends strongly on the materials and manufacturing sectors. Presently, those industries are locked in fierce international competition and have been weakened considerably by increasing competition with Asian countries. Although there is still room for manufacturing sophisticated products, further cost reductions in production can hardly be expected. It is urgently necessary to innovate material and manufacturing industries and to establish novel technologies to strengthen industrial competitiveness internationally in consideration of the social demands of environmental awareness, energy conservation, and resource conservation. In response to these industrial and social needs, AIST will promote research and development of industrial technologies through the next mid-term under a new concept described below.

Current materials and manufacturing technologies are classifiable into the following three major aspects: (1) advanced technology providing novel or enhanced functions to materials and products; (2) technology for reducing environmental load with energy-savings and resource-savings in production; and (3) technology for practical use that achieves high-productivity and low cost. Even though the level of each facet of Japanese industry is among the highest in the world,



trade-offs exist among them. For example, advanced products are expensive and have adverse environmental effects. In addition, environmental concerns reduce competitiveness with respect to productivity and functionality. In this way, various barriers remain against resolving the trade-off relations among currently available technologies.

Aim to "Minimal Manufacturing"

In our opinion, one technology may allow integration and merging of these excellent individual aspects of technologies into a systematic one that will engender large advantages in international competitiveness (See the figure). In consideration of production costs and environmental care in productive processes, this technology in the near future will allow the manufacture of products with maximum functionality using minimal inputs of resources and energy while minimizing their inherent environmental load. We call this technology "minimal manufacturing".

It is necessary to be vividly aware of this concept from the early stages of R&D to respond to the aforementioned social requirements. Integration of required individual technologies is a key to realize minimal manufacturing.

AIST reorganized its research units investigating materials and manufacturing technologies in the fields of Nanotechnology, Materials, and Manufacturing, anticipating the next mid-term plan: the Advanced Manufacturing Research Institute was established, aimed at realizing minimal manufacturing. Previously, material and manufacturing technologies had been investigated independently in different research units. At AIST, they are addressed in a unified manner in this new unit. The Materials Research Institute for Sustainable Development, another new research unit in the field, tackles the tasks of developing technologies for global warming countermeasures. We have also improved the Nanotechnology Research Institute. In the new organization of this field, AIST has put all its efforts into promoting R&D of industrial technologies as a mop-up activity of the first mid-term and as a warm-up for the second one. AIST hopes to initiate innovation in industrial technologies and contribute to a society with sustainable development by realizing this new concept.

Magnesium: A Future Energy-Saving Material

Director, Materials Research Institute for Sustainable Development
Dr. Motohiro TORIYAMA

reduction of automobiles conserves energy without changing the body size relevant to amenity as well as methods of driving and maintenance. For reduction of CO_2 emissions by the public, it is important to develop such passive energy-saving technologies that are acceptable by everyone.

Global Environmental Problems and Energy-Saving Technologies

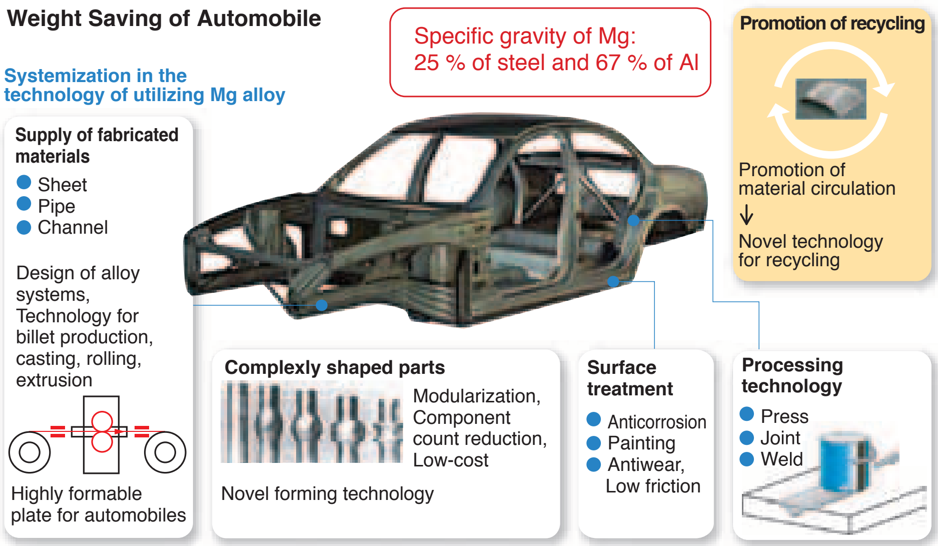
Japan is slated to reduce its emissions of greenhouse gases such as CO_2 to 6% below 1990 levels in the commitment period of 2008-2012 under the Kyoto Protocol, adopted at COP3. The Japanese government determined its "Outline for Promotion Effects to Prevent Global Warming" and set various approaches to reduce CO_2 emissions. However, the amount of greenhouse gas emissions continued to increase in 2000: the emissions are expected to increase by more than 20% in the civilian and transport sectors in contrast to a perspective to attain the emission target in the industrial sector. In the former, air-conditioning systems in private homes and other buildings consume vast energy resources.

The industrial sector is sensitive to energy costs. In this sector, it is also easy to introduce sophisticated energy management systems and new energy sources. On the other hand, those systems' introduction into the civilian and transport sectors is more difficult economically and technologically because civic life strongly requires amenity and safety.

Two ways exist to reduce CO_2 emissions from automobiles. The first reduces emissions on the energy generation side by adopting diesel engines with high combustion efficiency and fuel cells. Another method reduces energy consumption by lightening car bodies. We respectively refer to these two as "active" and "passive" energy-saving technologies. Weight

Comparison of mechanical properties of Mg alloy with those of other materials.

