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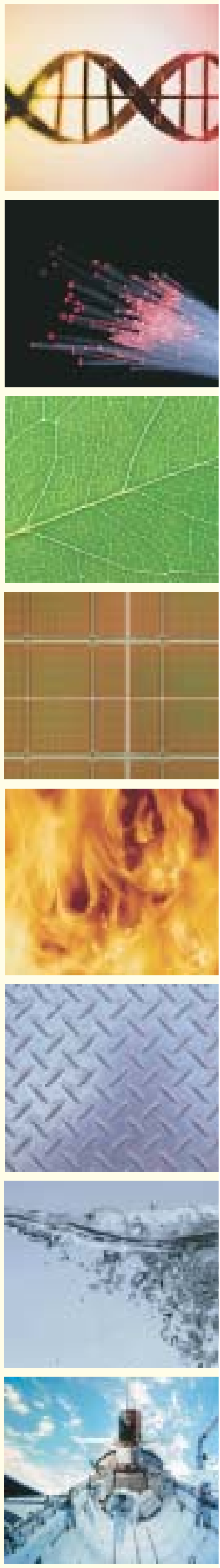

Life Sciences

➤ *Strategy of the National Institutes of Health (NIH) of the US to Accelerate Biomedical Research (NIH Roadmap)*

Information and Communication Technologies

➤ *Latest Trends in the Optical Disk Industry*
— The Superiority of Japanese Companies and a New China-U.S. Joint Effort for Standardization —

➤ *Trends of Research and Development in Semiconductor Manufacturing Technologies*
— From Presentations at Recent International Conferences and Other Sources —

Environmental Sciences

➤ *Recent Trends Concerning the Ecological Risk Assessment of Chemicals*
— Following the Revision of the Chemical Substances Control Law —

➤ *Pressing Issues in the Health Effects Assessment of Chemical Substances*

Nanotechnology and Materials

➤ *Trends in the Development of Heat Resisting Materials for High-efficiency Power Generation Gas Turbines*

➤ *Notable Points of the US "21st Century Nanotechnology Research and Development Act"*

Energy

➤ *Using of Power Electronics for the Development of Energy Infrastructures*

Science and Technology Policy

➤ *Evaluation of R&D Projects —European Practice—*

Foreword

This is the latest issue of "Science and Technology Trends — Quarterly Review".

National Institute of Science and Technology Policy (NISTEP) established Science and Technology Foresight Center (STFC) in January 2001 to deepen analysis with inputting state-of-the-art science and technology trends. The mission of the center is to support national science and technology policy by providing policy makers with timely and comprehensive knowledge of important science and technology in Japan and in the world.

STFC has conducted regular surveys with support of around 3000 experts in the industrial, academic and public sectors who provide us with their information and opinions through STFC's expert network system. STFC has been publishing "Science and Technology Trends" (Japanese version) every month since April 2001. The first part of this monthly report introduces the latest topics in life science, ICT, environment, nanotechnology, materials science etc. that are collected through the expert network. The second part carries insight analysis by STFC researchers, which covers not only technological trends in specific areas but also other issues including government R&D budget and foreign countries' S&T policy. STFC also conducts foresight surveys periodically.

This quarterly review is the English version of insight analysis derived from recent three issues of "Science and Technology Trends" written in Japanese, and will be published every three month in principle. You can also see them on the NISTEP website.

We hope this could be useful to you and appreciate your comments and advices.

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Executive Summary

Life Sciences

1 Strategy of the National Institutes of Health (NIH) of the US to Accelerate Biomedical Research (NIH Roadmap)

p.11

The National Institutes of Health (NIH) is an agency of the Department of Health and Human Services of the US. The NIH budget achieved significant growth over five years between 1999 and 2003, thanks to the doubling of NIH budget. The NIH budget of $27.1 billion was approved for FY 2004.

Meanwhile, starting of FY 2004, the NIH announced on September 30, 2003 the "NIH Roadmap for Medical Research in the 21st Century (NIH Roadmap)." The purpose was to continue using its research potentials recognized during the doubling of NIH budget and to launch a new policy as the new director took office.

After a series of expert meetings to chart the NIH Roadmap, the NIH identified three main areas for 28 initiatives to be carried out across the NIH as a whole.

The Roadmap implementation groups will begin their efforts to implement the initiatives from FY 2004 to FY 2005, as the need arises. The NIH is responsible for distributing a budget and managing a plan, and for each implementation group to implement the assigned initiatives. For the Roadmap initiatives, the NIH will commit $130 million in FY 2004, and a total of $2.1 billion in the five years to come.

The "NIH Roadmap," however, does not set a clear milestone for most of the initiatives. Rather, it lays out the direction for future research. In the area of basic research, post-genome research, development of post-genome analytical tools, and interdisciplinary research are made the priority initiatives. This shows that the NIH gives the utmost priority to the facilitation of clinical research in consideration of its mission. We will watch the future development of the NIH Roadmap closely to report on how the President's Budget proposals for FY 2005 weigh on the NIH initiatives and how Congress alters and agrees the budget for final approval.

(Original Japanese version: published in January 2004)

Information and Communication Technologies

2 Latest Trends in the Optical Disk Industry

– The Superiority of Japanese Companies and a New China-U.S. Joint Effort for Standardization –

p.17

The principles of optical disks, including the compact disk (CD) and the digital versatile disk (DVD), which are in widespread use by consumers worldwide, were invented in the Netherlands. However, Japanese companies have been winning an overwhelming victory in the optical disk industry by leading it in all areas of mass-production technology, standardization, and business. The situation has changed over the past few years and Japanese firms are now forced to collaborate with Korean and Taiwanese manufacturers through joint ventures and to face a new industry standard, the Enhanced Versatile Disk (EVD) being jointly proposed by China and the U.S. This is a move that can be considered part of their market acquisition strategy intended for reducing royalties paid to Japanese license holders.

This article discusses the characteristics of the optical disk industry, which is faced with such a situation, from four perspectives: (1) technology, (2) business, (3) standardization, and (4) patent status. Through the discussion, an explanation is given as to why Japan was able to maintain superiority for a long time, followed by a warning that if Japan takes wrong measures a profound change in the market share structure, which has already occurred in the semiconductor and liquid crystal display industries, can take place in the optical disk sector as well.

To prevent this from happening, Japan needs to increase its patent strength by linking it with industry standards. That is to say, Japan should direct its research efforts toward more fundamental themes and aim at a stronger patent position in terms of the number as well as quality of patents so that Japan's patented technologies can achieve levels that are high enough for adoption as industry standards. Moreover, from a medium- to long-term perspective, Japan will face an increased need to take steps to build research environments that promote the activities of open and creative researcher groups and more effectively facilitate breakthroughs in science and technology that can compare to the invention of the optical disk in the Netherlands.

(Original Japanese version: published in January 2004)

3 Trends of Research and Development in Semiconductor Manufacturing Technologies
– From Presentations at Recent International Conferences and Other Sources –

p.30

Despite technical and economic limitations, the pace of development of silicon MOS semiconductor technology is accelerating. LSI chips that rely on this technology to improve the performance of electronic equipment are acquiring more complex and versatile functions and more semiconductor devices will be used in more different products. Semiconductor technology will continue to be the fundamental technology supporting the development of not only electronics but also basic science and other technologies. Economically speaking, it should play a major role in key industries.

The stage was recently reached where conventional miniaturization of transistors cannot be expected to provide much further improvement in performance, so the focus of investigation is shifting towards new materials or new structures for transistors. It appears that we are at a turning point, and can expect a complete reexamination of the basic materials and structure of the silicon MOS transistors that have dominated the field for as long as 30 years.

Technology development is being driven by leading-edge processor manufacturers, mainly in the U.S., and the length of a generation in manufacturing technology has shrunk from 3 years to 2 years in the past decade. Limitations on technology development have been discussed, but no insurmountable barrier has yet been identified. The pace of development of leading-edge LSIs is believed to be sustainable with the use of new materials and new structures.

Semiconductor-related projects in Japan should also address these trends in technology development. As the state of the art in manufacturing technologies has recently been driven by processors, the question we need to consider is this: to what type of semiconductor products should Japanese companies apply the results of these projects? Also, projects in Japan should involve universities as collaborators. To accelerate the pace of development, universities can make good use of characteristic assessment, modeling and mechanism analysis.

In addition to growing technological barriers, the escalation of the capital investment required is going to make it almost impossible for one company to pursue semiconductor technology development alone. As a result, technology development is being carried out with horizontal specialization, especially overseas. If we follow these trends, then focusing on development in the areas where Japan is already strong, such as materials, manufacturing equipment, and key technologies should be a good option for us. If we can demonstrate our strength in some of these specific areas, we can expect to use them as starting points, involve related areas, and strengthen our industry-wide competitiveness.

(Original Japanese version: published in March 2004)

Environmental Sciences

4 Recent Trends Concerning the Ecological Risk Assessment of Chemicals
– Following the Revision of the Chemical Substances Control Law –

p.41

The decline of biodiversity has become one of the key issues concerning the global environment in recent years. Biodiversity does not merely mean the number of species or the size of the population. It is a concept that contains a vast array of diversity at various levels of stratification, including genetic variation within species, species richness, variation in species composition within communities, and variation in landscape consisting of biological communities and physical settings. Presently, living species of 10 million to 100 million are said to exist on the earth. An immense number of species contributes to the conservation of a wide variety of gene pools to allow numerous ecosystems to exist in various parts of the earth. The variety of ecosystems is a key to securing stable natural circulation of energy and substances from the earth level to the regional level.

The collapse of biodiversity will lead to the disappearance of genetic resources and deterioration of ecosystem functions, thereby damaging the basis for human activities in the long run. The habitat destruction of species is the biggest factor behind the significant decline in biodiversity in recent years. Environmental contamination caused by artificial chemical compounds is considered a serious problem comparable to the destruction of a tropical rain forest. The main focus of the safety assessment of chemical compounds has been their effects on human health. This, however, is changing because there has been an ever-increasing focus on biodiversity conservation on a global basis and that calls for the assessment of the effects of chemical compounds on other wildlife. Based on this idea, ecological risk assessment for chemical compounds has been considered worldwide. However, as the chemical industries are important economic infrastructures, ecological risk assessment for chemical compounds must be restricted by the sense of economy.

In practice, administrative bodies standardize assessment methods with a specific focus on domestic trade. In the face of the global free market, however, the world is moving toward the establishment of standardized testing and assessment methods.

Under the initiative of OECD, industrial nations have long begun efforts to implement measures to screen and regulate chemical compounds for ecosystem protection. Japan was the only industrial nation that had not introduced any legislative measures concerning the ecological toxicity assessment of chemical compounds until 2003, when it revised the Chemical Substances Control Law to introduce ecological toxicity as a screening requirement for the registration of new chemical compounds. To be more precise, acute toxicity tests for algae, Daphnia magna and fish (Oryzias laptipes) are required for registration under the revised law. Even if there is no toxicity against human beings, the production and import volume of the compounds that are “toxic to animals and plants” will be monitored.

In Europe and the US, examination is under way to determine whether tests for experimental population or community should be adopted, based on the contention that it is not possible to assess the effects of compounds on broad ecosystems by merely conducting three in vitro toxicity tests. It is considered that no test system will be able to reproduce an exact copy of complex and diversified natural ecosystems and that it is difficult to establish a universal assessment method. Rather, theory construction and modeling are required for the future development of ecological risk assessment in order to fill the gap between in vitro toxicity data and data obtained from natural field ecosystems. Multitudes of experimental studies are also required to provide support to the said theory and modeling.

Meanwhile, Japan should foster more researchers to strengthen the research base in the area of ecological risk assessment for its further development, following the inclusion of ecological risk as one of the requirements for the testing of chemical compounds. It is desired that university courses with a specific focus on ecological risk and the capabilities of research institutes be enhanced.

(Original Japanese version: published in February 2004).

5 Pressing Issues in the Health Effects Assessment of Chemical Substances

p.51

It’s not long since chemical substances came into widespread use in industry and the home. Mass production of chemicals didn’t begin until the latter half of the 20th century. Since problems are not instantly apparent, some chemicals with useful properties were found to be hazardous only after they had become ubiquitous - a situation that led to restrictions on their use.

Therefore there has been a growing trend to assess the potential risks of new technologies and products before they are commercialized. The mechanism by which the hazardous properties of chemicals is assessed is worth noting as a model for the systematic acquisition of information required for risk assessment.

The assessment of the hazardous properties of chemicals before use is effective in minimizing environmental pollution and preventing any possible impact on human health and ecosystems. Such hazard assessment is essential to evaluate the risks of chemicals. Despite its importance, however, hazard assessment of chemicals has yet to be carried out in a systematic manner.

In Japan, the “Law concerning the Evaluation of Chemical Substances and Regulation of their Manufacture, etc. (Chemical Substances Control Law)” has been in place since 1973. This particular law serves as a basis for assessing the hazardous properties of chemicals produced in or imported into Japan. Potentially hazardous substances are closely monitored or regulated if necessary. However, the majority of some 20,000 chemicals whose production and import started before the enforcement of the law have yet to be assessed for their hazardous properties - a situation that is also typical in Western countries. With this as a backdrop, the REACH System, a regulatory framework that mandates hazard assessments of chemicals on the market (or to be on the market) is likely to be adopted by the EU member states.

The biggest obstacle standing in the way of such assessments is the considerable amount of time and cost involved in the laboratory animal-based toxicity tests that are indispensable in assessing the health effects of chemicals. Data on toxicity should thus be accumulated efficiently by prioritizing potentially highly toxic substances. In establishing such priorities, there is a need to develop methods to predict the toxicity of chemicals quickly. Promising methods include 1) quantitative assessment of structure-activity relationships, which predict toxicity by comparing chemical structures of different substances with computer modeling, and 2) toxicogenomics, which is based on genetic information about organisms. Research on the toxicity of chemicals should be promoted further so that the safety and security of the public are ensured.

Hazard assessment of chemicals requires a broad range of knowledge concerning the physical properties and toxicity of the chemicals, fate of the chemicals in the environment and risk abatement techniques. On the international front, meanwhile, businesses are taking on greater responsibilities in assessing the hazard and risks associated with chemicals, a situation that is expected to increase the importance of experts in these areas. It is therefore recommended that graduate school in toxicology be set up in Japanese universities to develop human resources in toxicology and its related areas.

(Original Japanese version: published in March 2004)

Nanotechnology and Materials

6 Trends in the Development of Heat Resisting Materials for High-efficiency Power Generation Gas Turbines

p.61

Thermal power generation is responsible for a considerable portion of CO_2 emissions. Therefore, one of the practical methods to reduce CO_2 emissions as a measure against global warming is to improve the efficiency of thermal power stations by replacing inefficient coal-fired power plants with ultra-high-efficiency LNG combined cycle power plants. For ultra-high-efficiency LNG combined cycle power generation, the plan is to raise the gas temperature at the inlet of the turbine to 1,700°C, and development of excellent superheat-resistant materials and the corresponding turbine system technology is required to realize this.

For the construction of ultra-high temperature gas turbines, development of superheat-resistant materials is indispensable, and various types of heat resisting materials including nickel-base superalloys are being developed to meet this requirement. Superheat-resistant materials are key materials that significantly affect the heat efficiency of advanced heat engines such as gas turbines, which means that the development of such materials is a very important cross-sectional subject that covers a wide range of fields including environment, energy, and materials from the viewpoint of saving energy and resources. Under such circumstances, it is desired for Japan to enhance international competitiveness in this field through the strengthening of its technical capabilities.

Up to now, private companies have played important roles in the development of high-efficiency gas turbines and superheat-resistant materials. Today, when collaboration among industry, academia, and government is advocated, what is expected of the government is to provide an environment that enables cooperation and the appropriate division of roles in research and development through the establishment of a framework for interdisciplinary technical exchanges making use of academic societies and industrial associations as well as coordination of such exchanges. It is also necessary to establish technical bases such as the construction of databases relating to the material characterization technology and elemental technologies for system design. Furthermore, it is required to provide continuous support based on a long-term perspective so that superheat-resistant materials and turbine system technology that have been developed can be nurtured into independent businesses.

To enhance and maintain the international competitiveness of manufacturing industries, which are expected to lead economic revitalization, it is required to continuously promote the development of materials that serve for the minimization of burdens on the environment. Therefore, a subject for investigation is how to provide private companies with incentives that activate research and development and practical applications of materials and manufacturing technologies effective for saving energy and resources.

(Original Japanese version: published in January 2004)

7 Notable Points of the US "21st Century Nanotechnology Research and Development Act"

p.73

After the US Senate and House of Representatives had passed the bill entitled "21st Century Nanotechnology Research and Development Act" (S.189; hereinafter, "NRDA") at the 108th Congress, the bill became an official legislation on December 3, 2003 when President Bush appended his signature.

NRDA defines national nanotechnology R&D efforts as the National Nanotechnology Program, stipulates the roles of the National Nanotechnology Coordination Office and Advisory Panel, and expressly provides for triennial external review and expenditure budgets. It ultimately aims at "ensuring that advances in nanotechnology bring about improvements in the quality of life for all Americans." In this sense, the US government sets specific goals and priorities based on "national needs for a set of broad applications of nanotechnology." Specifically, the act clearly intends to accelerate deploying and applying basic science knowledge on nanoscale control and manipulation in the private sector including startup companies in order to enhance the productivity and industrial competitive edge of the United States. NRDA also aims at encouraging nanotechnology R&D and education activities to create the proper "culture" for interdisciplinary research activities.

In particular, NRDA mirrors current public awareness and clearly stipulates the attitude to integrate research on societal, ethical, and environmental concerns with nanotechnology R&D activities as much as possible. NRDA does not provide specific solutions for these adverse impacts of nanotechnology, but does mention the US decision-making process through establishing expert research programs and convening ongoing public discussions. They have already started nationwide discussions on societal implications of nanotechnology.

The United States is the first nation to enact a law regarding how to proceed with nanotechnology R&D activities. In this sense, NRDA will have influences on the future directions in other nations as well.

(Original Japanese version: published in January 2004)

Energy

8 Using of Power Electronics for the Development of Energy Infrastructures

p.77

Power electronics is a basic technology for energy infrastructures that contributes to the effective use of electrical energy. As a result of the expanding use of dispersion type power sources, such as fuel cells that provide direct current and information appliances that use direct current, electric power systems and power electronics devices are expected to be used more than ever to form interfaces for various applications.

We took over the lead in power electronics technology by succeeding in the development of high-capacity semiconductor power devices made of Si (silicon) in Japan. Recently the “development of ultralow-loss power device technology” project has been finished, which aimed at ultra-low loss, downsizing, and weight saving of power electronics devices made of materials such as SiC (silicon carbide) used for electric power systems and fuel cell vehicles, the next step of development is being investigated.

For the future, it is necessary to plan a project that aims at the practical applications of the results of material development on which the past project placed emphasis. Power electronics covers a lot kind of diversified areas including electric power systems, traffic and transportation systems, and household electric appliances; therefore, it is necessary to establish a roadmap based on the needs for technical development required by each field and to promote research and development. Since the recent expansion of the use of dispersion type power sources has caused concerns the electric power quality of Japanese electric power systems, it is particularly important to quickly realize the practical application of power electronics devices that contribute to the stabilization of electric power systems when dispersion type power sources are used in large quantities.

In Japan, private companies cannot actively invest in the development of new semiconductor power devices, and at the same time, there are problems in the development of human resources at universities. Furthermore judging from the numbers of papers, the United States and European countries are more actively conducting research on power electronics than Japan, and collaboration between the industry and academia is being steadily implemented. Projects that aim at the practical applications of power electronics must be promoted with a view that the industry, academia, and government should cooperate in fostering researchers and engineers who will play a major role in the development of next-generation technology.

(Original Japanese version: published in February 2004)

Science and Technology Policy

9

Evaluation of R&D Projects
–European Practice–

p.87

This article explains the competitive R&D fund scheme in Europe.

The European Union has been promoting the so-called "Framework Program," which is an R&D program to enhance its industrial competitive edge. This program solicits proposals from the public. Researchers must solicit for research institutions in at least three EU member states when submitting their proposal to the European Commission, which serves as the Framework Program's secretariat. The secretariat then evaluates these proposals to identify those deemed appropriate.

The initial evaluation process consists of two steps: peer review by panel members, and the subsequent coordination by the secretariat. Basically, the panel members must be experts who do not have any stake in the specific proposal. In this sense, the secretariat sometimes appoints panel members from non-EU member states.

Each panel member independently evaluates the proposals. After that, they hold a panel meeting with the coordinator to draw up a tentative consensus. Then, all the panel members have discussions to draw a final conclusion. For a large-scale project, they hold hearing sessions as well. After being notified of the evaluation result, an applicant may raise an objection over the evaluation result.

The EU probably spends 2% of its total R&D expenditures for this evaluation process. The initial evaluation process is very strict because the European Commission assumes accountability for EU member states and would like to select proper proposals submitted by motivated researchers.

All proposals are written in English, which means English is the only "official language" in the science and technology field. By doing so, panel members from different nations are able to join in the evaluation process.

The EU also has an ex post evaluation process, which commends project outcomes and strongly encourages the Program's continuity. However, according to trade statistics on the information and communication fields, the EU has a trade deficit against other developed nations. This fact indicates the Framework Program has not necessarily enhanced the EU's competitive edge.

In comparison with the EU, Japan does not have any evaluation process that involves foreigners. There is no national border for R&D activities. Japan should establish an appropriate system that requires R&D proposals and reports to be written in English.

(Original Japanese version: published in February 2004)

1

Strategy of the National Institutes of Health (NIH) of the US to Accelerate Biomedical Research (NIH Roadmap)

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1 Introduction

The National Institutes of Health (NIH)[1] is an agency of the Department of Health and Human Services of the US. The mission of the NIH is to "expand fundamental knowledge about the nature and behavior of living systems and the application of that knowledge to extend healthy life, and conduct and support research in the diagnosis, treatment and prevention of human diseases." The NIH consists of the Office of the Director and 27 Institutes and Centers. The Office of the Director is responsible for setting policies for the NIH and for planning, managing, and coordinating the programs and activities of all of its institutes and centers. The 27 institutes and centers include the National Cancer Institute, the National Heart, Lung and Blood Institute, and the National Human Genome Research Institute. The NIH conducts research through these institutes and centers, and fosters research work at universities and research institutes both in the US and abroad by providing grants and funding opportunities.

NIH announced on September 30, 2003 the "NIH Roadmap" that outlines its "strategy to accelerate biomedical research progress." The NIH Roadmap provides a framework of the priorities the NIH must address in order to improve its research capabilities and speed the movement of research discoveries from the bench to the bedside.

This article outlines an overall picture of the NIH Roadmap by illustrating its objective, crafting process, pressing issues, and other major features.

2 NIH R&D Budget

Congress has not yet approved the NIH R&D budget bill for FY 2004[2]. The bill, which had been passed by the Lower House on December 8, 2003, is expected to be approved by the Upper House in January 2004. If approved, the bill would provide the NIH with $27.1 billion in FY 2004 (up 3.2% from FY 2003). The nation's R&D budget totals $127 billion, of which $56 billion are directed to non-defense programs. This means that the NIH budget accounts for nearly 50% of the nation's non-defense budget[3].

The NIH R&D budget continued to mark a 7 to 8% annual increase until FY 1998. Upon the launch of the "doubling of NIH budget" under the initiative of President Clinton in FY 1999, the NIH budget continued to mark outstanding annual growth of 14 to 15% (see Table 1). The NIH budget request for FY 2004, however, shows that such a rapid increase has come to an end, as it proposes a 3.2% increase from FY 2003[2,4].

The NIH budget doubling campaign effectively increased the budget for all NIH institutes. For

Table 1 :Change in the NIH R&D Budget [2,4]

Fiscal year	Budget (million $)	Comparison with previous year (%)
1998	13,110	7.3
1999	14,995	14.4
2000	17,234	14.9
2001	19,807	14.9
2002	22,714	14.7
2003*	26,245	15.5
2004**	27,093	3.2

* Figure for the final NIH budget for FY 2003
** Figure for the NIH budget as of December 8, 2003

Source: Author's compilation based on Reference[2,4].

example, "Human Genome Research" saw a substantial increase in its R&D budget from FY 1999 to FY 2000 due to the strengthened effort to map the human genome. The Human Genome Project made a major breakthrough when the human genome was finally sequenced in 2001. There has also been a rapid increase in the R&D budget for "Allergy and Infectious Diseases" since FY 2002[5-9].

3 Background to the Creation of the NIH Roadmap

There are two major factors that prompted the NIH to chart the priority initiatives entitled the "NIH Roadmap."

Firstly, the NIH intends to continue using its research potentials recognized during the doubling of NIH budget, which lasted five years from FY 1999 to FY 2003. Secondly, Dr. Elias A. Zerhouni was appointed the new NIH director in May 2002.

4 Overview of the "NIH Roadmap"

This chapter outlines the NIH Roadmap based on official information on the NIH website[10, 11].

4-1 Purpose

The purpose of the NIH Roadmap was to "identify major opportunities and gaps in biomedhical research that no single institute at NIH could tackle alone but that agency as a whole must address to make the biggest impact on the progress of medical research." Traditionally, the NIH conducts research through its 27 institutes and centers to facilitate its own research programs and offer funding opportunities. The NIH Roadmap, however, highlights the "priorities the NIH must address by transcending traditional departmental boundaries."

The NIH decided to craft the NIH Roadmap due, in part, to a change in the nature of biomedical research. This change was initiated by the completion of the human genome sequence, which dramatically increased the speed of new discoveries in the last few years. However, the complexity of biology remains a daunting challenge for the NIH, which aims at transforming scientific knowledge into tangible benefits for people. To meet that challenge, the NIH had to review its strategy to conduct biomedical research and bring research discoveries from the bench to the bedside.

4-2 Crafting Psrocess

Soon after becoming the director of the National Institutes of Health (NIH) in May 2002, Dr. Elias A. Zerhouni convened a series of meetings and consultations to chart the NIH Roadmap.

The initial step in crafting the Roadmap process involved a series of five meetings. More than 300 nationally recognized leaders in academia, industry, government, and the public discussed about the most compelling initiatives that the NIH should pursue over the next 10 years. Participants were asked to address three key questions. "What are today's most pressing scientific challenges?," "What are the roadblocks to progress, and what must be done to overcome them?," and "What is the responsibility of the NIH as a whole?" Through discussions, three major areas (themes) emerged.

Later, a series of Institute Director-chaired Working Groups of NIH staff were formed to make final selections of key initiatives on the advice of the NIH Council and the NIH Advisory Committee.

The NIH leadership weighed all initiatives in the context of several broad criteria to make final selections that deserve funding. These criteria include: "Is the initiative truly transforming - will it dramatically change the content or the process of medical research in the next decade?," "Would outcomes from the initiative be used by, and synergize the work of, many institutes?," "Will the initiative be compelling to NIH stakeholders, especially the public?," and "Does the initiative position the NIH to do something that no other entity can or will do?"

The Roadmap working groups were then grouped into several Implementation Groups to devise and examine detailed implementation plans, and short- and long-term objectives for the next stage of the Roadmap for FY 2004.

4-3 Major NIH Roadmap Areas Themes

(1) New Pathways to Discovery

This theme addresses the need "to understand complex biological systems." Having completed the sequencing of the human genome, further progress in medicine will require quantitative knowledge about the many interconnected networks of molecules that comprise cells and tissues, along with improved insights into how these networks are regulated and interact with each other. Implementing groups in this area will address several initiatives, including "Structural Biology," "Proteomics (research to determine the amounts, locations, and interactions of the large numbers of individual proteins within a single cell)," and "Metabolomics (research to determine the metabolic components and networks within the cell)."

In this set of initiatives, researchers will also build a better "toolbox" for today's biomedical research. To fully capitalize on the recent sequencing of the human genome and many new discoveries in molecular and cell biology, these initiatives address the research community's need for database access and analytical technologies.

With this theme, the Roadmap addresses the following five initiatives.

(i) Building Blocks, Pathways, and Networks

- The National Technology Centers for Networks and Pathways will be established to promote the development of new technologies to describe the dynamics of protein interactions. The center will also develop instruments, methods and reagents for quantitative measurements and for measurements at very short timescales.
- New technologies will be developed to study metabolomics. Knowledge gained from these studies will be used to understand the role of metabolites in the context of cellular pathways and networks.
- Workshops will be convened to study proteomics and metabolomics in order to establish data standards for research in proteomics and metabolomics, and investigate ways for establishing an evaluation index for future research in proteomics.

(ii) Molecular Libraries and Molecular Imaging

- The NIH Bioactive Small Molecule Library and the Screening Centers will be established to develop new screening methods and provide a public molecule library.
- A database of chemical structures, properties, and activities will be established. A competitive research fund will also be established to promote the development of tools and technologies for chemiformatics.
- Compounds as basic research tools will be developed. Bottlenecks in the development of compounds as drugs will be targeted.
- An imaging probe with strong detection sensitivity and specificity will be developed. A 1,000-fold improvement in imaging probe detection sensitivity is targeted, ultimately, for basic research and clinical applications. The initial step is to achieve a 10 to 100-fold improvement within five years.
- A database of specificities, activities and applications of an imaging probe will be established.
- The core facility will be established to provide imaging proves and generate novel imaging probes.

(iii) Structural Biology

- Methods will be developed to produce protein samples that scientists can use to determine the three-dimensional structure of a protein, and apply obtained knowledge to determine the structure of membrane protein.

(iv) Bioinformatics and Computational Biology

- The National Centers for Biomedical Computing will be developed. This initiative will also create a national software engineering system in which researchers will be able to tap into a supercomputing network from anywhere in the country to share and analyze data.

(v) Nanomedicine

- A series of workshops will be convened in FY 2004 to prepare for the launch of the Nanomedicine Centers in FY 2005. These Centers will focus on quantitative measurement of biological processes at the nanoscale and the engineering of new tools to intervene at the nanoscale. This research will help scientists construct miniature pumps for drug delivery or tiny sensors to determine the cause of a disease.

(2) Research Teams of the Future

This theme is intended to address the issue of research system by implementing three initiatives: "Introduction of a new funding system," "Interdisciplinary Research," and "Public-Private Partnerships."

(i) High-Risk Research

A new funding system (NIH Director's Innovator Awards) will be introduced to provide support for "high-risk medical research that may achieve a major breakthrough." Historically, the NIH has almost exclusively supported low-risk research projects, because more detailed research proposals were selected over creative but high-risk proposals under its existing peer review system. The new award evaluates individual scientists in terms of their creative abilities, originalities, evidence of focused skillful habits of mind that predict perseverance and thorough exploration of his/her ideas, and prospects for making seminal biomedical research advances. In other words, originality or the potential of individual scientists weigh more than research proposals.

(ii) Interdisciplinary Research

There is a growing need for researchers to transcend the traditional departmental boundaries and to work with researchers in other areas of scientific interest, as today's biomedical research becomes increasingly diverse and complex. For instance, radiologists, physicists, biologists, and computer programmers may need to work together to solve a problem of image analysis. To keep pace with the changing nature of biomedical research, these initiatives will encourage researchers to "integrate different scientific disciplines." With this theme, the Roadmap seeks to address the following initiatives.

- Grants will be awarded to interdisciplinary research programs that use new approaches. A total of 15 grants will be awarded in FY 2004.
- Training will be provided to scientists in interdisciplinary research programs. This new model of funding will be introduced in FY 2004.
- Technologies and methods will be developed to facilitate interdisciplinary research.
- Structural barriers will be removed to facilitate interdisciplinary research.
- A model program for interdisciplinary research will be established within the NIH to provide training to scientists in interdisciplinary research and establish an interdisciplinary research team. The feasibility and benefits of the program will also be examined.
- The NIH and National Science Foundation (NSF) will hold the first interagency conference in FY 2004 to discuss "what needs to be done to encourage progress in the physical science that will provide support and underpinning in the future for advances in the life sciences."

(iii) Public-Private Partnerships

"Novel partnerships between the public and private sectors" will be encouraged to accelerate the movement of scientific discoveries from the bench to the bedside. There are two initiatives to encourage Public-Private Partnerships.

- The Public-Private Sector Liaison will serve as a resource to NIH staff on partnerships to set up an internal Public-Private Partnerships Coordinating Committee.
- Partnership Meetings will provide the NIH and potential partner organizations with opportunities to meet to discuss potential partnerships.

(3) Re-engineering the Clinical Research Enterprise

With this theme, the Roadmap addresses the need for "Re-engineering the Clinical Research Enterprise."

Ideally, basic research discoveries are quickly transformed into diagnostics, drugs, treatments or methods for prevention. Such translation lies at the very heart of the NIH's mission. The NIH has succeeded in fulfilling that mission. If such efforts are to remain as successful as they have been in the past, the NIH must renew its effort to improve the health of the people.

In the past, all research for a clinical trail could be conducted in one academic center. Clinical research, however, has become more difficult to conduct over the years. Today, it is necessary to develop new partnerships among organized patient communities, community-based physicians, and academic researchers in order to conduct clinical research. To address such need, the NIH will promote the creation of better integrated networks of academic centers to speed clinical applications of basic research discoveries and enhance clinical research capabilities. This theme is intended to address this crucial area by implementing the following initiatives.

- A clinical research process will be coordinated, standardized and streamlined.
- The efficiency and productivity of the nation's clinical research enterprise will be enhanced through the creation of clinical research networks.
- Specialized training will be offered to clinical researchers.
- The National Electronic Clinical Trials and Research Network will be established as the standard data system that enables clinical researchers to share data and resources.
- The translation of basic discoveries to early phase clinical testing (translational research) will be promoted.
- The Regional Translational Research Centers will be established to increase interactions between basic and clinical scientists. The essential core infrastructure will be consolidated into these centers.
- Technologies will be developed to better quantify clinically important symptoms and outcomes, including pain and fatigue and to determine the severities of illnesses.

5 Conclusion

The NIH plans to set up a common pool of resources to facilitate the effort to implement the NIH Roadmap initiatives across the NIH as a whole. In FY 2004, $130 million will be committed to the Roadmap initiatives, with a total of $2.1 billion for five years to come[12]. This is a new attempt for the NIH, as it has always distributed a budget to all of its institutes and centers. The NIH will play a central role in shaping a budget and observing the progress of implementation, with each implementing group translating a plan into action on behalf of the NIH as a whole.

Presently, the NIH is inviting scientists to submit research proposals for obtaining competitive research funds on website, which are intended to support the NIH Roadmap initiatives. The NIH will begin to implement most of the initiatives in FY 2004 (from October 2003 to September 2004). At the beginning of FY 2004, applications were being received for several Roadmap-related competitive research funds. A gradual rise in the number of Roadmap related funding opportunities shows that the NIH is committed to moving towards a full-scale implementation of the Roadmap initiatives.

It is believed that the announcement of the NIH Roadmap at the beginning of FY 2004 was prompted by the need to present a new policy for the NIH as a whole, following the appointment of the new NIH director and the completion of the doubling of NIH budget in FY 2003.

The "NIH Roadmap" does not set a clear milestone for its initiatives. Rather, it lays out the direction for future research. In the area of basic research, post-genome research, development of post-genome analytical tools, and interdisciplinary research are made the priority initiatives. This shows that the NIH gives the utmost priority to the facilitation of clinical research in consideration of its mission.

We will watch the future development of the NIH Roadmap closely to report on how the President's Budget proposals for FY 2005 weigh on the NIH initiatives and how Congress alters and agrees the budget for final approval.

Reference

[1] National Institutes of Health (NIH), http://www.nih.gov/

[2] AAAS, "NIH Wins 3 Percent Increase in Final FY 2004," Dec. 9, 2003.

[3] AAAS, "FY 2004 Federal R&D Climbs to Record High of $127 Billion," Dec. 8, 2003.

[4] AAAS, "Historical Data on Federal R&D, FY 1976-2004," March 7, 2003.

[5] AAAS, "FY 2003 Omnibus Bill Completes NIH Doubling Plan; Large Increases for Bioterrorism R&D and Facilities," Feb. 25, 2003.

[6] AAAS, "NIH Budget Climbs $3.2 Billion or 15.7 Percent," Jan. 4, 2002.

[7] AAAS, "Congress and President Clinton Agree on 14 Percent Boost for NIH," Jan. 4, 2001.

[8] AAAS, "Congress Agree on $2.2 Billion Boost for NIH, But Withholds $3 Billion Until Next September," Nov. 24, 1999.

[9] AAAS, "NIH Wins $2 Billion Increase in FY 1999," Nov. 13, 1998.

[10] NIH Roadmap, http://nihroadmap.nih.gov/

[11] Elias Zerhouni, The NIH Roadmap, Science, 302 (5642): 63 - 72.

[12] Chemical & Engineering News, 81 (40): 10.

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2

Latest Trends in the Optical Disk Industry
– The Superiority of Japanese Companies and a New China-U.S. Joint Effort for Standardization –

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1 Introduction

The principles of optical disks, including the compact disk (CD) and the digital versatile disk (DVD), which are in widespread use by consumers worldwide, were invented in the Netherlands. However, Japanese companies have been winning an overwhelming victory in the optical disk industry by leading it in all areas of mass-production technology, standardization, and business. The situation has changed over the past few years, and Japanese firms are now forced to collaborate with Korean and Taiwanese manufacturers through joint ventures and to face a new standardization proposal from China. The latter refers to the Enhanced Versatile Disk (EVD), a standard advocated jointly by China and the U.S. in a move that can be considered part of their market acquisition strategy intended for reducing royalties paid to Japanese license holders.

This article discusses the characteristics of the optical disk industry, which is faced with such a situation, from four perspectives: (1) technology, (2) business, (3) standardization, and (4) patent status. More specifically, the following topics are covered: (1) Why was it in the Netherlands where an invention as significant as the optical disk was accomplished?, (2) Following the invention, how has Japanese technology come to dominate the world? How did corporate research laboratories and public institutions contribute to this dominance as well as to next-generation optical disk technologies?, (3) How has the optical disk evolved as a product? How has the worldwide market share structure in favor of Japan been formed, and in the formation process, how have Japanese manufacturers been taking the initiative in standardization?, and (4) Does Japan have a strong patent position?

This article also provides details about the announcement of EVD as part of a new China-U.S. joint effort toward standardization. Then it examines the structure of the optical disk industry, which is experiencing such a movement, in comparison with the structure that caused the Japanese semiconductor industry to see a continuous decline in the worldwide market since the mid 1990s. Through this, the report warns that if Japan takes wrong measures, a profound change in the market share structure, which has already occurred in the semiconductor and liquid crystal display industries, can take place in the optical disk sector as well. To prevent this from happening, Japan needs to increase its patent strength by linking it with industry standards. That is to say, Japan should direct its research efforts toward more fundamental themes and aim at a stronger patent position in terms of the number as well as quality of patents, so that Japan's patented technologies can achieve levels that are high enough for adoption as industry standards. Moreover, the article presents a proposal, from a medium- to long-term perspective, in which Japan should take steps to build productive environments to promote the activities of creative researcher groups and more effectively facilitate breakthroughs in science and technology that can compare to the invention of the optical disk in the Netherlands.

2 Evolution of optical disk technology

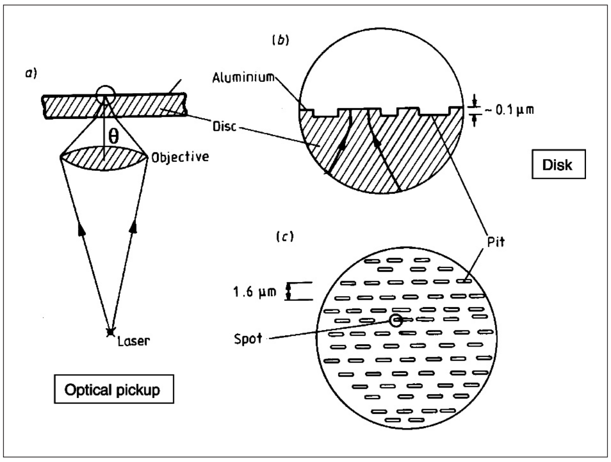
2-1 Optical disk technology

As shown in Figure 1, the basic structure of the optical disk system[1] consists of an optical pickup, a disk on which digital signals are recorded, a driving mechanism for them and its control circuit, and a circuit for decoding digital images and audio. The optical disk has the following characteristics: (1) Since the disk does not come into contact with the pickup, there is no wear on the disk surface, no matter how many times it is read; (2) Disks are available at low cost because mass duplication is easy; (3) Because of high recording density, a disk can store not only audio but even a two-hour movie; and (4) A single portable device can record and play a number of types of disks.

Competing high-density memory technologies such as semiconductor memory and magnetic memory do not provide such features. It is a known fact that for this advantage, the optical disk has come into widespread use worldwide as an external storage medium for audio, video, and computer data, both at homes and offices.

The recording density of an optical disk is determined by the spot size, which is restricted by the diffraction limit caused by the wave motion of light. In this case, the spot diameter (d) is given by d = λ /NA, where the wavelength of the light source is (and the numerical aperture for the disk side of the condenser lens is NA (NA = sin θ , where θ is the angle that the optical axis makes with the outermost beam, as shown in Figure 1). According to this formula, improvement in the recording density of an optical disk can be achieved by shortening the wavelength of the light source and increasing the numerical aperture of the condenser lens. By using this formula as the guiding principle, relentless efforts have been made to develop technology that can shorten the wavelength of the light source for the laser diodes used for optical disks, and improve the numerical aperture of lenses. In fact, as shown in Table 1, the wavelength of laser diodes has been shortening as the generation number for the optical disk technology increases: 780 nm with infrared laser diodes for CDs, 650 nm with red laser diodes for DVDs, and, for the next generation, 405 nm with blue-violet laser diodes for High-Definition (HD) DVDs and Blu-ray Disk (BD) formats. The numerical aperture has also increased as the generation number advances, from 0.45 for CDs to 0.65 for DVDs, 0.65 for HD DVDs, and 0.85 for BDs.

Figure 1 : Structure of the read-only optical disk



Source: Author's compilation based on reference[1].

Table 1 : Development of optical disk technology

Generation	Research stage	0th	1st	2nd	3rd	4th (Post-Blue)
Year Product	'62 –	'72 Video Disk	'82 CD	'94 DVD	'03-'04 BD/HD DVD	('12) (TB Disk)
Storage capacity	–	2 hours (30 cm)	0.68 GB	4.7 GB	15-20 GB	(Terabyte)
LD* wavelength	LD Emission	633 nm (He-Ne**)	780 nm	650 nm	405 nm	(405/280 nm)
Lens NA	–	0.45	0.45	0.65	0.85/0.65	(0.85/0.65)
Cover thickness	–	1.2 mm	1.2 mm	0.6 mm	0.1/0.6 mm	(Multilayer)

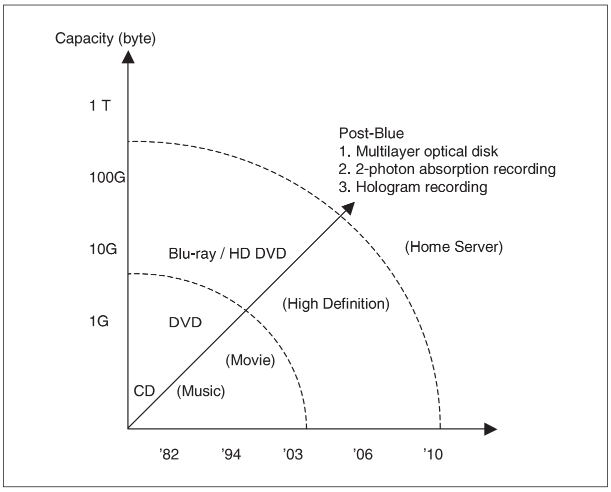
*LD: Laser Diodo
**He-Ne: Helium Neon gas laser

2-2 The future of optical disk technology

Figure 2 shows the roadmap for optical disk technology, where the vertical axis indicates the recording capacity and the horizontal axis the year. Following CDs and DVDs, the HD DVD and BD formats are becoming ready for commercialization. This section explains what technologies are expected after them. For the purpose of further reducing laser diodes' wavelength, which determines the recording density of optical disks, use of ultraviolet light in the range of 300 nm or less should be considered. Recently, a light-emitting diode (LED) that can emit light at a wavelength of 280 nm was reported, suggesting continued efforts toward the development of seed technologies. However, there are some challenges regarding materials, such as that plastic, the substrate for the current optical disks, absorbs light in the 200 nm range and is therefore unusable as it is for the next-generation technology. New materials need to be developed as a breakthrough. Another problem is that the energy of ultraviolet light is so high that using an ultraviolet LED as the laser diode source will increase light intensity per unit area, resulting in a higher possibility for crystals to be damaged. This highlights the need for developing technologies to ensure long life by preventing the deterioration of crystals over time through, for example, the ultimate minimization of crystal defects, which cause damage.