Properties	Mg alloy (AZ91D)	Al alloy (A380)	Steel (Carbon steel)	Plastic ABS	Plastic PC
Specific Gravity	1.81	2.70	7.86	1.03	1.23
Tensile strength [MPa]	250	315	517	96	118
Young's modulus [GPa]	45	71	200	2.3	6.7
Elongation [%]	7	3	22	60	2.7
Specific strength	138	117	66	93	96
Specific rigidity	25	26	25	2.2	5.4



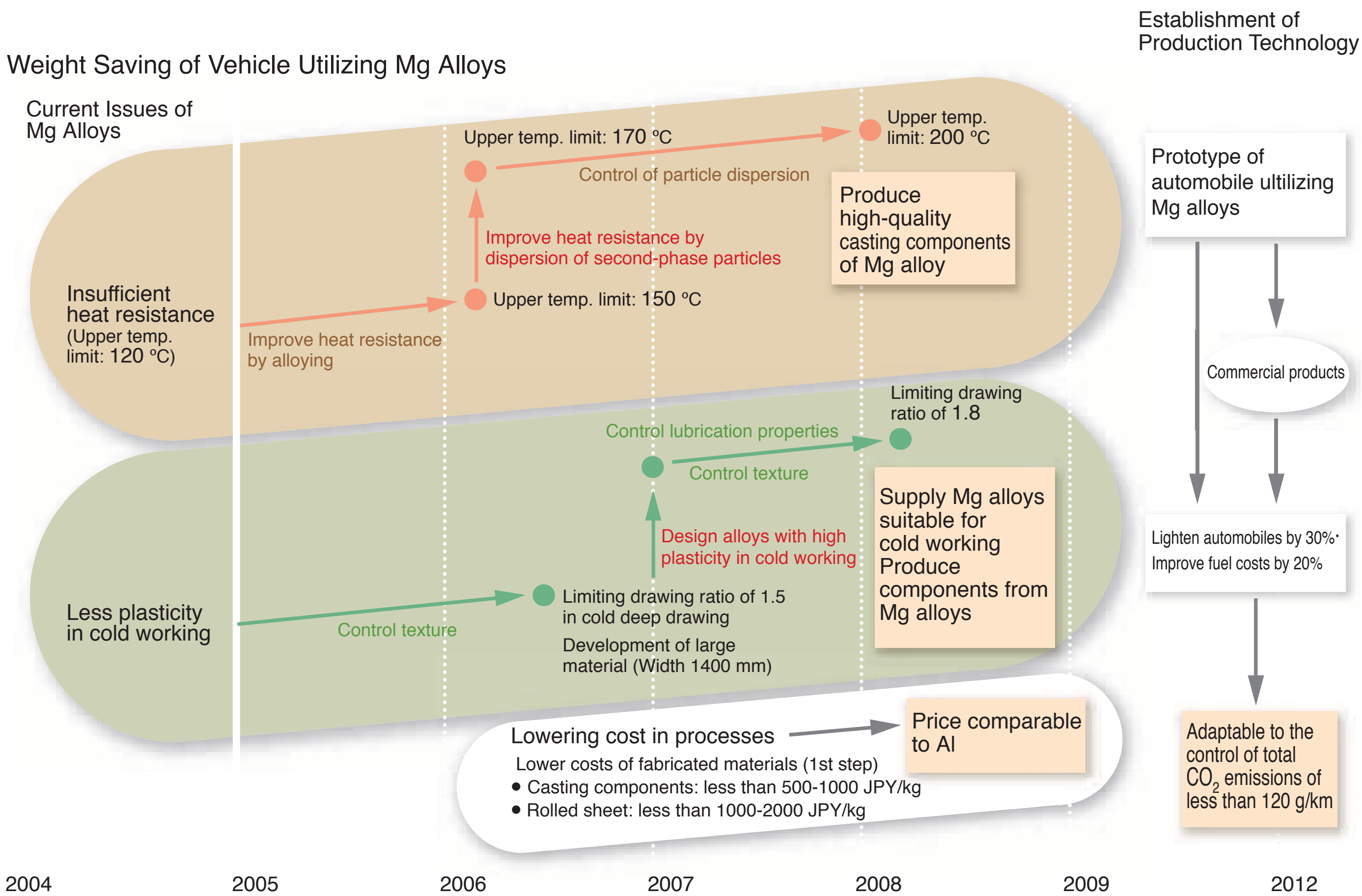
Current Issues and Perspectives in R&D

In Japan, high-strength steel has been adopted for use in lightweight automobile bodies; the use of aluminum is under development. On the other hand, R&D to utilize magnesium, the lightest metal among the practically useful metals, as an automobile material, has been extensively promoted in Europe because the EU has declared that after 2001, cars sold there must have limited total CO_2 emissions to less than 120 g/km.

Four hurdles must be surmounted to allow the use of magnesium as automobile components: (1) development of heat-resistant alloys with excellent cast properties and high creep resistance for its usage in engine parts; (2) development of sheets that are plastic formable in cold working for usage in car bodies; (3) development of technology for lowering the cost of fabricated magnesium to a level comparable to that of an aluminum one. At present, the former is several times more expensive than the latter - completely out of the range in cost as automobile materials - even though the prices of their ingots are nearly equal; (4) systemization of a series of technologies for processing automobile materials - alloying, casting, forging, plastic forming, jointing, and painting.

Among these issues, the Materials Research Institute for Sustainable Development has so far investigated the first and second, through that study, the material properties were improved. In addition, we began development of manufacturing technology for cost reduction of fabricated magnesium components, aiming first to lower parts prices to about twice those of aluminum parts.

Weight Saving of Vehicle Utilizing Mg Alloys



Social Impacts of Energy Saving Materials

A rough estimation reveals that a car will be lighter by 30% if its body and parts are made of magnesium, improving fuel consumption by 20%. Automobiles account for 55% of the total amount of CO_2 emissions from the transport sector in Japan. Therefore, more than ten million tons of CO_2 emissions would be eliminated if all cars were replaced with cars made of magnesium. Unfortunately, such magnesium cars will not contribute to reduction during the first period of the Kyoto protocol by 2012, considering the speed of R&D and the cars' acceptance into the automobile market. However, we consider that, to develop sustainable society while adapting to diverse values and life styles, such "passive" technologies for saving energy, which are expected to be effective through their incorporation to conventional systems, play an important role in addition to "active" ones based on development of new systems.

A Smart Window with Automatic Solar Control in Response to Environmental Temperature

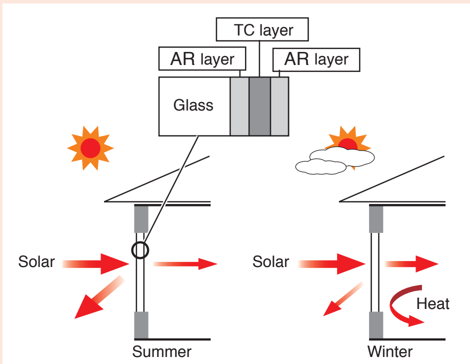
Senior Research Scientist, Materials Research Institute for Sustainable Development

Dr. Ping JIN

A large amount of heat exchange takes place through the window of a house or a building. For example, 48% of the heat escapes in winter and 71% invades in summer for a house with single-glassed window. Therefore, the control of heat flow through the window, better with response to seasons or the request of resident, provides both comfort and improved energy efficiency.

Energy-efficient window glasses such as “heat reflecting glass” and “low-E glass” have already been developed. The former reflects solar irradiation and the latter insulates heat. These windows, however, demonstrate only fixed optical properties without response to the seasonal requirements.

We have developed a novel smart window with active optical response to environmental temperature. In the developed window, a thermochromic (TC) layer made of vanadium oxide is applied in combination with antireflection (AR) layers or functionalized layers. The TC layer exhibits a phase transition induced by temperature, with large changes of optical performance.



Schematic structure and performance of the window.

Figure shows schematically an example of the structure and performance of the developed window. The TC layer of vanadium oxide is sandwiched by AR layers. The TC layer changes its optical properties automatically with response to environmental temperature; being semiconducting (transparent to solar irradiation) at low temperature and metallic (reflective) at high temperature. This means that the window shades extra solar irradiation in summer, and takes in solar irradiation and reflects back the heating within a room in winter, leading to more comfort and energy efficiency. It requires no other facility and energy supply, since the switch is automatic with response to environment temperature.

Mechanical Technologies Realize Dreams in Material Research

Director, Advanced Manufacturing Research Institute
Dr. Shuzo KANZAKI

Innovative manufacturing technology out of necessity

In Japan, international competitiveness relies strongly on manufacturing industries. After the collapse of the "bubble economy" in the 90s, the domestic industry has hollowed out and its technological development has stagnated, resulting in diminished international competitiveness. It is crucial to innovate manufacturing technology that compensates that hollowing effect to recover Japan's position in the worldwide economy. In addition, reduction of the environmental burden and improvement of safety are prerequisites for the development of industry in harmony with society.

Manufacturing technology can be regarded as a series of processes which impart shape and functions to materials and thereby convert them into commercial products. To date, shaping and functioning aspects have been treated separately. However, total integration of the two is necessary in order to establish environmental-conscious advanced manufacturing technology. To this end, the following interrelated key points are critical: high-efficiency, functional creativity, flexibility, and safety and reliability (Fig. 1).

Priority research subjects in AMRI

Figure 1 shows that the five outputs are deduced from these essential points. The Advanced Manufacturing Research Institute (AMRI) promotes the following ten priority research subjects to realize the outputs:

1. Low-temperature and high-speed coating technology.
2. Compact process to make components for industrial use.
3. 3D integration processing technology.
4. Tailored manufacturing processes.
5. Small-sized MEMS equipment.
6. Manufacturing technology with low-emission and resource-circulation.
7. Support technology for value-creating manufacturing.
8. Multi-scale and multi-physics CAE methods.
9. Indirect measurements for characterization in a wide range.
10. Fundamental technology for monitoring, diagnosis, and prediction of manufacturing processes.

I will introduce the outlines of two subjects among them.

Development of low-temperature and high-speed coating technology

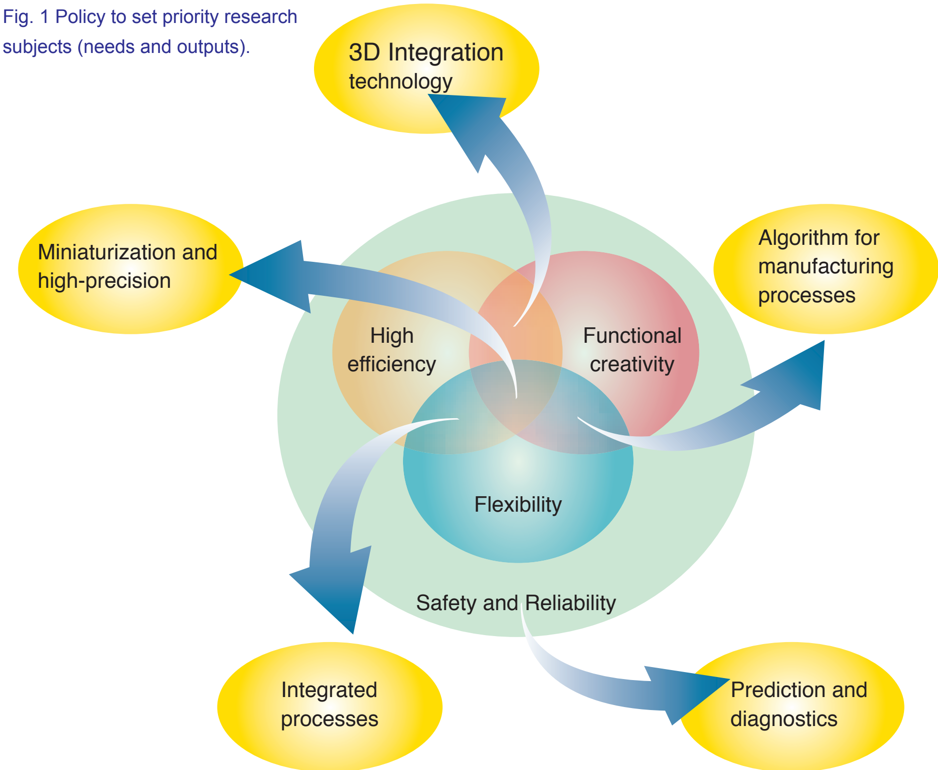
The aerosol deposition (AD) and metal-organic deposition (MOD) methods are ceramics-coating technologies that were developed originally at AIST. By combining these methods with conventional spraying technologies (HVOF, etc.), we develop a new coating technology for fabricating advanced ceramic films with a large area at high-efficiency and at low temperatures. (See Fig. 2)