One approach, aside from shortening the wavelength, to increasing the recording capacity is multi-layering the optical disk. While multi-layering does not raise the recording density per two-dimensional area, it increases the recordable space within the disk layer by allowing it to contain additional recording layers to provide extra recording capacity. A problem with this approach is the interlayer crosstalk (receiving unwanted information from an adjacent layer). To solve this issue, there has been a proposal in which voltage is applied selectively to the target layer that is to record or reproduce information, so that the layer is colored and thus becomes able to absorb laser light. Such properties are known as electrochromism, and electrochromic materials remain transparent while no voltage is applied, which is the key to preventing crosstalk with other layers. Multilayer disks with this kind of structure can have a recording capacity of 20 GB per layer, if the blue-violet laser is used. This means that a disk consisting of 50 layers can record as much as 1,000 GB or 1 TB (terabyte) of information. Optical disks for home use have so far developed as storage media to contain either 60 minutes of music (with 0.68-GB CDs) or a two-hour movie (with 4.7-GB DVDs). In the future, when optical disks are expected to find application as large-capacity memory devices for the Internet, to which individual homes are connected, there will be an increased need for storage media with a capacity as large as 1 TB. In terms of downsizing, on the other hand, a disk measuring 30 mm in diameter, which is much smaller than the now-prevalent 3.5-inch magneto-optical (MO) disk, is under development, presumably aiming at incorporation into personal digital assistants (PDAs) and mobile phones.

Figure 2 : Optical disk roadmap



2-3 The environment that facilitated the invention of the optical disk principles

This section focuses on research and development environments, taking the optical disk, the theme of this article, as an example. The two fundamental physical requirements for optical disks, namely, (1) the light spot diameter larger than the pit size and (2) the pit depth one-quarter the size of the wavelength of the light source, have become the two major principles of read-only optical disks. Both of these principles were discovered at the central research laboratory of Royal Philips Electronics in Eindhoven, the Netherlands. They were probably inspired by Dutch Nobel Laureate Zernike's principles of the phase-contrast microscope (1935). If you trace this farther back in the history of science and technology, the physical model of the diffraction limit determined by the light wave comes down to Huygens' principle (Christian Huygens: 1629-1695, the Netherlands) on wavefront formation. These facts suggest that the Netherlands has a long history in optics and that the nation's accumulation of profound physical knowledge in optics contributed to the invention of the optical disk principles.

The central research laboratory of Philips can be considered as a research group sponsored by the company, and also as an environment that facilitated invention and discovery by gathering Nobel-class scientists and researchers who have an acute awareness of science and technology. No one can invent or discover more than what he or she knows. When a new phenomenon occurs, a careless person tends to overlook its essence. By contrast, a person who is always making efforts to understand unknown phenomena and has a matured and acute awareness of things could feel and capture the essence of the phenomenon. This is how discovery occurs and what makes science different from careless speculation. There is no easy way to allow science to take deep root. Relentless and rigorous efforts alone will count. In order to maximize the national level of scientific and technology and to lead the world with its superiority, Japan needs to gather Nobel-class scientists and researchers with a shrewd awareness of science and construct for them an environment that promotes invention and discovery. It is important that outstanding talent who are young and confident come together so that they can develop themselves, while inspiring one another and achieving research results. These human resources must have substantial interest in and curiosity about science. Loyalty to the organization is a favorable character but not as valuable to a scientist as a personality to regard imitation as a shame, while trying to do what no one has attempted. In fact, when I was in the Philips laboratory, one of my Dutch colleagues said something like this, "In the Stone Age, those who handled only stone tools never had a chance to discover any metal tools. It was the existence of odd (daring) persons who had interest in other than stone tools that enabled the invention of metal tools. This is the essence of research." Such an approach, though it may not be necessary when incremental progress in science is deemed satisfactory, should be taken if Japan seeks a great leap forward, and this would be the only way to enhance the possibility of significant invention and discovery. Under the current economic slump, instead of private-sector companies, which cannot afford to support activities toward this end, the government is expected to take the initiative. We should recall the Institute of Physical and Chemical Research[2] in the prewar era, although a private research organization, as an excellent example of traditional Japanese models.

3 The superiority of Japanese technology and the formation of the worldwide market share structure

3-1 The role that the R&D division of Japanese companies played

The principles of read-only optical disks such as CDs and DVDs available today were, as described earlier, invented at Philips in the Netherlands, which introduced in 1972 the world's first optical disk equipment onto the market. The disk of those days measured as large as 300 mm in diameter and was designed to record a two-hour movie in the analog method (frequency modulation). Since the light source used in the equipment was a helium-neon laser that had a wavelength of 633 nm and consisted of a vacuum tube, shrinking the size of the equipment was impossible. This intensified the need for the commercialization of laser diodes that, like those available today, consumed less power, were small in size, and allowed for direct modulation.

As shown in Table 1, the world's first laser diode oscillation was confirmed in a low-temperature environment at Bell Labs and others in 1962. In 1972, 10 years later, Bell Labs in the U.S. designed the first laser diode that could operate continuously at room temperature by using the double-heterojunction technique invented by Dr. Izuo Hayashi and others, paving the way for commercialization. The most challenging problem in the early days of this new technology was the extension of life. Several Japanese electric machinery manufacturers, including Hitachi, Ltd. and NEC Corporation, addressed and invested in the issue as their priority R&D themes, resulting in the completion of technology to improve the crystal quality of GaAs (gallium arsenide) semiconductors. Put another way, technology to ultimately minimize the number of crystal defects, which are responsible for degradation, was successfully developed in Japan and brought about the realization of the long-awaited extended-life laser diodes. Japanese manufacturers subsequently devised other useful technologies such as the one for controlling the oscillation mode for improving laser diodes' performance and optical technology for aberration correction, while playing the key role in developing optical pickup technology, which was pursued concurrently.

Japan's optical technology, whose superiority was demonstrated in the development of optical pickups, has its roots in the technologies invented by traditional optics manufacturers, including those making cameras and microscopes. For example, the object lens for the optical pickup was originally a combination of multiple glass lenses for which cost reduction was difficult. To tackle the problem, Konica Corporation attempted to produce a single lens that is plastic and even aspherical, and eventually developed a low-cost lens of such kind whose performance is equivalent to that of glass compound lenses. However, not all optics makers could enter the optical disk equipment business, because optical technology, despite its connection with the core of the optical disk principles, was only a part of the overall hardware, for which electric companies had a total advantage with respect to the ability to design the overall system embracing digital signal processing, control circuits, and so forth. For this reason, optical engineers at electric machinery makers played an important role even in the field of optical technology like the optical pickup. Thus, Japan's traditional optics was combined with its electronics technologies, including laser diodes and electronic circuits, and the national strength in crystal growing techniques to help Japan fully secure technological advantage over the rest of the world in the optical disk sector.

3-2 The role of Japanese universities and public institutions

The importance of the contributions by universities and public research institutes to the advance of Japan's optics should not be underestimated. Specifically, this refers to lens design technology through the application of geometrical optics and optical measuring technology based on wave optics, which both have been studied at the Institute of Industrial Science of the University of Tokyo and the Department of Applied Physics, the School of Engineering of Osaka University, and also to applied optical technology such as holography researched at the Schools of Science and Engineering of the Tokyo Institute of Technology. These universities maintain world-class academic standards through logical and in-depth research into optics and future-oriented research themes, which are too risky for businesses to address. With respect to applied research, the universities have also contributed to improving the research standards in the private sector by raising interest in more basic themes and providing the logical foundations for applied research, whereby they can honor the authors of outstanding papers with a doctor's degree as an incentive that motivates corporate researchers.

Some of the research themes regarding future optical disk technologies being addressed at universities include super-high-density optical memory, which applies near-field optics, and holographic memory. In these fields, the School of Engineering of Osaka University and the Schools of Science and Engineering of the Tokyo Institute of Technology are working on unique projects. Because of the uncertain prospects of successfully recovering investments, such themes are not viable options for companies, and this is one of the areas where universities and public research institutes assume an essential role.

Another important aspect of the role of

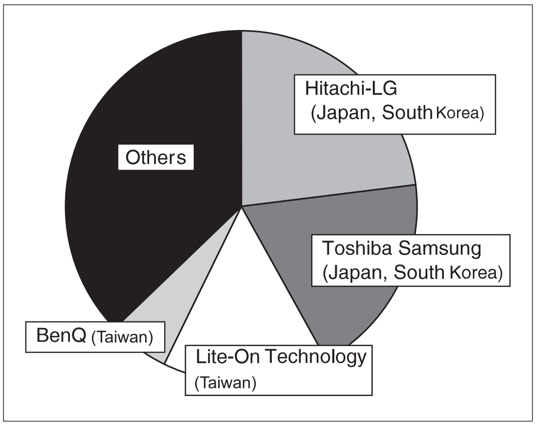
universities and public research institutes is scientific society activity. The International Symposium on Optical Memory (ISOM), a world-class international society for optical disks initiated by Japan in 1987, has been holding meetings at locations in Asia every year to serve as a place to present the latest findings. Every three years, the ISOM is held as a joint symposium with the Optical Data Storage conference, which is organized by the Optical Society of America.

3-3 The formation of the worldwide market share structure

The proliferation of full-fledged optical disk equipment, as previously described, started with audio compact disks (CDs). Japanese electric machinery manufacturers such as Sony Corporation and Hitachi, Ltd. forged alliances with Royal Philips Electronics, the inventor of the optical disk, to successfully acquire a large share in this market. In particular, Sony, which developed an excellent technology on error correction code in optical disk devices, established an industry standard by striking a technological balance between its proprietary technology and the optical disk principles invented by Philips, mentioned earlier, and established the so-called golden age of Compact Disk Digital Audio. Following the huge success in CD as an audio application, CD formats as external memory media to use with proliferating personal computers, such as CD-ROM (Read Only Memory), CD-R (Recordable), and CD-RW (Rewritable), emerged to contribute to the rapid growth of the computer-applied optical disk equipment business.

Meanwhile, those who developed the optical disk equipment had long dreamed of recording a two-hour movie on a CD-size (120 mm in diameter) medium. It was the research team at Toshiba Corporation[3] who realized this dream. They used laser diodes whose wavelength had shortened from 780 nm in infrared to 650 nm in red, while increasing the lens NA from 0.45 to 0.65, to expand the recording capacity of an optical disk by sevenfold. The result was a DVD that can contain a two-hour long movie, as mentioned earlier. They were able to increase NA to 0.65 because they reduced the thickness

Figure 3 : Worldwide optical disk equipment market share (based on unit shipment)



Source: Author's compilation based on an article in the September 23, 2003 issue of Nihon Keizai Shimbun.

of the cover layer on the disk from 1.2 mm to 0.6 mm to prevent malfunctions arising from the lens aberration. The thicker the cover layer is, the more likely aberration occurs. The concept of the Toshiba team was just like Columbus' egg. They discovered that the conventional cover layer thickness of 1.2 mm for dust protection was over-specified or simply too much.

Movie companies in Hollywood, the world's largest content provider community, welcomed this invention and formed alliances with Toshiba and other Japanese electric appliance makers. This allowed these electronic companies to acquire an overwhelming share in the worldwide markets for the all optical disk applications for music, movies, and computers. Their dominance in market share continued through the nation's bubble era in the 1980s and the early 1990s, as a matter of course, and still continues even after the bubble burst. A major change in share structure, which the semiconductor and LCD markets experienced, has not occurred, at least nominally, in this sector. However, since the leading Japanese manufacturers currently manage to maintain top shares through alliances, or joint ventures, with Korean or Taiwanese firms, future developments in the market should be carefully observed.

Actually, as indicated in the global market share in Figure 3, Japan-Korea joint ventures have proven to be competitive, such as the one established through a merger between Hitachi and LG Electronics of South Korea and the one founded through a merger between Toshiba and

Samsung. The global optical disk equipment market for 2002 has been valued at a little over ¥1 trillion, of which these top Japan-Korea joint ventures secured sales worth about ¥200 billion each. As opposed to this, the U.S. optical disk industry has contracted as once-dominant IBM, Xerox, Kodak, and Bell Labs lost their competitiveness in both the market and the R&D fields. From Europe, only Philips in the Netherlands manages to maintain a certain presence as a company of long standing.

Recently, a blue-violet (with a wavelength of 405 nm) laser diode based on gallium nitride (GaN) was developed in Japan, technically opening the door for the production of an optical disk that has four to five times the storage capacity of a DVD. This marked the start of a race between two major standardization groups to take the initiative in the third-generation optical disk. One group, led by Sony Corporation and Matsushita Electric, promotes the Blu-ray disk (BD), which can store up to 20 GB of data, and the other, headed by Toshiba Corporation and NEC Corporation, advocates HD DVD (formerly known as Advanced Optical Disk or AOD), which is a 15 GB storage medium. BD's recording capacity is larger than HD DVD by approximately 33%. However, the NA value of BD's object lens, which is as large as 0.85, poses a challenge concerning aberration due to the lens inclination caused during assembly or operation. To prevent such aberration, the thickness of the cover layer for dust protection has been reduced to 0.1 mm. A concern raised here is that since the 0.1-mm thick cover layer does not sufficiently serve its original purpose, extra protection against dust is required in the form of a cartridge, which could render BD more expensive or less easy to use compared with HD DVD. While it is still too early to predict which format specification will become prevalent, this is a matter that should be discussed from the perspective of cost and ease of use for consumers. Both groups should be careful to pay due attention to consumers in the standardization process and to prevent domestic disputes from growing so overheated as to allow other overseas standardization organizations to forestall them.

4 The initiative in standardization and the patent status

4-1 The initiative in standardization

The previous section mentioned how Sony and Philips led the standardization activities in the CD sector. In the area of recordable optical disks, however, there was a time when a different standardization process was adopted because the market was still immature, that is, several companies came together to agree on a single direction of standardization, thereby reducing the cost to develop large-scale integrated (LSI) chips. For error correction, Japan made a proposal against long distance code developed in the U.S., only to lose when Europe supported the strong will of the U.S. Japan, however, did not easily withdraw and continued a persistent and tough battle for a long time. Today, the reality is that there are a number of different format specifications for recordable media, whether it is for CD or DVD including -RAM, -R, -RW and +R, and manufacturers would rather let the market choose the optimum specification than standardizing the format. Although it would be desirable to advance technology through technological competition, this process could cause inconveniences to consumers and waste resources. A solution reasonable to both consumers and businesses is hoped to be found.

Thus, there have been desperate battles for survival among companies to acquire the initiative in international standardization. There are two organizations that played a critical role in uniting standardization activities by Japanese firms throughout this period: the Electrical Laboratory (now National Institute of Advanced Industrial Science and Technology) and the Optoelectronic Industry and Technology Development Association (OITDA)[4]. Their contribution is evident considering the fact that the first meeting of the SC23 (Special Committee 23), a sub-organization of the International Organization for Standardization (ISO), was held in Tokyo as shown in Table 2. Opinions of Japanese manufacturers were always perceived seriously at any of the total 17 international conferences held up until this year. Such a strong position of Japan can also be attributed to Japanese companies' outstanding capacity for technological development, which was demonstrated in the specifications for DVD, and patent strategy, mentioned later. Today, the standardization war is ongoing for the third-generation optical disk, which uses the blue-violet laser diode as the light source, and the two camps, each supporting BD and HD DVD (formerly AOD) respectively, are vying for leadership.

The digital video bandwidth compression technology that DVD adopts is a technology being employed in a variety of fields from optical disks to broadcasts, to communications. The Moving Picture Experts Group (MPEG), a standardization organization, advocates this technology and is actively promoting the standardization of bandwidth compression technology for video signals. The MPEG is a lower branch of ISO/IEC JTC1/SC29, of which SC29 is chaired by Professor Hiroshi Yasuda of the University of Tokyo. Table 3 shows the data transfer rate, major applications, and the effective date for individual MPEG phases.

Recently, three Japanese men became the heads of international organizations that set the global standards for electronic equipment and communications technology-Mr. Masami Tanaka for the International Organization for Standardization (ISO)[5], Mr. Yoshio Utsumi for the International Telecommunication Union (ITU), and Mr. Seiichi Takayagi for the International Electrotechnical Commission (IEC). Since standardization committees are international stages where experts discuss issues concerning industrial competitiveness, which are directly related to national interest, participating countries present opinions from diverse points of view with the intentions to acquire leadership. How the Japanese leaders of these organizations will manage the process of defining international standards in a fair manner is receiving considerable attention.

Table 2 : Past meetings of the optical disk standardization committee[3]

ISO/TC97/SC23			
1.	May 29-31, 1985	Tokyo	Japan
2.	September 22-24, 1986	Geneva	Switzerland
3.	October 13-16, 1987	Washington DC	USA
ISO/IEC JTC1/SC23			
4.	November 29-December 1, 1988	Maastricht	Netherlands
5.	October 25-27, 1989	Tokyo	Japan
6.	October 22-24, 1990	Washington DC	USA
7.	September 12-13, 1991	Sofia	Bulgaria
8.	April 22-23, 1993	Eindhoven	Netherlands
9.	November 3-4, 1994	Geneva	Switzerland
10.	October 26-27, 1995	Seoul	Korea
11.	October 24-25, 1996	Berlin	Germany
12.	October 16-17, 1997	Washington DC	USA
13.	October 29, 1999	Beijing	China

4-2 *Japan's patent status in the optical disk industry*

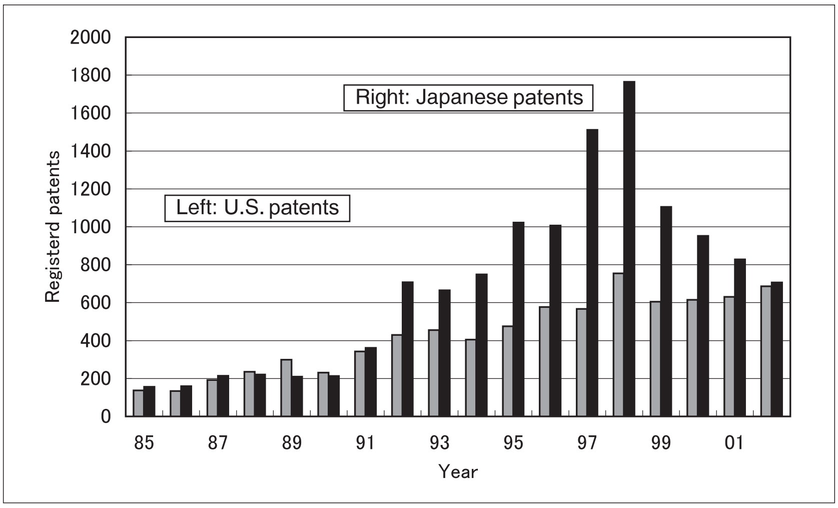
Figure 4 shows the change in the number of patents related to optical disk technologies registered with the Japan and U.S. patent offices over the years. While both countries' figures remained at almost the same level in 1991 and earlier, and in recent years, Japanese registered patents outnumbered those of the U.S. around 1998. Since the majority of the patent applications

Table3 : An overview of MPEG and the time of standardization

Phase	Data transfer rate	Major applications	Became effective in
MPEG-1	Approx. 1 Mbps	Video CD	March 1993
MPEG-2	Approx. 4-10 Mbps (SDTV) A few tens of Mbps (HDTV)	DVD Terrestrial/BS/CS/cable broadcast	March 1995
MPEG-4	Up to 384 Kbps (QCIF) 128 Kbps-2 Mbps (CIF) Approx. 15 Mbps (SDTV) 38.4 Mbps (HDTV)	Video phone, mobile communications, Internet, broadcast applications	May 1999
MPEG-7	–	Electronic program guide (EPG) Home server applications	September 2001

Source: Author's compilation based on the Web site of Pioneer Corporation.

Figure 4 : Change in the number of optical disk-related patents registered in Japan and the U.S.



Source: Author's compilation based on data published on the Web site of the Japan Patent Office.

to the Japan Patent Office are submitted by domestic organizations, most of the registered patents in Japan are assumed to belong to Japanese firms. The U.S. Patent Office, on the other hand, receives many applications from Japan and other countries. These facts indicate that, of the total patents granted in the optical disk field, at least 50% are owned by Japanese institutions. Therefore, it can be inferred that Japan's patent position is considerably strong at least in terms of number. In addition, from my own experience of patent application, I have discovered that over half of the citations presented by the U.S. Patent Office as public domain references to patent applications from Japan originate in Japan.

This strength in patents can be linked to specifications for standardization, as a means to reinforce the standardization efforts. In other words, it is necessary for Japanese organizations to pursue more fundamental research themes so as to obtain patents that can act as the basis for new products, seek stronger patent positions in both number and quality, and aim at adoption of their original specifications as the industrial standard. Another possible strategy is that individual patent holder companies, instead of separately utilizing their patents outside Japan, collaborate with one another to strengthen their positions.