Development of tailored manufacturing process

It is necessary to establish processes of manufacturing components cost-effectively to respond individually to various needs from industry. We develop the following three technologies in a unified manner to make components at lower cost and to further add value to them: manufacturing technology for complicated-shaped products in a wide range of sizes - from micrometer to meter scales; high-efficiency technology for making processes more efficient and simple; and technology for adding material functionality to structures. (See Fig. 3)

Through the aforementioned R&D efforts, we will present application prototypes, "AIST Products", to be considered for commercialization. We expect that our activities will contribute to strengthening the international competitiveness of industry and to establish a safe infrastructure.

Fig. 1 Policy to set priority research subjects (needs and outputs).



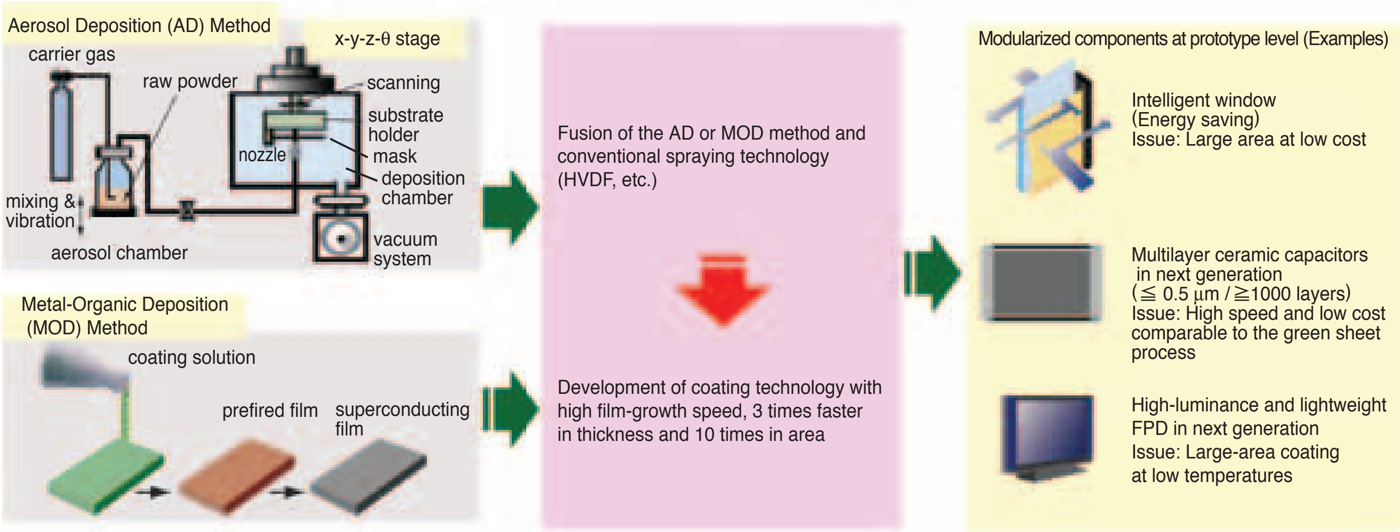


Fig. 2 Development of low-temperature and high-speed coating.

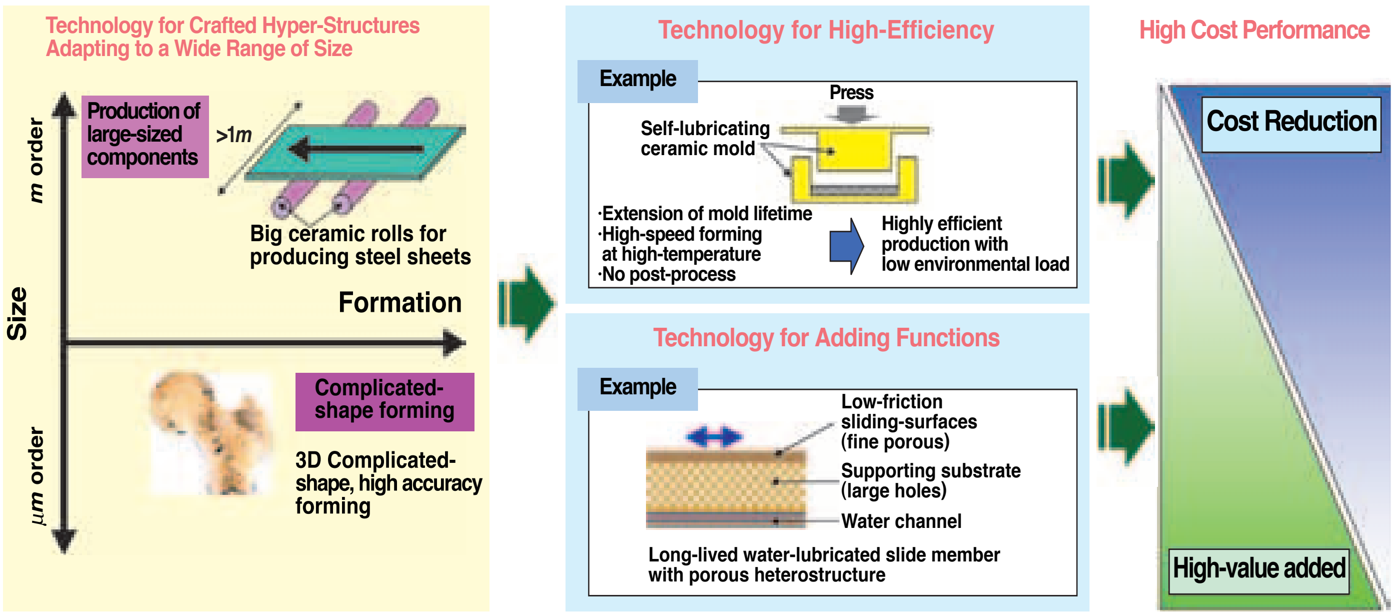


Fig. 3 Development of tailored manufacturing process.

Development of low-temperature and high-speed coating technology

Group Leader, Integration Process Technology Group,
Advanced Manufacturing Research Institute

Dr. Jun AKEDO

We have developed a novel ceramics-coating technology called aerosol deposition (AD) method. We discovered the shock-consolidation of nano-sized particles at room temperature, a ceramic process quite different from conventional ones, which is a core-technology in the NEDO Project "Nano Structure forming for Advanced Ceramic Integration Technology" promoted under collaboration with companies and universities. This project is intended to achieve a breakthrough in information devices in the next generation.

Daily research activity has rewarded me with stimulating experiences beyond usual research in various aspects such as elucidation of new phenomena, addressing practical applications in collaboration with companies, and patent strategies. At the same time, I feel a strong responsibility for organizing and promoting this large national project. I expect to cultivate the AD method as an important technology for device fabrication through the rapid realization of commercial products using this method.

Development of Tailored Manufacturing Process

Principal Research Scientist,
Advanced Manufacturing Research Institute

Dr. Tatsuki OHJI

Materials are used in a wide range of sizes, from parts smaller than 10 mm to components larger than 1 m in industry and society. They are often complexly shaped and require high accuracy. Recently, material properties have been improved remarkably. We have developed further cost-effective processing technology by integrating the material technologies and those for adding shapes to them to bring out the excellent properties efficiently in different sizes and shapes.

At present, technologies for adding shapes such as the forming technology are not necessarily systemized, but are often the accumulation of bits of information and experience, commonly known as *know-how*. We have addressed their organization and systematization scientifically and technologically into scientific technologies shared by industry and society.

Universalize Manufacturing Skills

Director, Digital Manufacturing Research Center
Dr. Kazuo MORI

Skilled engineers support manufacturing

Skilled engineers working at small and medium enterprises (SMEs) have provided the backbone of international competitiveness of Japan's manufacturing industries. Nevertheless, nowadays, it has become very difficult to secure these people in many SMEs because of the falling birthrate and the aging population along with the falling popularity of manufacturing jobs among young people. In addition, it is difficult to keep pace with the rapid progress of an information-oriented society. These situations shake the international competitiveness of Japanese manufacturing industry to its foundations.

Manufacturing support through amalgamating IT and MT

The Digital Manufacturing Research Center has carried out an R&D program - "Fusion of MT and IT to Enhance Manufacturing Capability". The objective of this program is to enhance the manufacturing ability of the machine parts industry, by sharing manufacturing skills as well as developing systems promoting IT within the firms. The basic concept of this program is "amalgamation of information technology (IT) and manufacturing technology (MT)".

IT has been regarded as difficult for application to MT, in particular, technological skills. To facilitate sharing of process information, it is necessary to develop technology that extracts, organizes, and systemizes manufacturing skills and transfers them into digitized information processible by IT. Furthermore, it is desirable that production sites provide information in a way that is suitable for processing by IT. That is to say, the concept of "amalgamation between IT and MT" is mutual progress in the use of it in MT and that in MT adaptable to IT.

Manufacturing Database for 15 processes

Skilled engineers are essential for the processing of machine parts. Why? One major reason is that process mechanisms have not been fully clarified yet. Consequently, processes require years of experience and sense of engineers.

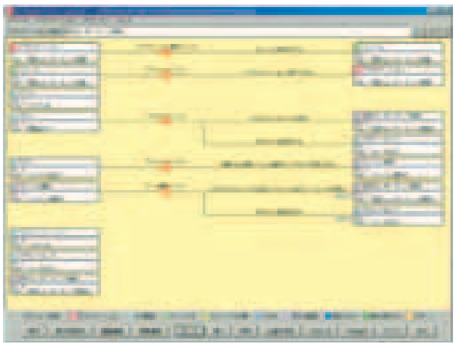
Furthermore, skilled engineers must make complicated judgments depending on the processes and their objectives. Engineers' intelligence should be transformed to digitized information for the enhanced use of IT in MT.

This project has developed a fundamental method to extract skills in principal processes and has constructed database systems that commoditize product information using IT, aiming to elucidate the mechanisms in manufacturing processes and to digitize skills relevant to decision-making processes.