5 EVD – A new China-U.S. joint effort for standardization

5-1 An overview of the EVD announcement

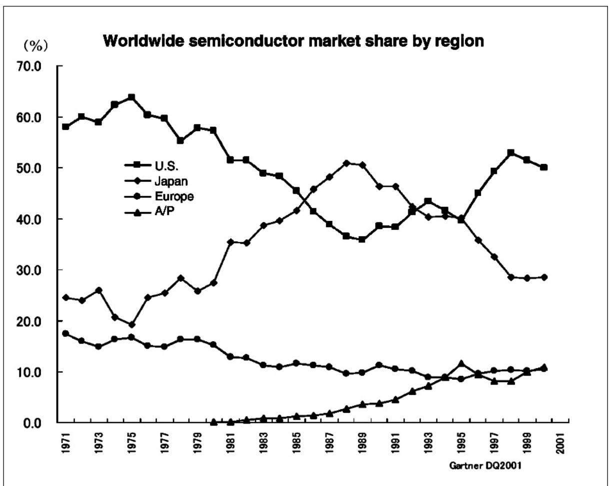
The previous chapter outlined the superiority of Japanese companies in the optical disk industry with an eye to technology, business, standardization, and the patent position. Despite their strength, Japanese corporations have been forced for the past few years to roll out their businesses through alliances with Korean and Taiwanese counterparts, which are rapidly growing. It was under such circumstances that a Chinese industry consortium announced EVD, China's original optical disk format. They claims that EVD uses VP5 and VP6, which are the high-definition video bandwidth compression technologies transferred from On2 Technologies of the U.S. to Chinese firms including Beijing E-World Technology, and that the EVD format can store a high-definition movie in a storage capacity equivalent to DVD (4.7 GB). With EVD, China probably intends to compete with the DVD camp, which has proposed a high-definition version based on the MPEG standard. So far, there is no telling which format can provide higher image quality, since there is no way to compare the two. It seems true, however, that EVD is an attempt to develop business in a new direction that is different from the path MPEG-based DVD has followed for standardization.

As explained in earlier chapters, DVD, in both image quality and ease of use, excels the videocassette tape, which is widely used throughout the world as a recording medium that can contain a two-hour or longer movie. For the past few years, DVDs have been quickly displacing videotapes in Japan as well as the U.S., and have been becoming an increasingly attractive product to Japanese electric appliance manufacturers. The retail market for DVD Video software is actually experiencing explosive growth and, according to an industry forecast, will reach ¥1.3 trillion in sales this year to outstrip the North American box-office revenue for the first time.

As a matter of fact, most DVD players are produced in China, which claims up to 70% of the global output of home DVD players. Last year, more than 30 million units of DVD players were manufactured in China, with most of them shipped to the U.S. for sale at low prices. The sale of these Chinese products is reportedly incurring considerable amounts of license fees payable to Japanese and Dutch manufacturers (USA Today, Nov. 18, 2003).

China's announcement of the EVD strategy is aimed at reducing royalty payments and to diminish domestic DVD producers' reliance on overseas technologies for optical disk equipment. EVD uses as the light source, the decisive factor of recording capacity, the red laser diode with a wavelength of 650 nm and provides a 4.7 GB recording capacity, which is equivalent to DVD. EVD is a standard that intends to seek technological strength in its high-definition video compression technology, as opposed to the existing standardization efforts toward next-generation high-resolution DVD based on MPEG. A noteworthy issue in this movement is that China plans to complete EVD by transferring U.S. venture firm On2's bandwidth compression technology to Chinese corporations, with reportedly lower license fees paid to On2 than what China now pays to Japanese and Dutch companies (USA Today, Nov. 18, 2003). The developers working at the core of China's EVD project are assumed to be a number of outstanding students sent to the U.S. by the Chinese government. Taking into consideration a characteristic of the Chinese market that consumers prefer inexpensive products, even if their image quality is somewhat inferior, there have been many attempts to standardize optical disks used for video. China, at one time, even presented proposals to IEC TC100 (home appliances) instead of IEC JTC1 as part of the move that has led to the unveiling of EVD. It is still uncertain whether the China-U.S. joint standardization strategy will prove effective as it is, because high-definition display equipment has yet to come into widespread use[4]. However, if the Japanese optical disk industry takes wrong measures, their scheme might pose a threat to Japan. In connection with this, China plans to introduce the "Chinese standard" onto the third-generation cellular phone industry, in an effort to secure patents related to their original standard so as to navigate the intellectual property negotiations with Japan, the U.S. and Europe in a manner favorable to them.

Figure 5 : A dramatic change in worldwide semiconductor market share



5-2 Comparison with the decline of the Japanese semiconductor industry

The semiconductor industry experienced a sea change in the global market share structure in the 1990s. It should be interesting to compare this with the case of the optical disk industry. As shown in Figure 5, the market share of the Japanese semiconductor manufacturers has significantly declined since the mid 1990s[7, 8]. One of the reasons is said to be the trade friction between Japan and the U.S. in the 1980s[9]. The U.S.-Japan semiconductor agreement

Table 4 : Industrial system structure for the optical disk/personal computer sector with Hollywood/Microsoft at the top and commodities at the bottom

	Optical disk		PC
Content	Movie companies (Hollywood)		Microsoft
Key devices	DVD disk Decoder (LSI) (MPEG as standard)	EVD disk Decoder (LSI) (VP6 as standard)	Windows CPU (LSI) (Intel as standard)
Hardware	DVD player	EVD player	PC
	No compatibility		
Commodities	Optical pickup, semiconductor memory, control circuit, mechanics		Memory (HDD, DRAM)

Knowledge intensity increases toward the upper part of the table.

required that Japan allow U.S. products to hold a 20% share of the Japanese market, while the U.S. Anti-Dumping Act regulated Japanese semiconductors' export prices to the U.S. This event marked the start of the fall in Japan's market share. Meanwhile, competitors elsewhere concentrated investments in their business strengths. Intel Corporation of the U.S. made the critical decision of abandoning the DRAM sector to focus on central processing units (CPUs), which resulted in success. Another U.S. firm Micron Technology, based on the analysis results that the cost of the mask layer used for DRAM production had a large impact on overall product cost, reduced mask count and significantly improved its cost competitiveness. Samsung and other Korean manufacturers took an approach of concentrating investments in DRAM itself, while Taiwanese counterparts became specialized in production technology; as a result, both groups successfully overtook Japan. A well-known fact is that in each country, excellent students who had studied in the U.S. and returned home played key roles. Some point out another reason behind the fall of the Japanese semiconductor industry. Since the specification of the CPU is reliant on Microsoft's design specifications for personal computers, Intel naturally formed a vertical alliance with the software giant that acted as a market access barrier to Japan before the two firms were even aware. This caused Japanese semiconductor manufacturers to be unable to have clear future visions, thereby contributing to a further reduction in market share.

Here is a comparison of the change in the worldwide market share structure in the semiconductor sector and the current situation in the optical disk industry. As Table 4 indicates, Microsoft corresponds to content producers, that is to say, the highly knowledge-intensive Hollywood movie companies. Recently, some of them are moving the production process to China in order to reduce the cost of filmmaking. In this context, the worst possible scenario might there emerge from a factor that can justify Hollywood adopting EVD rather than DVD to effectively promote its movie content in the enormous Chinese market, leaving all Japanese optical disk makers only to serve as commodity suppliers[10].

6 Conclusion

As described earlier, the principles of read-only optical disks such as CDs and DVDs, which are now widely available across the world, were invented and developed at the Dutch company Philips. Nevertheless, Japanese corporations, by taking advantage of their outstanding mass-production technology, have been the world leader in the optical disk sector in all aspects of technology, business, and standardization for over two decades since the 1980s. They have maintained the position as the overwhelming winner in this market. Now, Japan also takes the initiative in setting next-generation standard recording formats such as BD, which provides a storage capacity as large as over 20 GB, and HD DVD, which can contain 15 GB of data, with both formats using the 405-nm blue-violet laser diode developed in Japan. This makes Japan's dominance in the optical disk industry look promising into the next generation.

Japan should, however, carefully watch subsequent developments because, for the purpose of maintaining the lion's share, Japanese manufacturers have been forced to collaborate with Korean and Taiwanese rivals through the establishment of joint ventures. Now, at a time when high-definition displays are not yet in widespread use, it is unlikely that the present China-U.S. joint strategy for standardization will work effectively as it is[5]. If Japan takes a wrong measure, the optical disk sector might have to go through a sea change in the worldwide market share structure, as what occurred in the semiconductor and LCD markets. In connection with this, China plans to introduce the "Chinese standard" onto the third-generation cellular phone industry, in an attempt to secure patents related to their original standard so as to navigate the intellectual property negotiations with Japan, the U.S. and Europe in a manner favorable to them.

Yet another concern is the current domestic situation in which the BD group and the HD DVD group are in conflict. In addition, attention should also be paid to how Hollywood, which rules current-generation DVD content, moves in the process of standardization for next-generation optical disks intended for high-definition video recording.

To address these problems, Japan can use its dominance in all directions of technology, business, and standardization, and can also reflect its patent advantage into standard specifications for strengthening the standardization framework. In other words, it is necessary for Japanese corporations to pursue more fundamental research themes so as to obtain patents that can act as the basis for new products, seek a stronger patent position in terms of both number and quality, and raise the position to a level that is high enough for adoption as standards. Another possible strategy is that individual patent holder companies, instead of separately utilizing their patents outside Japan, collaborate with one another to improve their positions.

From a medium- to long-term standpoint, additional measures are needed to further promote open and active environments for researchers and facilitate scientific breakthroughs like the invention of the optical disk in the Netherlands. The Institute of Physical and Chemical Research in the prewar era was said to be ideal for such research activities, although it was a private-sector organization. Under current recession, it is not realistic to expect such sponsorship only from the private sector. This is where the government could play a supporting role.

To conclude this article, the author would like to express his personal opinions formed while writing this material. It is my fear that U.S. companies aim to confine their Asian counterparts to commodities production, in the manner where they caused a worldwide shakeup in the semiconductor and LCD market structures as discussed in section 5-2. More specifically, this is a strategy that intends to keep the brain and core components of systems under the control of U.S. firms and to let Asia produce unimportant parts. If this scenario becomes a reality, Japanese companies might be driven into a situation in which Japan is positioned at the same level with rising Asian countries such as South Korea, Taiwan, and China, and therefore is involved in cost competition with these Asian nations that, along with Japan, serve as parts production centers for the U.S. Japan must avoid such a situation. Japan should, rather than resigning itself to be a mere commodity producer, retain its strength in manufacturing, look to products that have higher added value and are more knowledge-intensive, and pursue transition to a post-industrial society with a diverse structure. The author believes Japan needs to search for ways to leverage the massive untapped market in Asia, including China with the world's largest population, to ensure the sustainable development of the Japanese economy and mutual coexistence with other countries in the world.

Acknowledgements

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References

[1] Edited by K. Bowhuis, "Principles of Optical Disk Systems" (Adam Hilger).

[2] Shinichiro Tomonaga, edited by Hiroshi Ezawa, “A Free Paradise for Scientists” (Iwanami Bunko)(in Japanese).

[3] Hisashi Yamada, “DVD: Big Success Created by Synergy of Technology and User Needs,” Journal of IEICE Vol. 87, No. 1, pp. 10-15, January 2004.

[4] Yoshinobu Mitsuhashi, International Symposium on Optical Memory 2000 (ISOM 2000), Commemorative DVD-ROM, “Chronicle of ISOM.”

[5] http://www.meti.go.jp/kohosys/press/0004519/, “Election of the next president of the ISO.”

[6] http://j.peopledaily.com.cn/2004/01/09/jp20040109_35725.html, “Players to be released by two firms in the ‘EVD federation’ ” (in Japanese).

[7] Toshiaki Ikoma, Proceedings, “The Second International Conference on Technology Foresight,” 2-2 (Feb. 27-28, 2003, United Nations University Headquarters).

[8] Kumi Okuwada, “Role of Universities in the Research on Silicon Semiconductor Devices,” Science & Technology Trends-Quarterly Review, No.9, October 2003.

[9] Yukio Sakamoto, “Why Japanese DRAM declined ?”, Nikkei 4946 File, December 2003 issue (in Japanese).

[10] Takahiko Soejima, “Deposit moratorium”, Shodensha (in Japanese).

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3

Trends of Research and Development in Semiconductor Manufacturing Technologies – From Presentations at Recent International Conferences*1 and Other Sources –

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1 Introduction

Despite technical and economic limitations, the pace of development of silicon MOS semiconductor technology is accelerating. LSI chips are acquiring more complex and versatile functions by incorporating even radio-frequency and analog technologies inside that were thought too difficult for silicon MOS devices in the past. Increasingly, semiconductor devices will be used in a variety of products, including commonplace commodities. Semiconductor technology will continue to be the fundamental technology supporting the development of not only electronics but also basic science and technology. Economically speaking, it should play a major role in key industries.

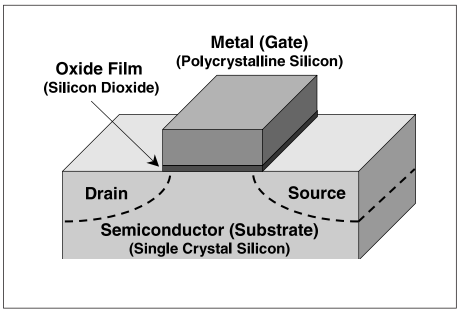
This report will survey recent trends in research and development of semiconductor technology, focusing on the underlying manufacturing technologies, and will also touch briefly on the challenges faced by semiconductor-related projects in Japan.

2 Development of next generation MOS transistors

2-1 Development of MOS transistors is in transition

A transistor usually works as a switch in digital circuits by changing its status between "on" and "off". A key type of transistor that has supported the technical revolution of semiconductor integrated circuitry is a unipolar transistor*2 with a structure called MOS (Metal-Oxide-Semiconductor, see Figure 1).

Figure 1: Basic materials and structure of silicon MOS transistor



The basic materials and structure of MOS transistors*3 have not changed much since their beginnings, as far back as 1970. The MOS transistor uses a conductor made of polycrystalline silicon*4 doped with a high concentration of impurities, a silicon dioxide film (SiO_2) made by thermal oxidation of single-crystal silicon, and single crystal silicon, for metal, oxide and semiconductor, respectively. In spite of the MOS name, the major elements in an MOS transistor are just silicon and oxygen, the two most abundant elements on Earth.

After the basic materials and structure of MOS transistors were determined, semiconductor manufacturing technology saw a new generation emerging every three years, thanks to lower defect densities in silicon crystals, higher purification of other materials and miniaturization technologies. Advances in fine patterning and accurate processing by lithography have enabled the continuous improvement of LSI integration, as can be seen in

Table 1:Evolution of MOS transistor materials

	Past		Under development or in future	
	After ca. 1970	After ca.1990	Present needs	Candidates
Gate Electrode (M)	Polycrystalline Silicon	Double layer with metal silicide	Low resistivity	Metal as W or Mo
Gate Oxide (O)	Silicon dioxide	Small amount of nitride and others added to silicon dioxide	High dielectric constant	Oxide of Al or Hf family
Semiconductor (S)	Silicon	Silicon	High mobility	Strained silicon SiGe

DRAMs.

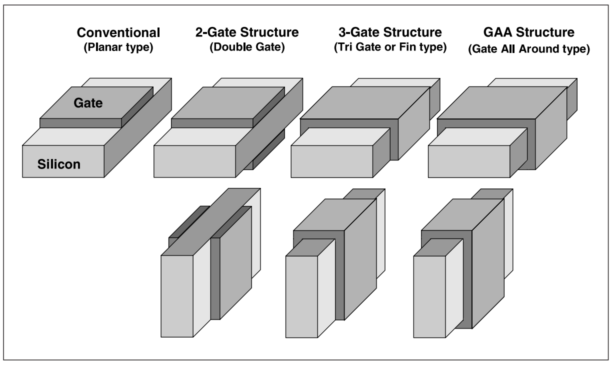
In the 1990s, the issues were how to cope with parasitic effects such as increased resistance and capacitance caused by the miniaturization of transistors and connections within LSIs. The following materials or structures were introduced separately to reduce these effects. (1) A compound of silicon and a metal (silicide or metal-silicide), (2) New materials such as copper (Cu)[*5], and (3) a partially new structure like SOI[*6].

But recently we have arrived at a stage where further miniaturization of transistors by conventional methods does not necessarily promise additional performance enhancement. For example, when the gate oxide becomes too thin, it does not work as an insulator any more and gate leakage current increases.

The issues and problems above are forcing the reexamination of the conventional materials and structures of transistors that have brought us to this point.

The response is the recent aggressive research and evaluation of new materials, as shown in Table 1. The central focus for the gate electrode is the use of metallic materials with lower resistivity. Examples include tungsten (W) and molybdenum (Mo), which have lower resistivity than polycrystalline silicon and can endure the high temperatures encountered during the manufacture of semiconductors. For the gate oxide, high dielectric constant films are evaluated, as high electric field can be applied at lower voltages, resulting in lower leakage current from the gate electrode. Examples are oxides of aluminum (Al), hafnium (Hf) and others. For the semiconductor, re-investigation is focused on high-mobility materials that have faster charge carriers than those in conventional silicon. Some examples are strained silicon and a compound of silicon and germanium (SiGe).

Figure 2:Structure of multigate transistors



As for transistor structure, a new transistor with multiple-gate electrode is being investigated, in contrast to a conventional transistor, which is planar and has a single-gate electrode. The goal of the investigation is to improve controllability of the electric field[*7] through the gate electrode and create a transistor with excellent on/off switching characteristics. Examples of this are the double-gate transistor, and the tri-gate or fin-type transistor, as shown in Figure 2. The electric field in the channel region will be better controlled if the gate electrode is attached to the region from not just a single side, but from two or three, or even if the electrode surrounds all sides of the region. New MOS transistor structures aim at this effect.

2-2 Evaluation status of new materials and structures

(1) High-k (high dielectric constant) insulating film

Until around the year 2000, various compounds[*8] were candidates for high-k (high dielectric constant) film materials, and various formation methods were discussed. The hafnium oxide group looks most promising, due to its dielectric constant and thermal stability. At IEDM2003[*9], "Hf-based Gate Dielectrics" was the only session on high-k insulating films, which is good evidence that the material selection is being narrowed down. The thin film formation method called ALD (Atomic Layer Deposition), that deposits films layer by layer in atomic or molecular status, is moving into the mainstream.

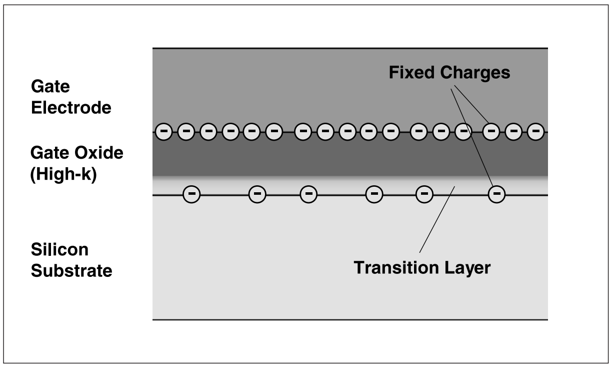
At first it was thought that optimization of high-k film properties should lead to better transistor characteristics. However, as is described in next paragraph, during the investigation of the application of this technology to real devices, it became clear that simple replacement of the dielectric with the high-k film, while it improves the dielectric constant, also leads to overall degradation of device performance.

The problem initially encountered was a reduction of carrier mobility by around 50%[1] due to transition layers and fixed charges located at the interface with the silicon substrate, or by lattice scattering caused by polarized bonds called soft phonons that are peculiar to high-k films. This leads directly to the degradation of device performance and has to be fixed before the adoption of high-k films. At a VLSI symposium held in 2003, it was reported that mobility of up to 80 - 90% of the level of conventional film can be recovered[2] if nitrided hafnium silicate (HfSiON) film is plasma oxidized or plasma nitrided after the film deposition. However, at the same VLSI symposium, another report said that fixed charges generated at the interface between polycrystalline silicon and high-k film prevent the control of the transistor threshold voltage by the channel impurity concentration and the capacitance of the gate insulator. This reconfirms the difficulty of bringing high-k film into mass production[3]. In other words, conventional silicon dioxide has ideal interface properties.

High-k films also present reliability issues, as was recently pointed out[4]. Some examples are the change of film properties when an electrical field is continuously applied, and degradation of the film properties by injection of some portion of high energy electrons or holes into the high-k film from the channel under prolonged use.

Silicon dioxide films have been used extensively, and there is abundant and cumulative information concerning the changes undergone

Figure 3 : Issues with High-k films



by gate dioxides after long hours of use. For high-k films, on the other hand, discussion of reliability data has just begun. Whenever new issues concerning high-k films are raised, the view gains more ground that replacing silicon dioxide with other materials is not so easy. Silicon dioxide has gone through many improvements in film formation technologies in the past and has reached its ultimate thickness - or thinness - at about 1 nm. Still, Intel and AMD have announced[5,6] that high-k film along with a new gate metal will be adopted for the 45 nm generation to be shipped in 2007.

(2) Strained silicon

The strained-silicon MOS transistor has entered the limelight since two papers[7,8] on it were submitted by IBM at the VLSI Symposium in 2001. Strained-silicon technology adds tensile or compressive strain to the channel region in order to increase carrier mobility, which is one of the characteristic of a substrate material. It was generally expected that its mass production would begin after 2005 at the earliest, which was IBM's own view.

However, in 2002 Intel announced the application of strained-silicon technology to the Pentium 4 beginning in 2003. Also in 2002, AmberWave Systems*10 in the U.S. was reported to be preparing for licensed sales of strained-silicon substrate technology[9]. These developments quickly intensified the limelight on the technology.

In the CMOS device session of IEDM2003, there were many presentations on strained silicon that drew much attention, including a posting to the Late News*11 from Intel. A dozen papers were presented at IEDM2003 on strained silicon, including those in the late news. The subject was addressed in about 40% of the entire 30 papers presented in the CMOS session. It seems that interest in the development of next-generation transistors has recently focused on strained silicon and on the multigate transistor that will be discussed in the next section.

What Intel announced[10] is independent optimization of silicon strains in NMOS and PMOS channel regions by applying mechanical stress separately to each area, with adequate control. As this applies strain only locally to channel regions, it may not really constitute a change of the basic materials of the MOS transistor underneath the gate electrode. But this technology is noteworthy as it is being applied to the first product of the 90 nm generation, the Pentium 4, with only a 1 - 2 % increase in its manufacturing cost.

(3) Multigate structure

For some time, a double-gate structure has been investigated in combination with an SOI structure. In the past few years there has been much more active interest in a tri-gate structure whose channel region is covered by the gate electrode from three sides and that can only be fabricated by vertical processing onto the substrate. The tri-gate transistor is often called a “FinFET” especially when the gate electrode is formed well underneath the semiconductor substrate as shown in the bottom drawing of tri-gate structure in Figure 2 below.

FinFETs can be fabricated fairly easily only by processing from the direction vertical to the substrate, and six papers on the concept were presented at IEDM2002 by IBM and others. Fin-FETs give an easy performance improvement while suppressing the side effects that accompany miniaturization. But at IEDM2003, the number of papers on the technology went down to 2, because FinFET requires the formation of near 3-dimensional deep patterns on the substrate, though processing itself can be performed only from the direction vertical to the substrate, and because wiring connection to the FinFET was difficult. This indicates that the hot interest in this transistor structure quickly cooled and the focus shifted to strained-silicon technology.

AMD announced a tri-gate transistor at SSDM2003 (2003 International Conference on Solid State Devices and Materials) held in September 2003. In this transistor, with its channel region surrounded by metal gate on three sides (as shown in the top of tri-gate structure drawings in Figure 2), they deformed the silicon lattice locally and enhanced carrier mobility. By covering three sides with the gate electrode, the effective channel width is increased and better controllability of on/off switching is obtained, leading to improved transistor performance. The structure is closer in shape to a planar transistor as its metal electrode is formed only shallowly into the substrate, and it is more compatible with conventional processes.

The GAA (Gate All Around) type transistor that has its channel region surrounded by gate electrode on all sides is called an ultimate MOS structure. But the structure presents difficulties for higher integration with MOS processing, and its performance is under evaluation mainly with vertical MOS structures[11] where current flows perpendicular to the semiconductor surface. Recently, investigation of GAA structure has begun on transistors whose channel is formed over carbon nano-tubes.

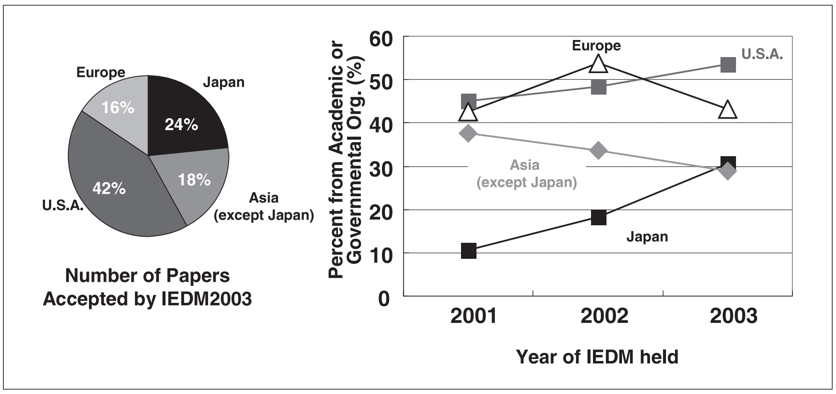
3 Number of papers accepted by IEDM

The pie chart to the left in Figure 4 shows the number of papers accepted by IEDM2003 by country or region of the author’s organization, and the right-hand side shows changes in the percent of papers coming from academic and governmental organizations for IEDM2001 - IEDM2003. Here, papers originating in multiple organizations are proportionally allocated according to the organizations involved.

The distribution of the number of papers accepted by IEDM2003 by country and region is not significantly different over these few years[12]. Slightly less than half of the total were submitted from the U.S., about a quarter from Japan, and the rest from Asia (excluding Japan) and Europe.

In the past, papers from Japan were credited mainly to industry, but with the changes in progress since 2001 the non-industrial

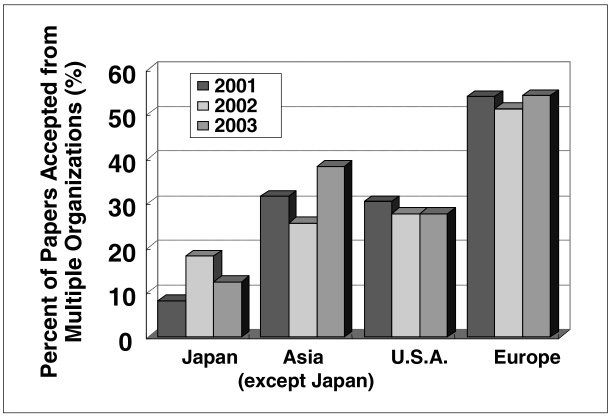
Figure 4 : Number of papers accepted by IEDM2003 by author's country or region (left), and percent of papers from academic or governmental organizations (right)



contribution is increasing. They came mainly from research organizations involved in national projects, and the contribution from universities was 10 - 15 %, with no significant change from 2001 or earlier.

Figure 5 shows the percent of papers accepted by IEDM from multiple authors of multiple organizations by country and by region in 3 recent years. It has already been pointed out that in Japan, not only cooperation between industry and universities, but also cooperation within industry itself or between universities is rather small compared with other countries or regions[13]. Actually, joint research in industry is increasing in Japan, reflecting the trend towards market reorganization and/or business alliances. But the result of joint research projects with universities or governmental organizations is not yet visible, or at least not reflected in the number of accepted papers above. For example, the ratio of accepted papers from collaborations of universities and those with multiple research organizations involved is about 30% for Japan, 40% for the U.S. and 90% for Asia (excluding Japan) and Europe.

Figure 5 : Ratio of accepted papers by IEDM from multiple organizations for 3 years



4 Semiconductor technology roadmap and technology development speed

The ITRS (International Technology Roadmap for Semiconductors)[14] identifies the technological needs facing the semiconductor industry over the next 15 years. The needs for lithography for example, include resolution and accuracy, overlay accuracy, and exposure area. In addition to lithography needs, the technological needs for various areas like silicon wafers and each process step of semiconductor fabrication and assembly processes are listed there. The ITRS was targeted for U.S. domestic use when it originated in 1992, as the NTRS (N stood for National). Now, it has become international. The contents of the ITRS are based on the consensus of participating specialists. In reality, as technology development is achieved ahead of ITRS requirements, its roadmap is moved up every time the ITRS is updated.

As the pace of generational change has apparently gone up recently, what was initially the "move-up" of the ITRS is now perceived as a normal development schedule, at least by leading companies. In other words, since long before the first ITRS was compiled, generational change of semiconductor manufacturing technologies took place in a 3-year cycle (from 1977 to 1995), but after 1995 it was reduced to 2-year cycle. This was initially thought to be an exceptional phenomenon in a specific generation, but leading companies now often describe their technology roadmaps and new product availabilities based

Figure 6 :ITRS forecast on generation change of semiconductor manufacturing technologies and its results

Forecast Timing	Year of Roadmap Update					
	1994	1997	1999	2001	2003	Reference**
1994						
1995	_350_*					
1996						
1997		_250_				
1998	250					
1999		180	_180_			
2000						
2001	180			_130_		
2002			130			
2003		130				_90_
2004	130			90	90	
2005			100			65
2006		100				
2007	100			65	65	45
2008			70			
2009		70				32
2010	70			45	45	
2011			50			22

* Actual implementation of process generation is shown in italics
** Roadmap of leading companies as of 2003
Note : Generation of semiconductor manufacturing technology is described by a representative number called Technology Node. Units are nm.

Source: Author's compilation based on ITRS official site[14] and Intel's web site[10].

on a 2-year cycle of generational change over the long term.

The ITRS is only a guideline, and compliance with it will not always guarantee safe and easy positions for corporations in the fiercely competitive business world. This amply explains the fact that technology development is achieved ahead of the needs of the ITRS. As mentioned in chapter 2, we are coming to a turning point where basic materials and structures will be renewed, but leading companies are still announcing new product schedules assuming a 2-year cycle for generational change of manufacturing technologies.

For example, AMD says that they plan to go into mass production of the tri-gate transistors in 2007 that they demonstrated at SSDM2003. This means acceleration of ITRS2003 by two years[6].

Also, Intel announced[10] in their processor roadmap that they would enter into mass production of the 65 nm generation in 2005 and the 45 nm generation in 2007, along with the employment of new materials and new transistor structures. Though somewhat delayed from their initial announcement, they started shipment of the 90 nm generation of Pentium4 (codenamed Prescott) recently (in Feb. 2004). It is two years since the rollout of the previous generation.

In spite of these circumstances, the future portion of the roadmap, even in the newest 2003 version of the ITRS*12, is described in terms of a 3-year cycle as is shown in Figure 6. Any development schedule based on the ITRS may be continuously obsolete and require updating.

5 Technology driver

DRAM, which drove semiconductor manufacturing technologies for nearly 30 years since its debut in the market in the early 1970s, is already lagging behind the ITRS generation change schedule of manufacturing technologies. Development of 4 Gbit DRAM was announced in 1997 at a society meeting[15] according to the anticipated development schedule from the past trend. But at the end of 2003, six years after the announcement, even 1 Gbit DRAM is still at the sampling stage. If the past trend had continued, 1 Gbit DRAM should have been in mass production around the year 2000. Today, as large capacity DRAMs, we have the 256 Mbit DRAM in the mainstream and the 512 Mbit in the production ramp-up stage[*13]. The gap was caused by a change in market requirements. In the past, users thought that data capacity was primary. But a need for speed became much more urgent over those years.

By its basic principle, miniaturization increases DRAM's memory capacity but will not significantly affect the read and write speeds[*14] of basic memory units. In contrast, by miniaturization, processors gain significant speed improvements in addition to more transistor integration. This tightens the bottleneck for data transfer between processor and DRAM, and actually limits processor performance.

As a result, the recent target for DRAM development has been the improvement of the data transfer rate by some tweaks in architecture like peripheral circuits or bank[*15] organization rather than the miniaturization of memory cells. New high speed DRAM technologies like synchronous DRAM and the Rambus DRAM[*16] are the result of these efforts. Today's typical DRAM chip does not require state-of-the-art fabrication lines or equipment as it did in the past. Manufacturing processes from some generations behind the most advanced products can be converted and used for DRAM.

Replacing DRAM, state-of-the-art processors are now the drivers for semiconductor manufacturing technologies. The processors are not necessarily high-end chips for servers and the like. The real drivers of the technology are the processors for desktop PCs that promise a reliable market size as a basis to justify large capital investment. There are plenty of PC users who are willing to pay more for a processor with a slightly higher clock rate once it is on the market. Competition among manufacturers has become fierce to bring higher performance products to the market as soon as possible, especially when there is compatibility among processors from multiple vendors. IBM, AMD and others have formed alliances to compete against Intel. As a result, leading-edge semiconductor manufacturing technologies are driven by those companies.

The requirements for higher integration, from DRAM to semiconductor manufacturing technologies, are basically fine patterning and accurate processing. For processors, speeding up the operation of transistors, including wiring, is most important. For better performance, elaborate efforts are often required in conjunction with circuit design technologies such as prioritized miniaturization of gate electrodes and local use of new wiring structures.

Aside from processors, in some cases cutting edge production lines are required for video game semiconductors, which require system LSIs, and have a fairly large market on the horizon[16]. This can be another technology driver in addition to processors. However, due to its longer life cycle, a generation of manufacturing technologies for video game semiconductors corresponds to two generations of processors. Their manufacturing technology will be prepared for specific market events.

In summary, what drives semiconductor manufacturing technologies is LSI, high speed, and in some cases, low power dissipation that involve new technologies, and that many users are willing to pay more for.

6 Challenges of semiconductor related projects in Japan

The semiconductor manufacturing industry in Japan quickly lost its competitiveness in the late 1990s and was thrown into restructuring and integration. To recover the lost competitiveness, consortiums and national projects were rapidly organized after the year 2000 under the leadership of industry organizations and the government. But those consortiums and national projects are not responsive enough to the recent changes in overseas technology development discussed above.

The ultimate goal of projects initiated to catch up with the trend should be to develop world-class state-of-the-art manufacturing technologies and to improve development efficiency with technology standardization.

But today, as was stated in Chapter 5, with conditions in the industry and semiconductor technology development that are different from the early 1990s, the goals of these projects are not directly linked to improving Japan's competitiveness. When DRAM drove the semiconductor manufacturing technologies and the main product of Japanese companies was DRAM, acquisition of leading-edge manufacturing technology should have enhanced the competitiveness of the Japanese semiconductor industry. But today, when processors drive the technologies not only in architecture or circuit design but also in manufacturing, mere acquisition of leading-edge semiconductor manufacturing technology will not necessarily strengthen the competitiveness of Japanese products. This is because Japanese companies do not have processor products and because they cannot enter the market with only the new manufacturing technologies since there are other big technological barriers. In the changed environment, it is imperative to acquire the newest technologies and to determine which products they should optimally be applied to. Recently, SoC (System-on-a-Chip), system LSI and LSI for digital consumers have attracted attention as the segments where Japan can maintain its competitive edge. But these (except LSIs for video games) are all high-mix low-volume products with little commonality of technology development from a manufacturing technology viewpoint, and therefore cannot be the technology drivers.

Another challenge for semiconductor-related projects in Japan, is how to cooperate with universities and to benefit from their strengths as shown in Chapter 3. Universities in western countries, for example, often support corporate research with detailed evaluation of device characteristics and new transistor modeling based on that. This is very effective in extracting the issues during the investigation of new materials or new device structures, and analyzing failure mechanisms. Such cooperation can work well to accelerate development.

One peculiarity of semiconductor technology development is that the investment required of the front-runner is extremely large[*17] compared with other industries. In addition to increasing technological barriers, the increase of required investment makes it almost prohibitive for one company to pursue semiconductor technology development alone. At the same time, major companies and Asian countries position semiconductor technology as their strategic segment in view of its strong impact on entire electronic equipment industries. Partnership or alliance between corporations can establish a mutual complementary relationship that fosters survival under these conditions. For example, in Taiwan, a company that started as a foundry manufacturer in the U.S. now has a major role in an alliance to develop manufacturing technology. Europe is advancing specific investigations like "Mixed Signal" that put analog and digital circuits on a single chip.

If we follow these overseas moves towards horizontal specialization in technology development, we have options to exert our strength even in national projects. We still have many areas in Japan where we have the highest technologies, such as materials, manufacturing equipment and the key technologies of semiconductors. For national projects, we might better think of nurturing our strength by focusing on these areas. If we demonstrate our strengths in some of the specific areas above, we can expect to use them as starting points, draw in related areas, and strengthen our industry-wide competitiveness.

7 Conclusion

From recent international conferences and other sources, we have surveyed the trends in the research and development that support semiconductor technology. Up to now, silicon MOS transistors could be improved by miniaturization. But as we recently reached the stage where further performance improvement cannot be expected from further miniaturization of transistors by conventional methods, the focus of investigation is moving toward the use of new materials or new structures for transistors. This indicates that we are just arriving at a turning point that requires us to completely review the basic materials and the structure of silicon MOS transistors that have dominated for as long as 30 years.

Furthermore, technology development is driven by leading-edge processor manufacturers, mainly in the U.S., and the rate of succession of generations has shrunk to 2 years from the 3 years that prevailed during the past decade. Also, some ultimate limitations on technology development have been discussed, but no insurmountable barrier has yet been identified.

Semiconductor-related projects in Japan must also take into account these trends of technology development in the rest of the world. In the recent past, state-of-the-art manufacturing technologies have been driven by processors, and we need to review the type of semiconductor products to which Japanese companies should apply the outputs from these projects. Also, projects in Japan should involve universities as collaborators. To accelerate the pace of development, universities should be made better use of in characterization, modeling, mechanism analysis and other areas of concern.

In addition to growing technological barriers, the increase in the required up-front investment will make it almost impossible for one company to pursue semiconductor technology development alone. As a result, especially overseas, even technology development relies on horizontal specialization. If we follow these moves, then focusing on development in the areas where Japan is already strong should be one of the good options for us. These areas include, for example, materials, manufacturing equipment, and key technologies. If we can demonstrate our strength in some of the specific areas above, we can expect to use them as starting points that will then involve related areas and strengthen our industry-wide competitiveness.

Glossary

*1 International Conferences

Three of the best known international conferences are, IEDM (International Electron Devices Meeting, focusing on electron devices), ISSCC (International Solid-State Circuits Conference, focusing on semiconductor circuits) and VLSI Symposium (covering LSI manufacturing technology and circuits). They are all famous for their high editorial standards, with about a 30 percent rate of paper acceptance, and for papers representing the technical levels of attending companies and research organizations. Leading technology companies often adjust their official announcement schedule of new technology development in sync with their presentations at these conferences. These conferences have extended their role beyond just being international society meetings to being key public relations tools for corporations.

*2 Unipolar Transistor

In semiconductors, there are two types of carriers, electrons and holes. A unipolar transistor uses either one of them for its operation. A bipolar transistor uses both carriers.

*3 Basic Structure of a Transistor

A bipolar transistor was first used to replace a vacuum tube. Being a current-driven device, its power consumption is relatively high. As the current flows vertically to the semiconductor surface in bipolar transistor, its manufacturing process tends to be complex and higher integration is difficult compared with MOS transistor. On the other hand, a MOS transistor is a voltage-driven device and the power consumption is basically low. If two different types of MOS transistors are combined to make CMOS (Complementary MOS), it produces a basic circuit unit always kept “Off” and there is no static current in an entire circuit. This means further reduction in power consumption is possible. The CMOS transistor has been sustaining semiconductor integrated circuit technology due to its suitability for low power and high integration.

*4 Polycrystalline Silicon

If impurities are diffused after a gate electrode is defined, then diffusion layers such as source and drain can be formed as self-aligned to the gate electrode. In the past, about 1000 °C was required for the formation of the diffusion layers, and aluminum, used as a gate electrode up to then, was replaced with polycrystalline silicon mainly for thermal stability.

*5 Cu

As the aluminum (Al) that was used then has high wiring resistance, it was replaced with lower-resistance copper (Cu) in some LSIs.

*6 SOI

Abbreviation of "Silicon on Insulator", which means single crystalline silicon (substrate) on insulating film. The SOI structure improves the operating speed of a device by reducing the junction capacitance of the diffusion layers.

*7 Controllability of the Electric Field

An MOS transistor works as a switch by changing the electrical conductivity of the semiconductor surface with the gate electrode controlling electric field of the surface. A transistor is said to have a better characteristic if a lower voltage applied to the gate electrode can switch it.

*8 Various Compounds

In addition to hafnium, which is the mainstream material under investigation today, oxides of other metals such as titanium (Ti), tantalum (Ta), yttrium (Y), lanthanum (La), aluminum (Al), zirconium (Zr) and others had been evaluated.

*9 IEDM2003

In this report, we will abbreviate "IEDM held in year 2003" thus. Similar rules will be applied to other years or other society meetings.

*10 AmberWave Systems

A spin-off venture company of MIT. The basic technology of strained silicon has been under development by Prof. E.A. Fitzgerald of MIT since the beginning of 1990. The company owns critical intellectual property relevant to the reduction of defect density in strained silicon and they say that they can well compete with IBM's technology.

*11 Late News

Papers accepted after the due date for regular papers. A very limited number of the latest important research reports are often published as late news.

*12 2003 version of ITRS

In the 2003 version of ITRS, no update to the 2001 version was made regarding the schedule of generation change of manufacturing technologies. Leading companies had announced that they started mass production of the 90 nm generation at the end of 2003, but those may not have met the ITRS specification.

*13 DRAM Capacity

DRAM capacity has quadrupled from generation to generation. But from 64 Mbit DRAM, it slowed down to just double between generations.

*14 Read and Write Speed of DRAM

DRAM needs to perform read and write operations at finite intervals called the cycle time. Improvement of DRAM cycle time has been limited to just one order level for nearly 30 years, from 500 ns in the 16 Kbit DRAM era to 50 ns with the newest 256 MBit DRAM. Clearly, memory capacity has increased by sixteen thousand times during that period while memory speed increased by just 10 times.

*15 Bank

Block of memories of certain size that a memory control circuit manages as a unit.

*16 Synchronous DRAM, Rambus DRAM

High speed DRAM. Both are designed to transfer data in synchronization with a clock signal of a certain frequency. Rambus DRAM transfers data through a high speed interface developed by Rambus Inc. in the U.S.

*17 Investment for Research and Development (R&D)

Percent of R&D investment to total revenue averages 2.8% in whole industries, and 5.8% in the precision instrument industry, while it amounts to about 15% in the semiconductor industry[17].