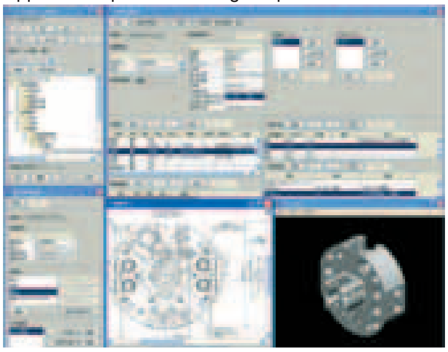
Machine parts are, in most cases, produced through several steps of manufacturing processes. We selected 15 principal processes for machine parts, such as forging, cutting, and coating. From the viewpoint of technological analyses of process mechanisms, we have translated know-how required for these processes, from their preparation to finishing, into technological information. We accumulated

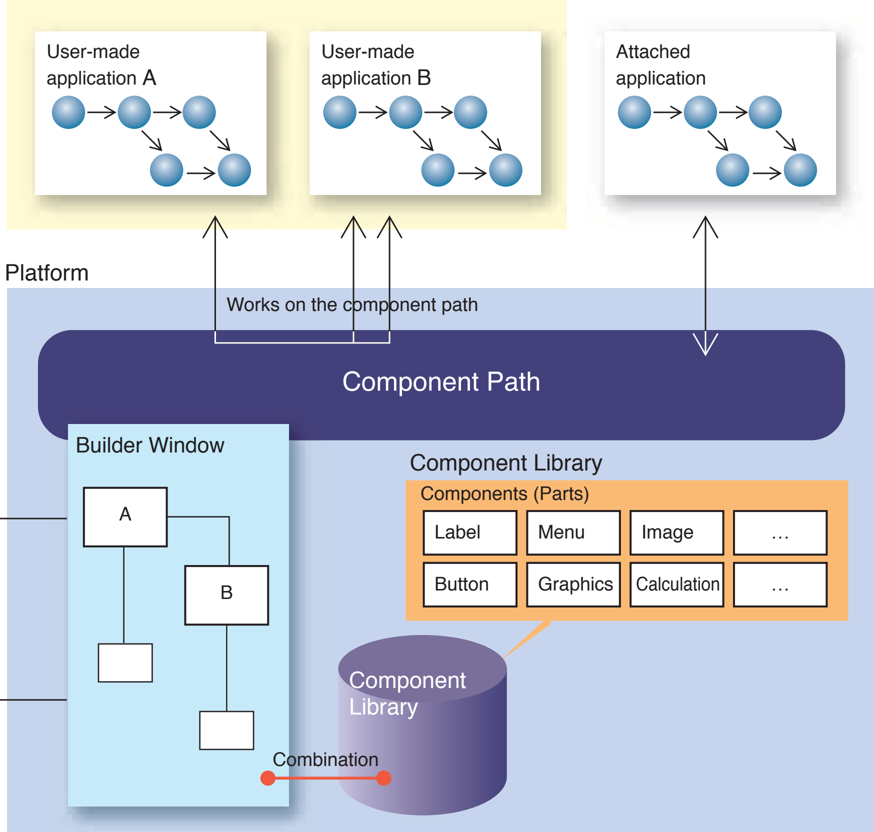
Examples of windows of the Manufacturing Database.

Builder Window



Administration table — an example of applications produced using the platform





MZ platform functions.

that expertise into a database.

That database is now available on the Internet along with the main functions of proper process conditions, a search function for examples, and trouble prevention and countermeasures. We are planning to improve that database by adding new functions: guidance to achieve the process objectives and outputs of standard documentation, explicitly indicating technological information diagnosed by skilled engineers.

The MZ Platform promotes IT use in design and manufacture

It is not so easy for SMEs to use IT which has become widespread in production sites. Reflecting on such a situation, we have developed, in the R&D program, an environment in which the affinity of it to MT is increased, the "MZ Platform".

The MZ Platform, developed using Java, is a novel development and execution environment for software. Briefly described, using this platform, one can easily produce application software for design and manufacturing by combining components (JavaBeans) with single functions, using a graphics-creation tool and various data operations, on a window called a builder. That is, the platform allows the customization of business software that is adaptable to any company in a short time without any software expertise. We have released its first edition.

More detailed information on how to use the Manufacturing Database and MZ Platform is obtainable from our web site at: http://unit.aist.go.jp/digital-mfg/

Small Businesses Expectantly Watch Nakano's IT Effort:

Interview with President Yasuhisa NAKANO of Nakano Manufacture Co., Ltd

Q: Where in your business do you apply the platform and the database of DMRC ?

We manufacture car components. When an order is received, we hold a meeting of engineers who are well versed in the specific field. We have a discussion to build an outline of the manufacturing process for the order. Then engineers compile a document called "administration table." On the platform, we develop an application for creating an administration table. At the same time, we use the manufacturing database to make settings for machining conditions used for the task.

Q: How effectively do you think you have used the database?

Now that we have digitized the administration tables, it is by far easier to search for technical information on similar products we handled in the past. This means, we can verify and make better use of data and information we have accumulated for years in our database. We used to write on paper to make a table. Now the digitized administration table is really multifunctional. In addition, the digitization has helped speed up the table creation process at a meeting.

Q: How do you plan to further integrate IT into your operations?

The digitization of the administration table is just the start of our IT reform. We must utilize our manufacturing database and the platform more effectively, as well as developing more databases of our own.

Microreactors Offer a Wide Array of Nanotech Worlds

Director, Micro-Space Chemistry Laboratory
Dr. Hideaki MAEDA

Microspace Applied to Chemical Reactions

Microreactors have fine fluid channels whose widths are from several micrometers to several hundreds of micrometers. Such micro-spaces allow us to accurately control temperature, reaction time, and transport of reactants in chemical reactions. They also offer novel reaction fields like stable and high-stress fields. However, the high controllability of micro-spaces has not been applied to chemical industries. Our laboratory has investigated controlled chemical reactions in micro-spaces to innovate valuable industrial technologies, based on reaction designs and reactor designs. This article introduces our research activity regarding precise and continuous synthesis of fluorescent nanoparticles using microreactors as an example of application of the micro-space chemistry technology.

When semiconducting particles like CdSe are reduced to several nanometers in diameter, their fluorescence wavelength varies depending on their size, even in the same material, because of quantum size effects. Fluorescent nanoparticles offer the following advantages: Highly stable luminescence compared to conventional organic dyes, narrow wavelength distribution in emission spectra, simultaneous multicolor fluorescence by monochromatic excitation, and multi-labeling through the combination of fluorescent colors. These features have brought nanoparticles to popular attention as novel optical tags for analysis of biological and biochemical reactions. CdSe nanoparticles are usually synthesized by reacting organocadmium compounds and selenium in a hot surfactant at temperatures greater than 300°C. It is difficult to produce size-controlled semiconducting nanoparticles of less than 10 nm in diameter commercially because their preparation requires more precise conditions than larger-sized particles and their greater quantities of production makes it more difficult to accurately control the production conditions. For these reasons, nanoparticle syntheses reported in recent papers have been limited to laboratory demonstrations using a small amount of reaction solution - less than a dozen milliliters or so.

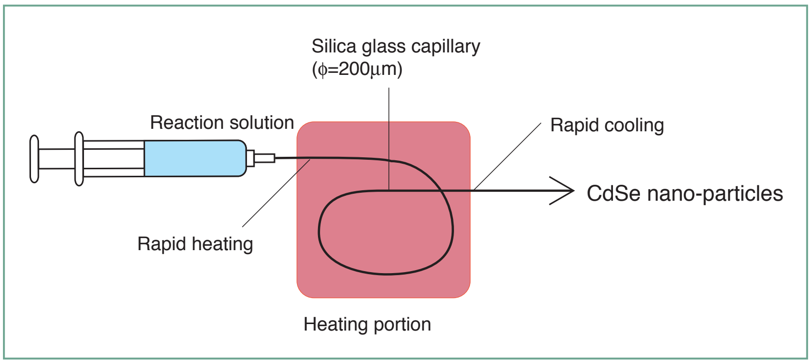


Fig. 1 Schematic diagram showing CdSe nanoparticle synthesis using the microreactor.

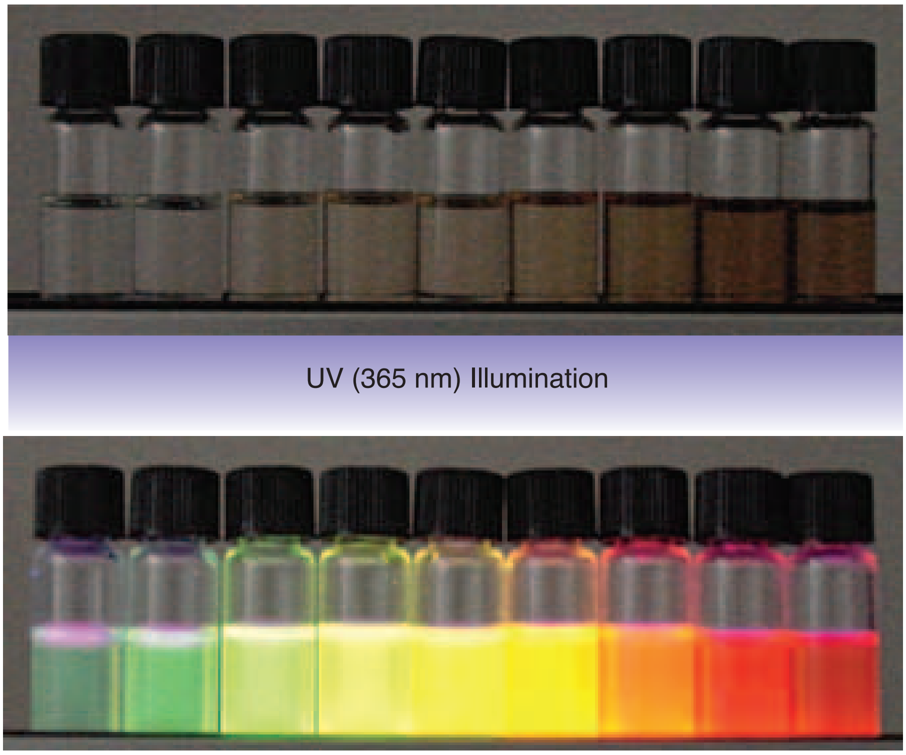


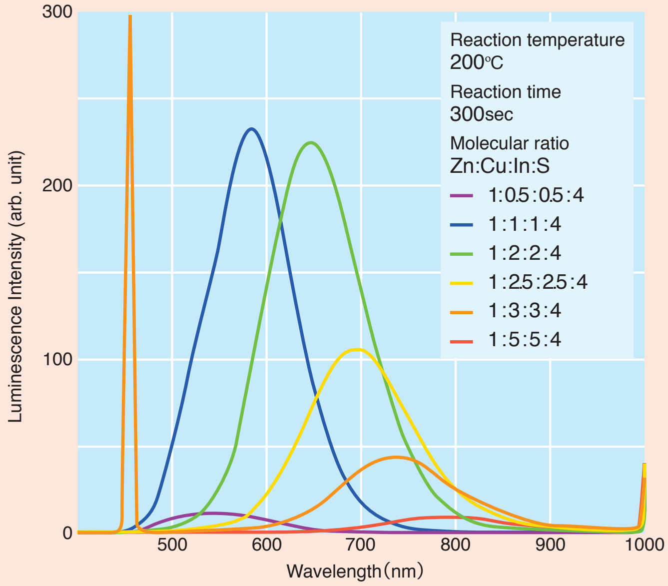
Fig. 2 Fluorescence from CdSe nanoparticles with various diameters that are synthesized by heating during 2-140 s at 300°C. Smaller particles (ca. 2 nm) prepared with shorter heating-time emit blue-green light, whereas larger ones with longer heating time emit red light.