References

[1] M. V. Fischetti et al., J. Appl. Phys., Vol.90, p.4587, 2001

[2] S. Inumiya, et al., "Fabrication of HfSiON

Gate Dielectrics by Plasma Oxidation and Nitridation, Optimized for 65nm node Low Power CMOS Applications” VLSI Symp. Tech. Dig., T3A-1, 2003

[3] C. Hobbs et al., “Fermi Level Pinning at the PolySi/Metal Oxide Interface” VLSI Symp. Tech. Dig., T2-1, 2003

[4] For example, Antony S. Oates ”Reliability Issues for High-K Gate Dielectrics” IEDM Tech. Dig., T38-2, 2001

[5] Intel’s web site : http://www.intel.com/labs/features/si11031.htm#1 ftp://download.intel.com/research/silicon/HighK-MetalGate-PressFoils-final.pdf

[6] AMD’s web site : “AMD Research Surpasses Semiconductor Industry’s 2009 Performance Projections” : http://www.amd.com/us-en/Corporate/VirtualPressRoom/0,,51_104_543_10218~74873,00.html

[7] W.-J. Huang et al., “Carrier Mobility Enhancement in Strained Si-On-Insulator Fabricated by Wafer Bonding” VLSI Symp. Tech. Dig., T5B-3, 2001

[8] K. Rim et al., “Strained Si NMOSFETs for High Performance CMOS Technology” VLSI Symp. Tech. Dig., T5B-4, 2001

[9] http://www.eetimes.com/story/OEG20011022S0078

[10] Intel’s web site : http://www.intel.com/labs/features/si11031.htm#1

[11] For example, J. M. Hergenrother et al., “The Vertical Replacement-Gate (VRG) MOSFET” IEDM Tech. Dig., p.75, 1999

[12] K. Okuwada, “Role of Universities in the Research on Silicon Semiconductor Devices”, Science & Technology Trends-Quarterly Review No.9, October 2003: http://www.nistep.go.jp/achiev/ftx/eng/stfc/stt009e/STTqr9.pdf

[13] A. Ogasawara, “Trends in Research and Development on Next-Generation Devices (from IEEE IEDM)”, Science & Technology Trends-Quarterly Review No.4, December 2002 : http://www.nistep.go.jp/achiev/ftx/eng/stfc/stt004e/STTqr4.pdf

[14] ITRS official site : http://public.itrs.net/

[15] T. Murotani et al., ISSCC, TP 4.6, 1997

[16] Sony’s press release : http://www.sony.net/SonyInfo/News/Press/200304/03-0421E/

[17] Semiconductor Industry Research Institute Japan et. al “Open up IT World in 21st Century” (in Japanese) : http://www.semiconductorportal.com/Content/Y2003/M05/D16/JEITA030509.pdf

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4

Recent Trends Concerning the Ecological Risk Assessment of Chemicals – Following the Revision of the Chemical Substances Control Law –

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1 Introduction

The decline of biodiversity has become one of the key issues concerning the global environment in recent years. Presently, living species of 10 million to 100 million are said to exist on the earth. An immense number of species contributes to the conservation of a wide variety of gene pools to allow numerous ecosystems to exist in various parts of the earth. The variety of ecosystems is a key to securing stable natural circulation of energy and substances from the earth level to the regional level.

The collapse of biodiversity will lead to the disappearance of genetic resources and deterioration of ecosystem functions, thereby damaging the basis for human activities in the long run. The habitat destruction of species is the biggest factor behind the significant decline in biodiversity in recent years. Environmental pollution caused by artificial chemical compounds is considered a serious problem comparable to the destruction of a tropical rain forest.

The main focus of the safety assessment of chemical compounds has been their effects on human health. This, however, is changing because there has been an ever-increasing focus on biodiversity conservation on a global basis and that calls for the assessment of the effects of chemical compounds on other wildlife. Based on this idea, ecological risk assessment for chemical compounds has been considered worldwide. However, as the chemical industries are important economic infrastructures, ecological risk assessment for chemical compounds must be restricted by the sense of economy.

In practice, administrative bodies standardize assessment methods with a specific focus on domestic trade. In the face of the global free market, however, the world is moving toward the establishment of standardized testing and assessment methods. In this article we will explain the status of the ecological risk assessment for chemical compounds both in Japan and abroad, and discuss the future direction of the ecological risk assessment.

2 OECD's effort for ecological risk assessment for chemical compounds

OECD takes the lead in standardization for the ecological risk assessment for chemical compounds. The OECD test guidelines for toxicity of chemicals have been adopted globally as the relevant testing methods. OECD has been working to eliminate non-tariff barriers created by different regulations in different countries since the second half of the 1970s. It has set up the Chemical Programme that is concerned with the safety assessment of chemical compounds, under which standardization efforts are going on to consolidate the existing testing methods, for example, to determine the environmental fate of chemicals and the impacts on ecosystems and human health. As part of this program, a collection of in vitro tests have been developed to assess the ecological impacts of chemical compounds on aquatic and other organisms.

Particular emphasis is placed on the assessment of impacts on aquatic organisms, because many chemical compounds are believed to reach aquatic environments in the end and such environments are essential for human activities. This signifies the utmost importance of evaluating the impacts of chemical compounds on biota, which is indispensable for the conservation of aquatic environments.

3 Development of the OECD test guidelines for toxicity of chemicals

The OECD Test guidelines for toxicity of chemicals for the assessment of effects on biotic systems may be closely examined on the Web site, which are now being subject to additions and revisions to update. There are so far 17 approved guidelines for the tests, No. 201 to No. 217, as of March 2003. Table 1 shows the outlines of major tests adopted in the OECD guidelines.

OECD is making effort to develop and adopt new tests, as the existing tests alone do not provide sufficient assessment. The followings are major issues being examined at OECD.

3-1 Fish reproductivity / life cycle test

An introduction of a method for life cycle test in fish is being considered at OECD, because the existing tests do not include a chronic toxicity test. The life cycle test is intended to cover all life stages of fish from the newly fertilized eggs to the adult fish, and to define the effects of chemicals on reproductivity of test species (fitness). To evaluate the effects throughout the entire life stages of fish, Oryzias laptipes with a short life cycle has been made a candidate for test species.

3-2 Test for benthic organism

Benthic organisms such as crustacea and shellfish play a significant role in the purification of aquatic environments, as they consume organic matters in sediment. Residual water insoluble chemicals contaminated in aquatic environments tend to accumulate in sediment. Therefore the development of a test for species that live in sediment is becoming important, in addition to the tests for conventional swimming/floating species, such as algae, Daphnia magna and fish. New methods of the examination using juvenile Chironomid midge or Eisenia foetida. as test animals are now proposed and the investigations are under way.

3-3 Test for terrestrial organism

This test is intended, in large part, to determine the effects of agrochemicals on birds, honeybees and soil microorganisms. Fewer data have been available for terrestrial organisms compared to aquatic organisms. There are many tasks to be solved concerning the development of the tests for terrestrial organisms, including the revision of the existing tests.

3-4 Test for sparingly water soluble chemical substances

The OECD test guidelines for toxicity of chemicals are used to assess ecological risk in many countries around the world, which were focused mainly on the assessment of their effects on fish, Daphnia magna and algae in most cases. The tests for these aquatic organisms are based on years of discussions and accumulation of data and are known for its highly reliable reproducibility. However, they were originally intended for testing water-soluble substances. In reality, many of chemical compounds are sparingly water-soluble, which makes it difficult to conduct a test in many cases. Traditionally, co-solvent agents such as solvent and detergent have been added to test water to handle such substances.

In the 1990's, Europe took the lead in calling for a change in this practice to prevent interaction of test substances with auxiliary agents, which led to the establishment of the "Guidance Document on Aquatic Toxicity Testing of Difficult Substances and Mixtures" in 2000. This guidance document declares that, in principle, no dispersing agent should be added to test water. The OECD test guideline for toxicity of chemicals is also moving towards the establishment of a principle in which exposure of test animals to a test substance should be carried out within the concentration of their water solubility without auxiliary substance.

Table 1 :Outline of major OECD test guidelines for toxicity of chemicals (Approved guidelines only)

No.	Test Name (Major Test Species)	Purpose of Test	Outline of Test Procedure
201	Alga, Growth Inhibition Test (Selenastrum capricornutum)	Assessment of effects on single-cell green algae as a primary producer in the biotic system.	Investigate the change in growth speed of algae by inoculating it into test culture containing a test article in the concentrations varying stepwise.
202	Daphnia sp. Acute Immobilization Test and Reproduction Test (Daphnia magna)	Assessment of acute toxicity effects on minute invertebrates as a primary consumer in the ecosystem.	Investigate the inhibition of the swimming (abnormal behavior) of juvenile Daphnia magna after 48 hour exposure to test water containing a test article in the concentrations varying stepwise.
211	Daphnia magna Reproduction Test (Daphnia magna)	Assessment of chronic effects on Daphnia magna as a primary consumer in the ecosystem. Examination of the numbers of adult Daphnia magna whose swimming was interrupted together with the numbers of their offspring during 21 days of feeding and exposure to test water containing a test article in the concentration varying stepwise after inoculating juvenile Daphnia magna to the water.	
203	Fish, Acute Toxicity Test (e.g., Oryzias latipes, Brachydanio rerio)	Assessment of acute toxicity effects on fish, representative species of aquatic organisms and are high order consumers in the ecosystem.	Determine the lethality of a test fish after 96 hour exposure to test water containing a test article in the concentration that changes stepwise.
204	Fish, Prolonged Toxicity Test (e.g., Oryzias latipes, Brachydanio rerio)	Applicable to substances having high lipid solubility and accumulate gradually within the fish body to express their toxicity.	Determine the lethality and the presence of abnormal behavior of a test fish during 14 day exposure to test water containing a test article in the concentration varying stepwise while feeding.
210	Fish, Early-Life Stage Toxicity Test (e.g., Oryzias latipes, Brachydanio rerio)	Determine if there is a lethal effect on fish in an early stage of life from embryo to juvenile fish.	Place fertilized eggs of the test fish to hatch. Determine the effect on the rate of hatching, survival of juvenile fish after hatching, and growth.
209	Activated Sludge, Respiration Inhibition Test	Determine the effects on activated sludge being a community of microorganisms responsible for decomposition in the biotic system.	Determine the change in respiratory activity by adding a test article to activated sludge from a sewage plant in a manner where concentration varies stepwise
205	Avian Dietary (Mixed Feeding) Toxicity Test(e.g., Anas platyrhynchos, Coturnix japonica)	Determine the extent of acute dietary toxicity on birds.	Determine the lethality by feeding for 5 days with bird feed containing a test article in the concentrations varying stepwise.
206	Avian Reproduction Test (e.g., Anas platyrhynchos, Colinus virginianus, Coturnix japonica)	Determine the effects on avian reproduction.	Feed a test bird for 8 weeks with bird feed containing a test article in the concentrations varying stepwise followed by having it lay eggs in the subsequent few weeks. Examining the death, weight, symptoms of parent birds, number of laid eggs, rate of hatched eggs, and the survival rate and weight of juvenile birds to determine the effects on avian reproduction.
207	Earthworm, Acute Toxicity Tests (Eisenia foetida)	Determine the effects on Eisenia foetida as a decomposer of soil.	Determine the lethal concentration by having Eisenia foetida contact with a filter paper impregnated with a test article in the concentrations varying stepwise.
203	Terrestrial Plants, Growth Test	Determine the effects on germination and early growth of terrestrial plants.	Control the soil artificially to contain a test article in the concentrations varying stepwise, grow test plant, followed by measuring the rate of germination and the weight of harvest to work out inhibitory concentration on germination and growth of the test organism.
213	Honeybees, Acute Oral Toxicity Test (Apis mellifera)	Assess acute oral toxicity to adult honeybees as a useful insect.	Give 100 to 200 μg of water containing 50% sucrose and an appropriate concentration of a test article to determine the lethality concentration.
214	Honeybees, Acute Contact Toxicity Test	Assess acute contact toxicity to adult honeybees as useful insects.	Apply, with a micro applicator, 1 ul of solution containing an appropriate concentration of a test determine the lethal concentration.

The ban on the use of dispersing agents is based, in part, on results of experiments showing that only "dissolved" test substances demonstrate bioavailability for test species, and that test substances remain un-dissolved in the form of "suspended materials", are hardly taken into the body of organisms. Test substances are taken into the body of aquatic organisms mainly through bio-membrane such as gills, a mechanism known as passive diffusion, and un-dissolved test substances are not supposed to interact with bio-membrane.

Test substances, while showing toxicity when they are dissolved, insoluble remainder of the substances can also physically exhibit their apparent toxicity. This happens when aggregates formed from un-dissolved substances that may stick to gills or bio-membrane, or may block up the respiratory organ or feeding organ, which could result in the inhibition of the swimming behavior or the death of test species, even if test substances themselves have no toxicity. Therefore, the use of dispersing agents should be avoided in order not to destroy the aggregates causing apparent toxicity, together with the fact that the use of dispersing agent is unrealistic since, in the natural field, the concentrations of the chemical substances in water never exceed their intrinsic solubility.

4 Testing methods adopted in the US and member states of the EC

As pioneers in the field of ecological risk assessment, the US and EU have developed and established various testing methods using many species. Their development activities exert a substantial influence on the development of new guidelines at OECD.

There are two major guidelines in the US, one developed by ASTM (American Society for Tests and Materials) and the other released by US-EPA (US Environmental Protection Agency). ASTM publishes standard test methods that enable the toxicity assessment of not only chemical substances but also of discharged water.

EPA issued two Test Guidelines, OTS (Office of Toxic Substances) Guidelines intended for industrial chemicals and OPP (Office of Pesticide Program) Guidelines for pesticide chemicals. OPPTS (Office of Prevention, Pesticide and Toxic Substances) has consolidated these guidelines to develop new test guidelines to ensure harmonization with the OECD test guidelines for toxicity of chemicals. Among the OPPTS Guidelines, the Ecologic Effects Test Guidelines called the Series 850 have been accessible through the EPA's Web site since 1996.

Table 2 Data set of ecological effect tests required for registration of new chemical substances by individual country

Country	US	Canada	EU	Japan
Production volume to be regulated	less than 10 tons per year	more than 10 tons per year	more than 1 ton per year per manufacturer	more than 1 ton per year
	Data in hand acceptable.			
Fish, Acute Toxicity	(required for certain circumstances)	○	○	○ *
Daphnia magna Acute Toxicity	(required for certain circumstances)	○	○	○ *
Algae, Growth Inhibition	(required for certain circumstances)	–	○	○ *
Activated Sludge, Respiration Inhibition	(required for certain circumstances)	–	○	–
Biodegradability	(required for certain circumstances)	○	○	○
Bioaccumulativity	(required for certain circumstances)	–	–	○
Hydrolyzability	(required for certain circumstances)	–	○	–
Adsorption-Desorption Screening	(required for certain circumstances)	–	○	–

* Required under the revised Chemical Substances Control Law.

In the meantime, the OECD test guidelines for toxicity of chemicals have been established as the standard guidelines in the EU, because the EU member states represent a large part of the OECD countries and the OECD guidelines originally derived from the EU guidelines.

The following testing methods are used to obtain data required for the toxicity assessment of new chemicals to be manufactured or of import chemicals to be registered. Table 2 shows testing requirements by countries.

Unlike other countries, there is no need to submit specific pre-manufacture data items when applying for the registration of new chemical substances in the US, because the data in hand are considered sufficient. Upon the receipt of application, EPA estimates the effects of chemicals based on Structure Activity Relationships (a technique routinely used by EPA to estimate physiological activity or toxicity of new chemicals from their chemical structure, using the database on a correlation between the structure and physiological activity of chemical compounds) and may request for the submission of relevant data.

In Japan, "Law Concerning the Evaluation of Chemical Substances and Regulation of their Manufacture, etc." (hereinafter "Chemical Substances Control Law") was applied to industrial chemicals to ensure their risk management. There was no need to submit data on an ecological toxicity test, because the purpose of this law was to evaluate the impacts of chemicals on human health through environmental pollution. However, an ecological toxicity test became a part of the screening requirements when the law was revised in May 2003.

5 Regulations and management of chemical compounds in Japan – revision of the chemical substances control law –

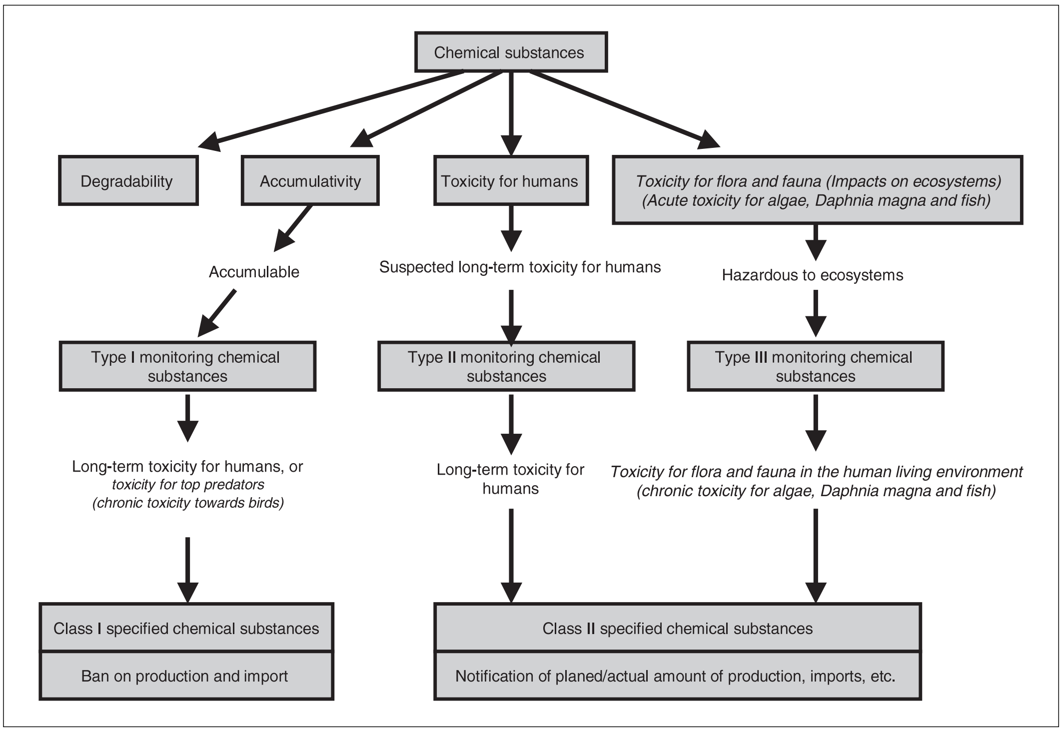
As already said, Japan had not taken any legislative measures to impose the assessment of ecological toxicity of chemical compounds, despite the efforts of other industrial nations to develop and implement measures for wildlife conservation. As such delay was clearly against global trends of the time, the OECD Environmental Performance Review of January 2002 recommended that Japan "further extend the scope of regulation to include ecological toxicity."

The Basic Environment Plan has "Harmonious Coexistence" as one of the long-term objectives and the National Biodiversity Strategy outlines the general direction of Japan's domestic environmental policies concerning chemical compounds. Both of them state the need to "facilitate the assessment and management of the effects on ecosystems in an appropriate manner" with regard to measures concerning chemical compounds. The result was the revision of the Chemical Substances Control Law. The revised law has a new objective to "prevent environmental contamination caused by chemical compounds that may impact human health and wildlife."

The revised law includes the ecological toxicity test as a screening requirement for the registration of new chemicals with an eye to identifying chemical compounds that may have some impact on ecosystems. Specifically, the acute toxicity test must be conducted for algae, Daphnia magna and fish (Oryzias latipes), representative species in the food chain, as is required in the US and Europe.

Figure 1 shows the outline of procedures required under the new screening system. Under the revised law, production and import volume will be monitored for chemical compounds toxic to animals and plants, even if there is no "long-term toxicity against human beings." If there is a risk of environmental pollution, employers will be directed to conduct the "chronic toxicity test" for animals and plants that are likely to be impacted as part of the hazard assessment. If that impact may extend to animals and plants that are related to the human environment (e.g., useful and familiar animals and plants), the employer is obliged to register the concerned chemical compounds as Class II Specified Chemical Compounds and notify of the scheduled production and import volume, in addition to the actual production and import

Figure 1 : Outline of screening and regulation systems for chemical substances under the revised Chemical Substances Control Law



Italics show new screening requirements adopted by the revised law.

volume. If necessary, measures will be taken to limit the synthesis and import volume of such chemical substances.

Production and import of “Class I Specified Chemical Compounds” such as PCBs, which are persistent environmental contaminants that accumulate rapidly in the human body and show long-term toxicity, are already banned. Under the revised law, chemical compounds toxic to animals such as birds and mammals high up in the food chain are also subject to similar regulations (even if they are not toxic to human beings).

All the ecological toxicity tests shall be done in accordance with the OECD Test Guidelines for Toxicity of Chemicals. Guidelines for the “Acute toxicity test for Algae, Daphnia Magna and Fish,” which are necessary for the preliminary review of new chemical compounds, are almost ready. Presently, the law envisages introducing the “Chronic Toxicity Test for Algae, Daphnia Magna and Fish” as a means to examine “toxicity against familiar animals and plants” for the classification of new chemical compounds as “Class II Specified Chemical Compounds.” Furthermore, the “Test for Avian Reproduction” is expected to be adopted for the assessment of “Toxicity against High-level Predators” to classify new chemical compounds as “Class I Specified Chemical Compounds.”

Japan has little experience in conducting the chronic toxicity test or reproduction test, which makes it necessary to increase the number of laboratories that comply with Good Laboratory Practice (GLP) in the future.

6 Definition of sparingly soluble chemical substances in the revised Chemical Substances Control Law – consistency with global economy –

In connection with the inclusion of the ecological risk assessment in the Chemical Substances Control Law, there was a heated discussion on how to address the issue of “sparingly water soluble substances.” As already stated, the existing OECD test guidelines for toxicity of chemicals provide that no dispersing agents should be added to test water when conducting a test for sparingly water soluble chemical compounds and that their concentrations should never exceed the maximum concentration in purified water, namely the aqueous solubility. However, chemical compounds of strong physiological activity tend to have high lipid solubility (e.g., insecticide, fungicide), hence sparingly water-soluble. The law provides that all toxicity tests shall be done at the concentration within the water solubility of the chemicals. So, there is a possibility that it would be wrongly concluded that compounds hard to dissolve "pose no threats to ecosystems."