Synthesis System of Nanoparticles

Our laboratory has developed a quite simple nanoparticle synthesis system utilizing micro-spaces (Fig. 1). A raw material solution pushed out from a syringe is heated inside the heating portion of the reactor, followed by cooling outside it. Because of the small heat capacity and large surface area of the reactor, it achieves very high-speed and high-accuracy control in the solution temperature. Laminar flow in the

Success in Synthesizing Less-Toxic Semiconducting Quantum Dots

The wavelength of light emitted from semiconducting quantum dots is tunable even though they are made of the same material. Their application is expected in various fields such as displays and illumination in addition to fluorescent tags for biochemical analysis. However, because most semiconducting quantum dots are made of II-VI compounds, typically CdSe, the toxic effects of their constituent elements prevent the promotion of their industrial use. Our laboratory has succeeded in synthesizing environmentally friendly and less-toxic semiconducting quantum dots made of ZnS-$CuInS_2$ systems as an alternative to CdSe dots. The wavelength of fluorescence is tunable in the range of 550-800 nm by varying the molecular ratio of their constituent elements (See the Figure).



Detailed analyses of optical properties of these nanoparticles have revealed their complex structure of ZnS(core)/$CuInS_2$ (shell). Among the several works on $CuInS_2$ nanocrystals, none has synthesized a high-quality fluorescent nanocrystal. Therefore, we presume that the core-shell structure is relevant to improving the quality of $CuInS_2$ crystals. Two possible reasons for the high quality are as follows: (1) The mismatch in the lattice parameters is small (ca. 2%) between the ZnS and CuInS2 crystals. (2) The raw material for ZnS contributes to stabilizing the oxidation number of Cu.

We have demonstrated that, even for materials that degrade easily because of defect formation under natural conditions, relatively high-quality crystals can be grown by utilizing the high-quality surfaces of nanoparticle cores as deposition sites. This technology will be quite useful in the future to add advanced or multiple functions to nanoparticles.

channel prevents substantial back-mixing. Therefore, the reaction time is also precisely controllable - within the sub-second range.

Using this reactor, adequate tuning of reaction temperature and time allows the preparation of nanoparticles with different fluorescent colors from the same material (Fig. 2). They are synthesized in well-controlled conditions with high reproducibility. Such high controllability and reproducibility indicate that micro-spaces achieve a precise control of reaction, thereby ensuring, in principle, stable commercial production by means of scaling up of the system through parallel operation.

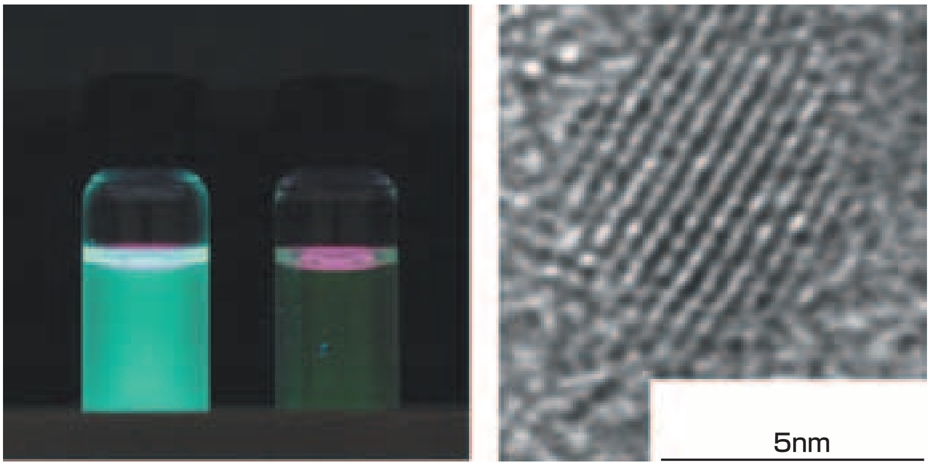


Fig. 3 ZnS/CdSe/ZnS nanoparticles (the left bottle) exhibit fluorescence at 480 nm with several dozen times stronger intensity than that of conventional CdSe/ZnS nanoparticles (the right bottle). The TEM image depicts the size of ZnS/CdSe/ZnS nanoparticles: ca. 5 nm diameter.

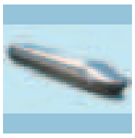
Adding Higher Function

When CdSe nanoparticles are used as fluorescent tags for biochemical analysis, the particles are usually coated with ZnS with a wider gap to more efficiently confine electrons that are photoexcited within the CdSe cores and to improve water- and oxidation-resistance. A serial combination of microreactors shown in Fig. 1 realizes a multi-step continuous synthesis: the preparation of CdSe cores followed by the coating of ZnS shells on them.

By advancing this technology, our laboratory recently succeeded in synthesizing multilayered nanoparticles: ZnS(core)/CdS(core)/ZnS(shell). The CdSe shell in the fine quantum-well structure emits light because of quantum size effects and its luminescent properties are drastically improved (Fig. 3). These results indicate that microreactors not only prepare nanoparticles, but are also able to add higher functions to them.

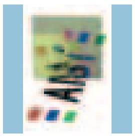
As mentioned above, micro-spaces allow continuous synthesis of nanoparticles under the precise control of conditions with high reproducibility. The high reproducibility in this method implies stable preparation without lowering the quality of products, even in pile-up reactors. Our laboratory is currently expanding this technology to application in various kinds of materials such as organic and metallic nanocrystals, aiming to establish novel technology for producing nanomaterials using micro-spaces.

Materials & Manufacturing Technology in AIST
Get Maximum Output with Minimal Input



Large-sized structure from extruded Mg-alloy (Roof Box)
See P4
Photo provided by Dr. Motohiro TORIYAMA
Materials Research Institute for Sustainable Development

Micro-optical scanner
It is fabricated by the aerosol deposition method.
The scale bar at lower right indicates 500 μm.
See P4
Photo provided by Dr. Jun AKEDO
Advanced Manufacturing Research Institute



A smart window glass with automatic solar control
The transparency of the glass increases substantially compared with conventional ones (lower left part).
See P5
Photo provided by Dr. Ping JIN
Materials Research Institute for Sustainable Development

Fluorescence from Size-controlled nanoparticles
Nanoparticles are synthesized by microreactor.
See P10
Photo provided by Dr. Hideaki MAEDA
Micro-Space Chemistry Laboratory

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