As the OECD members, the US and EU have long started efforts to develop tests to deal with the issue of sparingly water soluble chemical substances, based on the understanding that they tend to move into sediment. Examination is under way to establish the test for benthic organisms, using Chironomid midge in the form of embryo and other organisms. If this benthic organism assessment is formally adopted as the OECD test guidelines for toxicity of chemicals, Japan will introduce it in the future. This, however, raises a question. Can we afford to leave the issue of sparingly water soluble chemical substances unaddressed until such time as the said testing method is approved, knowing that Japan relies more heavily on water resources including rivers and lakes than other countries? In the process of revising the law, the author pointed out this problem as a member of the Ministry of Environment Ecological Risk Test and Assessment Technology Commission. The author then proposed the use of detergent and other agents to some extent to observe how sparingly water soluble substances demonstrate their activity against aquatic organisms when the aqueous solubility cannot be determined. The ultimate objective of the ecological toxicity test is "wildlife conservation," although it uses only three aquatic organisms, namely algae, Daphnia magna and fish, as test species. This prompted the author to decide that some options should be introduced to learn as much as we can from these tests. For this proposal to be adopted into the revised law, the potential creation of trade barriers posed the biggest problem. Because the use of auxiliary agents do not comply with the OECD guidelines, it is not possible to request importers of new chemical substances to conduct the test using auxiliary agents, or to submit test data involving the use of auxiliary agents for export purpose. After endless discussions, a draft of the ministerial ordinance was developed. It stipulates that the law can demand a test that uses the dispersal system and auxiliary and other agents, provided that it is impossible to measure the aqueous solubility and obtain acute toxicity data concerning aquatic organisms. This example shows that the global free market could be a cause of new screening requirements.

7 Need for and direction of new ecological risk assessment

Japan will at long last join other industrial nations as it begins the ecological risk assessment of chemical compounds. However, the assessment is based sorely on toxicity tests for a few test species adopted in line with the international standards, which created more than a little criticism that such assessment is absolutely insufficient for the protection of the ecosystem as a whole.

An ecosystem is a complex organic network consisting of a dynamic set of living organisms all interacting among themselves. Different ecosystems are found in different regions, and, as already stated, there is an immense number of species on the earth that are crucial to its biodiversity. It should not be a surprise if some question the relevance of relying on the toxicity test conducted in a beaker for only three species (algae, Daphnia magna and fish) to protect such complex and diversified ecosystems.

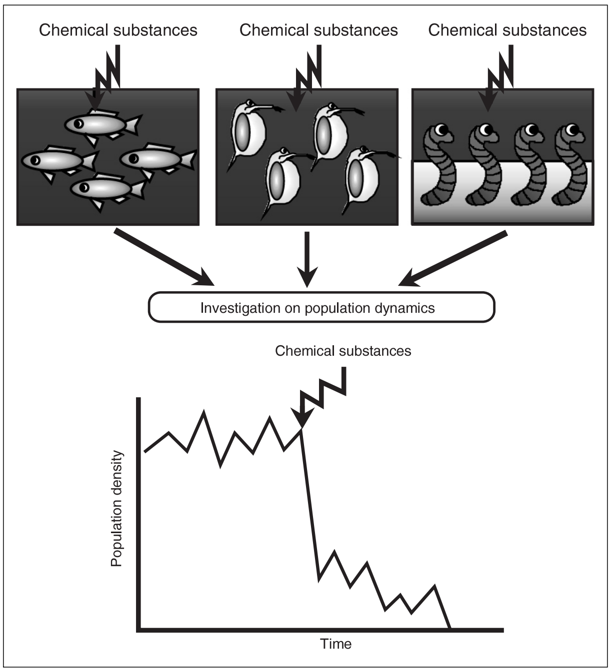
To respond to such criticism from the perspective of ecological science, continuing efforts are under way to explore ways to migrate from the risk assessment at an individual organism level to one at a higher level. For example, the US and Europe have proposed the use of more than five test species for a fish toxicity test, and developed a test at a population level. In addition, model development is being conducted to identify the effects of chemical compounds for each development stage of test species, work out how those chemicals impact the reproductivity (fitness) of test species, and finally estimate probability of extinction of the population (Figure 2).

A macrocosm test[*1] provides a new possibility for the assessment of effects of chemical compounds at the ecosystem level (Figure 3). In this test, an "experimental ecosystem" is constructed to simulate parts of natural aquatic ecosystems by placing various species in a large tank set up in a laboratory or conservatory to which test substances are applied. These "high-level test systems" are aimed at assessing ecological effects of chemical compounds more "realistically" by reproducing a complex ecosystem in the best possible way to simulate a natural ecosystem. It is, however, simply impracticable to cover all natural ecosystems with different diversity in different regions or for different seasons, however complex the constructed test systems are. Any tests could end up a case study.

Meanwhile, development efforts are going on for genetic toxicity tests that do not use individual species. Toxicogenomics is a recently developed field in toxicology and involves a process known as microarray analysis, which obtains substantial quantities of data to identify the level of expression for all genes. It holds a key to estimating the toxicity of chemical substances towards living organisms as it identifies their effects on the expression of specific genes. This new technique, if established, is expected to lead to significant reductions in the time and costs associated with the breeding of test species and the standardization of tests, and to improve the efficiency of ecological effects assessment. It is necessary to investigate this technique more carefully to decide if risks to ecosystems can really be estimated by observing changes in gene expression.

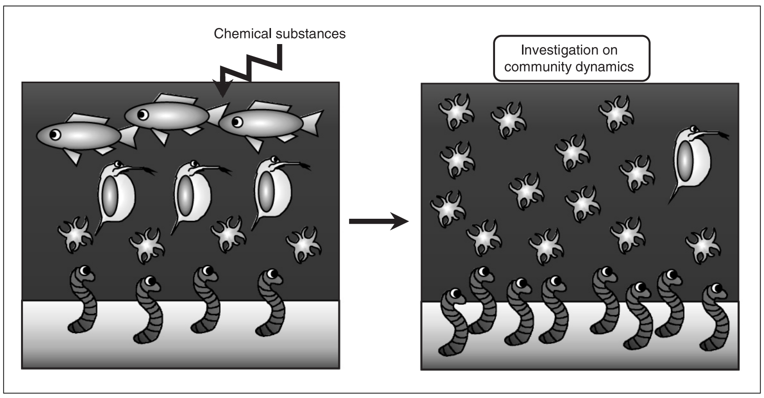
Rather, future ecological risk studies would require model development and validation studies to fill a gap between in vitro tests and natural field ecosystems. Toxicology must investigate ways to estimate potential events in natural ecosystems based on in vitro toxicity tests including those based on gene expression. To do so, it is necessary to examine the various possibilities from the standpoints of population biology such as population ecology, community ecology, and population genetics and to develop

Figure 2 : Ecological effects test in population level



Expose test population of test species to chemical substances and identify changes in population density.

Figure 3 : Ecological effects test in community level



Create a test community consisting of various species such as Chironomid midge, algae, Daphnia magna and fish, administered chemical substances to the community, and identify changes in the community structure (the formation of species and community density).

a mathematical model. The aforementioned "high-level test systems" should be used to accumulate data to confirm the effectiveness of a mathematical model. Data collection should also be conducted in various field locations.

8 Requirements for ecological risk assessment in Japan

It will take considerable time for such an ideal model to be established. A weak research environment and lack of researchers are two major obstacles for the advancement of ecological risk studies in Japan. It has been quite some time since words such as "conservation biology" and "biodiversity conservation" gained popularity. However, only a small number of ecologists address issues related to chemical compounds and their production and disposal. For example, the Japanese Society of Environmental Toxicology has only about 400 members, when its US counterpart SETAC (The Society of Environmental Toxicology and Chemistry), a leading society that represents eco-toxicology researchers in the US, has more than 5,000 members. These figures show that the Japanese researcher population in the field of environmental toxicity or ecological risk is smaller than that of the US and Europe. There is one other factor. In Japan, only a handful of university laboratories and research institutes are specialized in the assessment of ecological effects of chemical substances, and this makes it difficult to foster a large number of researchers. The immediate task required for Japan's ecological risk studies is to foster more biology researchers in a way so that they develop interests in environmentology and other research fields. To accomplish this, it is necessary to resolve a disjunction between the academic emphases of the societies for toxicology and the societies for ecology by developing a linkage mechanism that connects academic societies. The possibility of establishing a multi-disciplinary organization such as a consortium of academic societies should also be examined.

For the progress of ecological risk studies, it is necessary to create a social setting that would generate more attention and interest in this research field in general. Various possibilities should be looked into to promote the understanding of ecological risk assessment among the general public. Attaching labels with the words "Creature Friendly" to chemical compounds that meet the requirements of the ecological risk assessment may be a good idea. Chemical makers and distributors tend to see the ecological risk assessment as a heavy burden because it could lead to strengthened regulations. At the same time, it would enable them to publicly announce the safety of chemical compounds and differentiate them from other products, once they are confirmed complying with regulations. Environmentally friendly chemical compounds may help create a new market sector. If the ecological risk assessment provides some potential commercial benefit and more companies show interest in this research field, it will become a new, attractive research theme, which could grow into one research field in the future.

The OECD test guidelines for toxicity of chemicals and the Chemical Substances Control Law were derived in the shadow of two concepts, economic development and environmental conservation, which are contradicting but necessary for human society. The latest revision of the Chemical Substances Control Law and the inclusion of the ecological risk assessment represent a huge step forward. There is no doubt that requirements and criteria for the ecological risk assessment will be increasingly severe both domestically and internationally. As a big trader, Japan must be prepared to take the leadership in this field. The environmental effects assessment of chemical substances is essential for environmental conservation. Researchers with a love for nature should take a strong interest in chemical compounds, which are a near-cause of environmental destruction. Japan must strengthen its efforts for the advancement of ecological risk assessment studies.

Glossary

*1 Macrocosm test

The word macrocosm, derived from a "miniature universe," means an artificial ecosystem created in a tank in which a population or community of organisms are cultivated. In short, it is a flask level test system conducted in a controlled environment. For comparison, a large-scale test system conducted in the enclosing parts of existing ecosystems is called the mesocosm test.

References

[1] OECD Web site : http://www.oecd.org/oecd/pages/home/displaygeneral/0,3380,EN-document-519-14-no-6-25073-0, FF.html

[2] Chemical Substances and Eco Toxicity, Akiko Wakabayashi (2000), Japan Environmental Management Association For Industry, Tokyo (in Japanese)

[3] Toxicology, compiled by Shoichi Fujita (1999), Asakura Shoten, Tokyo (in Japanese)

[4] ECOFORUM Aquatic Report (1999): Ecological Committee on FIFRA Risk Assessment Methods

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5

Pressing Issues in the Health Effects Assessment of Chemical Substances

YASUNOBU AOKI *(Affiliated Fellow)*

1 Introduction: Hazard and risk assessments of chemical substances

It's anybody's guess how many different chemicals are currently used in items such as chemical products, solvents and synthetic resins. Estimates abound, but the number of registered or listed chemicals suggests that some 100,000 chemicals are in use today, of which as many as 50,000 are on the Japanese market.

It's not long since most these chemicals[*1] came into widespread use - the latter half of the 20th century saw a rise in their mass production, with a variety of synthetic processes developed. For this reason, some "dream" chemical substances with useful properties were found to be hazardous only after they had become ubiquitous. For instance, trichloroethylene and tetrachloroethylene - chemicals once termed "dream detergents" - were used in large quantities as degreasing/cleaning agents for precision instruments and semiconductors. Because they were shown to be carcinogenic in animal experiments, however, their use was restricted in many countries including Japan. Fortunately, both trichloroethylene and tetrachloroethylene were shown to be hazardous before they began to have an impact on human health. Much has to be done to assess the hazardous properties of many other chemicals.

As we enter the 21st century, there has been a growing trend to assess the potential risks of technologies and products developed in the 20th century before making use of them. For instance, the Cartagena Protocol, which was concluded in 2003, regulates the import of genetically modified organisms; their potential risks should be assessed to conserve biodiversity and minimize impacts on human health. Underlying these arrangements is the concept of precautionary approach to control agents of unknown hazard.

Any secondary hazard should be quantified to assess the potential risks of new technologies and products. One of the reasons why the health effects of radiation are assessed strictly is that an enormous amount of biological and medical research has shed light on the relationship between the dosage of radiation and the associated hazard. To assess the risks of chemicals, therefore, there is a need to quantify their hazardous properties, particularly the probability of an impact on human health. The mechanism used to assess the hazardous properties of chemicals is worth noting as a model for systematically acquiring the information required for risk assessments.

2 Why should the hazardous properties of chemical substances be assessed in advance?

In Japan, the hazardous properties of chemical substances are assessed in accordance with the "Law concerning the Evaluation of Chemical Substances and Regulation of their Manufacture etc.", which was enacted in 1973 (hereinafter referred to as "the law") in the wake of the Yusho incident - a PCB poisoning that occurred primarily in northern part of Kyushu area in 1968. This incident revealed that environmental pollution by PCB was widespread in Japan and its accumulation in organisms was more serious than expected, a situation that raised public awareness of health effects due to exposure to hazardous chemicals. The law is one of the first of its kind in the world to regulate production and import of chemical substances in view of their potential impacts on human health. It's safe to say that Japan led the way in taking safety measures against chemical substances when it instituted the law. We learned some important lessons from our experience in industrial pollution, which may have prompted us to take specific action.

The hazardous properties of chemicals should be assessed in advance to minimize environmental pollution and prevent any possible impact on human health and ecosystems. It usually takes some time before the hazardous properties of chemical substances are well understood by the public, and appropriate safety measures are in place. In the U.S., for instance, commercial production of PCB began in the 1930s, but it was not until the latter half of the 1950s that reproductive failure was found in minks fed with PCB-contaminated fish. In Japan, meanwhile, a total of some 60,000 tons of PCB was produced in the 18 years from 1954 (when commercial production of PCB started) to 1972 (when production was discontinued due to the Yusho incident)[1]. The pollution was already widespread when PCB proved to be hazardous. Cases abound in Japan where soil and groundwater are polluted with heavy metals and persistent chemicals such as PCB and trichloroethylene[2] (see Figure 1). The cost of removing pollutants already dispersed in the environment is extremely high, and could have been avoided if appropriate antipollution measures had been in place based on an understanding of their hazardous properties.

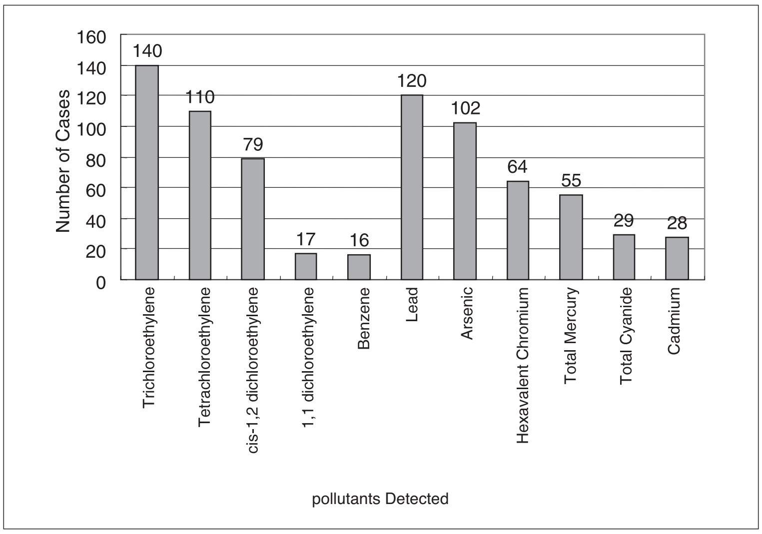
Assessing the hazardous properties of chemicals is essential to assessing the risks of exposing humans to them, and this is becoming increasingly important. Specifically, risk assessment of chemicals refers to quantitative assessment of the health effects on humans and wildlife exposed to them in the environment. Fundamental to risk assessments of exposure to chemical substances is to identify 1) the toxicity of the chemical substances concerned, and 2) the possible amount of which humans and other organisms are exposed to them. In other words, the degree of toxicity multiplied by the amount of exposure equals risk[3].

Generally speaking, hazard assessments of chemicals mean identification of the toxicity of the chemicals concerned. As there are still a number of chemical substances whose hazardous properties have yet to be determined, assessing the toxicity of each individual chemical is essential to appropriate risk management - e.g., risk assessments of a variety of chemicals, and risk abatement measures.

3 Status of hazard assessment of chemical substances

Chemicals can be broadly classified in two categories for management purposes. Those

Figure 1 : Number of cases where concentration of pollutants in soil exceeded standards



Source: Outline of the Survey of Soil Contamination, Antipollution Measures, etc., by the Ministry of the Environment (2001) whose production and import started after the enforcement of the law (1973) are termed "new chemical substances." The businesses concerned are obliged to conduct the tests for hazard assessment, the results of which are reviewed jointly by the Ministry of Economy, Trade and Industry, the Ministry of Health, Labour and Welfare, and the Ministry of the Environment to control the production and import of potentially hazardous chemical substances. The goal is to reduce their release to the environment and human exposure. Other chemical substances, whose production and import started before the enforcement of the law, are termed "existing chemical substances"; their hazardous properties are being examined by the government so that they are included in the framework of chemical substance management (see Figure 2).

Businesses dealing with existing chemicals such as benzene, the hazardous properties of which have yet to be determined, are using their accumulated knowledge to reduce the release of those chemicals into the environment.

Other countries are taking similar measures to control potentially hazardous chemicals. The hazardous properties of new chemicals are determined by governments (based on data provided by businesses), while those of existing chemicals are reviewed independently by each country.

3-1 Assessment of the hazardous properties of new chemical substances in Japan

Under the previous version of the Law concerning the Evaluation of Chemical Substances and Regulation of their Manufacture etc., the hazardous properties of new chemicals were determined based on their 1) biodegradability, 2) bioaccumulativity and 3) the results of toxicity screening tests. With the law revised in 2003, the results of ecological toxicity tests will be added to the existing criteria in fiscal 2004 (refer to page 41 of this bulletin[4]).

The toxicity of chemicals should be determined by the results of a variety of long-term tests such as those for chronic toxicity, carcinogenicity and teratogenicity - an extremely costly procedure. Thus two types of convenient tests (screening toxicity tests) complying with the OECD Directive (1983) will be used to examine the possible long-term toxicity of chemical substances to humans. One is a genotoxicity test, which uses bacteria and cultured cells to examine the possible carcinogenicity of chemical substances. The other is what is called a "repeated-dose 28-day oral toxicity test," which administers chemical substances to rats for 28 consecutive days to determine the maximum

Figure 2: Chemical substance management system

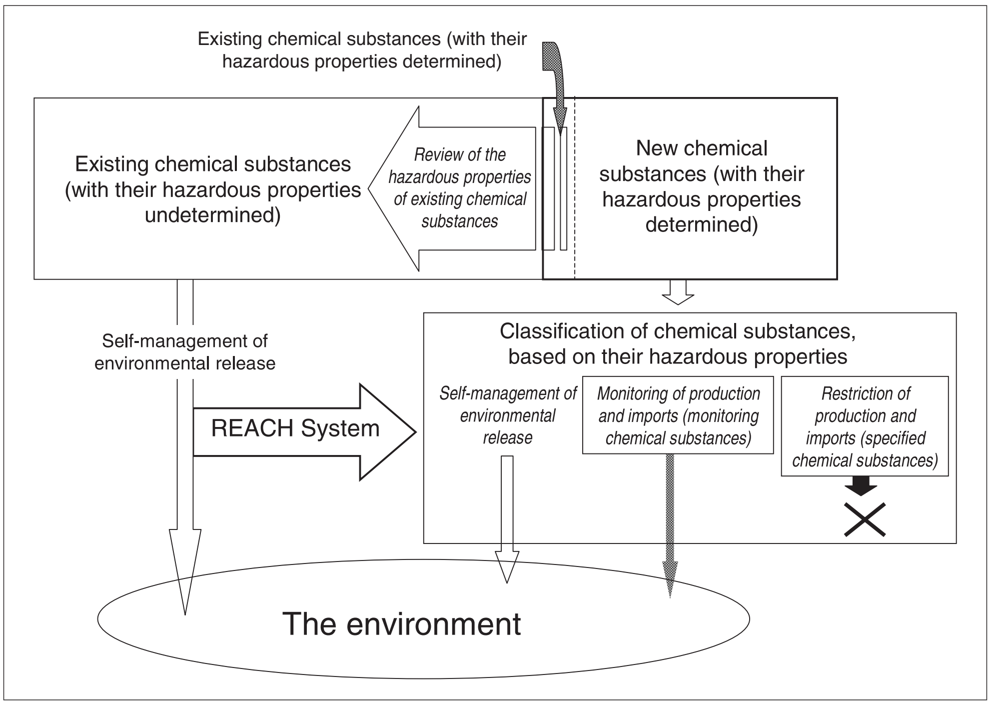
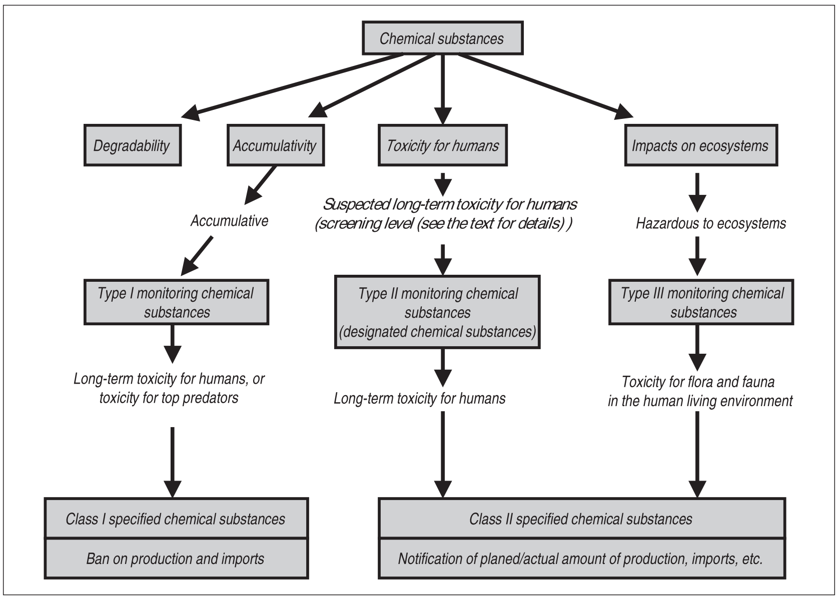


Figure 3 : Outline of the revised Chemical Substances Control Law (2003)



Subjects relevant to health effects are presented in italic

dose that does not produce pathological changes. The degree of toxicity is determined, taking into consideration the results of these tests. Both businesses and reviewers are making significant efforts to conduct the screening toxicity tests.

The hazardous properties of chemical substances are determined, based on the results of tests conducted by businesses, and those chemicals are monitored and controlled in accordance with their hazardous properties. With the law revised in 2003, potentially hazardous chemicals will be classified into three categories (Type I-III monitoring chemical substances), based on the nature of their hazardous properties. The actual amount of their production and import are to be reported. On the other hand, chemical substances to be monitored, whose long-term toxicity to humans or wildlife has been identified, will be classified into two categories (Class I-II specified chemical substance), and they will either be banned or regulated (see Figure 3). A total of 4,322 chemicals were reported as "new chemical substances" during April 1987 and December 2002 (the period when the conventional examination system was in place), of which 821 (or about 19% of the total) were classified as "designated chemical substances[5] (equivalent to "Type-II monitoring chemical substance," under the revised law).

3-2 *Assessment of the hazardous properties of new chemical substances in other counties*

In accordance with the 7th Council Directive (1992) on the classification, packaging and labeling of dangerous substances, hazard assessments are in place in the EU for any chemical substance that is produced in or imported into the region in quantities greater than one ton/year, following procedures similar to those in Japan. Specifically, chemicals determined to be hazardous should be labeled according to their hazard levels before going on the market, and those involving significant risks should be closely monitored and regulated.

In the case of the U.S., meanwhile, chemicals are regulated in accordance with the Toxic Substance Control Act (TSCA). Any data concerning the hazard of chemical substances that have been produced in or imported into the country since 1980 in quantities greater than 10 ton/year should be reported to the Environmental Protection Agency (EPA). Chemicals determined to be hazardous should be handled and disposed of in accordance with the procedures specified by the Act.

4 Reactive hazard assessments of existing chemical substances

4-1 Status in Japan

About 20,000 items are registered as "existing chemical substances" in Japan, most of which have been in use. The Ministry of Economy, Trade and Industry has jurisdiction over biodegradability and bioaccumulativity tests, and the Ministry of Health, Labour and Welfare, over toxicity screening tests, the results of which serve as the basis for reclassifying some of the existing chemical substances as designated chemical substances (equivalent to "Type-II monitoring chemical substance," under the revised law). Beginning fiscal 2004, the Ministry of the Environment will take charge of ecotoxicity tests to designate "Type-III monitoring chemical substance."

Yet little progress is being made in hazard assessment of existing chemicals. In fact, of some 20,000 registered "existing chemical substances," a total of only 1,377 items have been tested for their biodegradability and bioaccumulativity by 2002, while about 200 items have undergone toxicity screening tests, and 134 items have been classified as "designated chemical substances[5]."

4-2 Status in EU and the U.S.[6,7,8]

As many as 100,000 items registered as "existing chemical substances" were produced in or imported into the EU member states before 1981; those involving more than 1,000 ton/year of production or import have been tested for their toxicity and possible impacts on ecosystems. The results of these tests are in the "International Uniform Chemical Information Database (IUCLID)," which has information on the hazard of various chemical substances. Risk assessments of existing chemical substances have been underway since 1994 based on this database. The results: 141 items are designated as "priority chemical substances" and a risk report was drafted in April 2002 for 88 items, with risk-reduction measures required for 45 items.

In the U.S., businesses are conducted to assess the hazardous properties of priority existing chemical substances (more than 500 items) designated by EPA in accordance with TSCA. However, only 80 items have been examined so far - a delay due to the need to test various toxicity such as chronic toxicity and carcinogenic tests. According to the TSCA inventory, the total of new chemical substances and existing chemical substances is approaching 70,000, with data on their hazard available for public review.

4-3 OECD program to investigate high production volume (HPV) chemicals[9] (OECD HPV Program)

Chemicals being produced in large quantities have a greater likelihood of being released into the environment, thus increasing the possibility of human exposure. The OECD published a rule in 1992 for HPV (High Production Volume) chemical substances involving more than 1,000 ton/year of production in a given country. Each country is to prepare a report on the hazardous properties of the HPV chemicals concerned, collecting data on their physico-chemical qualities, environmental fates, ecotoxicities and toxicities (repeated-dose 28-day oral toxicity etc.) - a minimum requirement for hazard assessments. A program to investigate HPV chemicals (OECD HPV Program) was launched in 1999, with the aim of assessing 1,000 items out of some 5,200 on the list by 2004. However, only 371 items had been completed as of 2003[10].

The U.S. also launched its own initiative, termed the "HPV Challenge Program", in 1998 sharing relevant information with the OECD[7,11]. The HPV chemicals to be investigated in this program (i.e., organic compounds that are produced in or imported into the country in quantities greater than 454 ton/year; polymers excluded) totaled some 2,800 items, which originally accounted for 11% of the items listed on the TSCA inventory, or 95% of the total production of chemical substances in the country. However, complete data on health and environmental effects are available for only 7% of the HPV chemicals to be investigated, which clearly suggests the need to prioritize the hazard assessment of HPV chemicals.

Of 1,606 chemicals, knowledge of whose production in or import into Japan is made available to the public, 798 items are produced in or imported into the country in quantities greater than 1,000 ton/year (see Table 1). The production and import of all the chemicals on the market needs to be made public to promote hazard and risk assessment.

5 Trends in the management of new chemical substances in the EU: the REACH System

The European Commission proposed the "Strategy for a Future Chemicals Policy" in February 2001. The underlying goal of this strategy is to avoid using chemicals with unknown toxicity. To this end, 1) new chemical substances and existing chemical substances will be regulated, based on the same standards (see Figure 2), and 2) the burden of proof regarding the safety of chemical substances will be transferred from the governments of the member states to the industries concerned (including not only chemical manufacturers and importers but also users). There is also a move afoot to shift the entire responsibility for controlling chemical substances from government to industry[7,12].

The REACH (Regulation, Evaluation and Authorization of Chemicals) System is a framework for implementing the proposed strategy. Regardless of the categories of chemical substances, it stipulates that 1) data on the toxicity and the amount of human/environmental exposure of chemicals be registered with the system by businesses, 2) the hazardous properties of chemicals produced or imported in large quantities be evaluated thoroughly, and 3) highly hazardous chemicals in terms of their carcinogenicity and teratogenicity be authorized prior to use (These chemicals, in principle, should be replaced by safer chemicals. Their production or import will be banned unless businesses can prove that they pose a negligible risk or have no substitutes available.)

The proposed strategy is under consideration by the European Parliament. It is indeed an epoch-making initiative to prevent the release of hazardous chemical substances into the environment, though there are many who disapprove of this attempt, asserting that "it may impose too much of a burden on industry." It is worth noting, however, that the environmental movement in Europe has become so powerful that it is beginning to have much sway over industrial policies in the region.

Table 1 :Survey of production and imports of chemical substances in fiscal 2001

Production/Imports (ton)	Number of Items
1 – 10	12
10 – 100	239
100 – 1,000	557
1,000 – 10,000	446
10,000 – 100,000	216
100,000 – 1,000,000	99
1,000,000 – 10,000,000	34
10,000,000 or more	3

Source: Chemical Management Policy Division, Manufacturing Industries Bureau, Ministry of Economy, Trade and Industry

6 Measures to complement efficient hazard assessment of existing chemical substances

The majority of existing chemicals have yet to be assessed for their hazardous properties, both at home and abroad - a situation due in part to the considerable amount of time and cost involved in toxicity tests*2.

It is ultimately impossible to assess the toxicity of chemical substances without animal experiments. Meanwhile, it would be ideal if all the chemicals on the market could be assessed, but this is also impossible in view of the cost and time involved. While hazard assessments are currently prioritized for HPV chemicals, potentially highly toxic chemical substances should be screened out and assessed for their toxicity as a means to prevent adverse health effects from exposure to chemicals, with the first priority being to collect data efficiently. A simple, quick and easy way to predict the toxicity of chemical substances should thus be developed to determine these priorities.

Risks associated with chemicals can be reduced by preventing the release of hazardous ones into the environment, as well as preventing the exposure of humans and wildlife. In this context, chemicals that are detected frequently and in high concentrations in the air and water should be assessed for their hazardous properties, regardless of their production or import volume.

It is also essential that the domestic institutional framework be improved to promote hazard assessments of existing chemical substances - which should be based on more reliable data obtained through overseas HPV programs, rather than on data collected in Japan. OECD, EU, the U.S. and Japan have yet to share their databases on toxicity with one another. These databases should be unified to promote hazard assessments on a worldwide basis.

Promoting efficiency in obtaining toxicity data is important not only with respect to existing chemicals. With the revised law in place, chemicals produced or imported in quantities smaller than 10 ton/year (the previous threshold: one ton/year) are classified as “chemical substances with low volume manufacturing/import,” most of which are exempted from toxicity tests. New chemical substances, however, include a great many chemicals that have been in use for a relatively short time. For instance, the variety of designated chemical substances containing fluorine has increased dramatically in recent years. The number of items registered increased from only a handful a year to some 50 in 2000 and 2001 combined. As part of the precautionary approaches for new chemical substances, which are expected to increase further, voluntary efforts should be encouraged as necessary to assess the hazardous properties of “chemical substances with low volume manufacturing/import” that are potentially highly toxic.

7 Status of and prospects for the development of toxicity prediction methods

The following two methods are considered promising ways to predict the toxicity of chemical substances:

7-1 QSAR (Quantitative Structure Activity Relationship)

This method involves predicting the toxicity of new chemicals, based on a comparison of their toxicity levels, chemical structures and physico-chemical qualities with those of known chemicals. In compliance with TSCA, QSAR model termed ECOSAR has been used to predict the ecotoxicity for about 10 years. Specifically, chemicals are classified into 59 categories, and the regression function between logKow (the octanol-water partition coefficient, used to describe the lipophilic or hydrophobic properties of chemical substances) and toxicity (concentration at which 50% of the test organisms are expected to die) is used to predict the toxicity of target chemical substances.

Other toxicity tests such as those for carcinogenicity are also expected to adopt QSAR[13]. EU’s REACH System is following suit in an effort to promote hazard assessments.

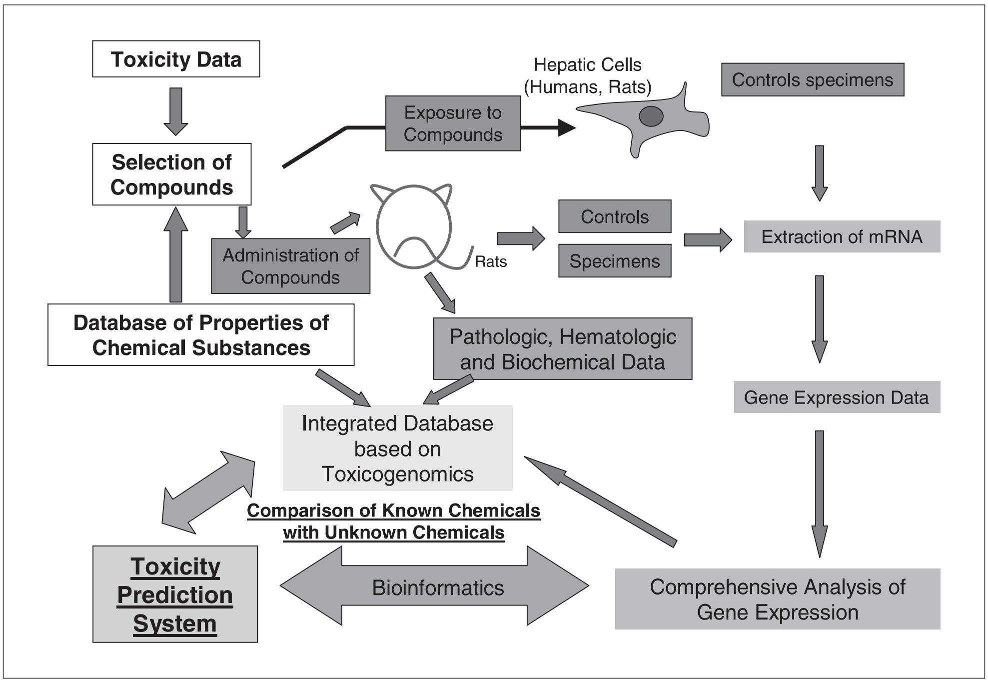
7-2 Toxicogenomics

This method predicts the toxicity of chemical substances using DNA micro array technology. When administered hazardous chemical substances, animals or their cultured cells exhibit certain responses: either increases or decreases in the expression levels of particular genes. With an estimated 10,000 to 20,000 genes to be observed, each of which may respond specifically to the chemicals administered, the changes in gene expression profiles go into a database from which the carcinogenicity of unknown chemicals can be predicted. Specifically, the gene expression profiles of carcinogen are compared with those of other chemicals of unknown carcinogenicity (see Figure 4).

This prediction method, when commercialized, is expected to dramatically improve the efficiency of toxicity tests, as it requires only about one-tenth the time and one-hundredth the cost of conventional methods for predicting the carcinogenicity of a chemical substance.

In the U.S., the National Institute of Environmental Health Sciences, an affiliate of the National Institutes of Health, created the National Center for Toxicogenomics (NCT) in September 2000, which is working on a comprehensive database of gene expression due to exposure to chemical substances[14]. Its “Concept Statement” stipulates that the mission of the NCT is to “use and promote toxicogenomics as a means to guide

Figure 4 : Toxicity prediction based on toxicogenomics



Source: Website of the National Institute of Health Sciences

federal agencies and legislators in developing guidelines and laws that regulate the levels of various chemicals in the environment." On the domestic front, meanwhile, toxicogenomics projects are underway, sponsored by the National Institute of Health Sciences, the Ministry of Economy, Trade and Industry, etc. Expectations are growing for the commercialization of toxicogenomics-based toxicity prediction in five year's time.

The toxicity prediction methods to be developed next should focus on possible impacts of chemical substances on the offspring in the next generation. There have been concerns over the teratogenicity of chemicals (i.e., the potential to cause birth defects) and their detrimental effects on the nervous system of the fetus. Endocrine-disturbing chemicals also threaten to have possible impacts on the offspring in the next generation. At the present level of technology, however, these impacts can be determined only through animal experiments - a situation that demonstrates the need to develop new toxicity prediction methods.

The development of genetically modified animals is also underway in an effort to come up with tools that would predict the carcinogenicity of chemical substances with short-term tests. When applied systematically in the early stages of the development of new chemicals and pharmaceuticals, these toxicity prediction methods could make it possible to examine products from the viewpoint of their benefits and safety - which will open up the way to safer chemical substances.

8 Conclusion

A great many chemical substances were developed in the 20th century. Exposure to chemical substances previously nonexistent in nature, and their accumulation in human body, were both unprecedented in human history, and hence much remains to be seen about how they impact humans and wildlife. Research on the toxic mechanisms of chemical substances holds the key to developing toxicity prediction methods. For instance, any chemical substance is expected to have hazardous effects on organisms when it is dosed over a threshold level. Strictly speaking, "zero risk" may not be feasible, but safe exposure levels could be set by accumulating quantitative findings on the hazardous properties of chemical substances. Research on the toxicity of chemical substances should be promoted to ensure the safety and security of the public.

Those who have firsthand experience in hazard assessments of chemicals realize clearly that they require a broad range of knowledge concerning chemical substances such as physico-chemical property, toxicity, fate in the environment and risk abatement techniques, etc. On the international front, the REACH system imposes greater responsibilities on businesses to conduct hazard and risk assessments of chemicals, which is expected to increase the importance of experts in these areas. In Japan, however, a variety of departments such as those of chemistry (Faculty of Science), applied chemistry (Faculty of Engineering), sanitary engineering, veterinary medicine (Faculty of Agriculture), public health (Faculty of Medicine) and pharmaceutical science are engaged independently in education and research on toxicology, which is required for hazard and risk assessments - a situation that may not be ideal for educating and training experts. There is thus a pressing need to set up graduate school in toxicology and its related areas.

In the U.S., some 80 universities offer courses for master and doctoral degrees in toxicology. About 200 students earn a Ph.D. in toxicology every year, and become engaged in research activities at universities, research institutes, companies, administrative agencies and NGOs[15]. US society definitely needs toxicology experts (toxicologist). The US government, for instance, is more demanding than its Japanese counterpart as far as chemical substances are concerned; it requires businesses to disclose information regarding the hazardous properties of the chemical substances they handle, along with the amount released into the environment, as a way to respect the public's right to know the truth. In contrast, there are not many toxicologists in Japan. In typical Japanese universities, education and research on toxicology and its related areas are usually conducted by one laboratory in their Faculty of Pharmaceutical Sciences or Medicine. No systematic educational system is in place for toxicology.

"Risk assessment" has become a common buzzword. However, for risk assessments to take root in society, they should be conducted properly, and the public should be able to understand their results correctly. If risk assessments are to be required in Japan, there is a need to improve the institutional framework for hazard assessments, develop human resources to disseminate information regarding hazard and risk assessments of chemical substances, and train experts to take charge of conducing on-site risk assessments. Graduate schools in toxicology are also expected to play a critical role in developing such human resources.

Acknowledgements

I would like to express my gratitude to the personnel of the Research Center for Environmental Risk, the National Institute for Environmental Studies, for their support in providing information for this report.

Notes

*1 "Chemical substances" or "chemicals" are such general terms that they could be applied to any material, but for our purposes here they may include not only products sold as chemicals but also unintended byproducts of chemical processes such as dioxin, although those are not included in this report, which only deals with chemicals on the market.

*2 A repeated-dose 28-day oral toxicity test costs about ¥7.5-9.5 million and takes about half a year to complete. Long-term toxicity tests are also costly. A typical carcinogenicity test costs about ¥200 million and takes some three years to get results.

References

[1] Isono, N. 1975. Chemical Substances and Human Beings, Chuokoron-Shinsha.(in Japanese)

[2] The ministry of the Environment. Outline of the 1999 Survey of Soil Pollution and Remediation. March 2001. (in Japanese)

[3] Gamo, M. 2003. Environmental Risk Management Handbook: p130, Asakura Shoten (in Japanese)

[4] Goka, K., and Urashima, K., "Recent Trends Concerning the Ecological Risk Assessment of Chemicals", p.41 of this bulletin

[5] The Ministry of Economy, Trade and Industry, the Manufacturing Industries Bureau, the Chemical Management Policy Division, the Chemical Safety Section. Japan

Chemical Industry Ecology-Toxicology & Information Center, Information A, vol. 25, No.11, 2003. (in Japanese)

[6] Website of Japan Chemical Industry Ecology-Toxicology & Information Center : http://www.jetoc.or.jp/excistinfo.html#

[7] The 2nd Chemical Substance General Management Policy Workshop, May 2002. : http://www.meti.go.jp/policy/chemical_management/kennkyuukai/kennkyuu-kai-top.htm

[8] The Ministry of Environment : http://www.env.go.jp/chemi/seitai-kenko/h13/05/06.pdf

[9] Website of OECD; Co-operation in the investigation of existing chemicals : http://www.oecd.org/department/0.2688.en_2649_34379_1_1_1_1_1.00.htmp#top

[10] OECD; Joint meeting of the chemicals committee and the working party on chemicals, pesticides and biotechnology, 36th joint meeting, Feb. 2004.

[11] Website of the Environmental Protection Agency (US) : http://www.epa.gov/chertk/volchall.htm

[12] Website of EU : http://europa.eu.int./comm/enterprise/chemicals/chempol/whitepaper/reach/htm

[13] Matthews, E.J. and Contrera, J.F. 1998. Reg. Toxicol Pharmacol, 28,242-264.

[14] Website of NTC : http://www.niehs.nih.gov/net/home/htm

[15] http://www.gradschool.com/listing/

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6

Trends in the Development of Heat Resisting Materials for High-efficiency Power Generation Gas Turbines

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1 Introduction

In the Kyoto Conference in 1997 (COP3: The 3rd Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change), Japan's goal for reducing greenhouse gas emission was set to 6% below the level of 1990, and it was written into the Protocol with the condition that the goal should be achieved between 2008 and 2012, and Japan ratified this Protocol in 2002. Thus, development of innovative technologies for the reduction of CO_2 emissions is strongly required from the viewpoint of the prevention of global warming.

While it is well known that the emission of CO_2 originating from the energy conversion sector including power stations can be greatly reduced by replacing thermal power plants with nuclear power plants, current situations do not permit the unfettered construction of nuclear power stations due to various accidents that have occurred recently. Under such circumstances, improvement of the efficiency of thermal power generation, which accounts for a great part of total electric power generation, is desired as a practical means to reduce CO_2 emissions.

It is known that the efficiency of heat engines such as gas turbines and jet engines is effectively improved by raising the temperature of the high temperature side of Carnot's cycle[*1], and, in order to raise the temperature, high-performance heat-resisting materials must be used.

The Council for Science and Technology Policy identified "Advanced materials for environmental preservation and energy utilization" as a priority subject in the fields of nanotechnology and materials, and the performance goal was set to the "Creation and practical application of materials required for the total reduction of CO_2 emissions to achieve the COP3 target." As an example of the technical target, "Development of metallic materials with improved high temperature strength and corrosion resistance that realize the reduction of CO_2 emission per unit thermal power generation by 30%" was cited. Specifically, it is required to develop superheat-resistant metals and turbine system technology that enable the increase of the turbine inlet temperature from the current 1,500°C to 1,700°C.

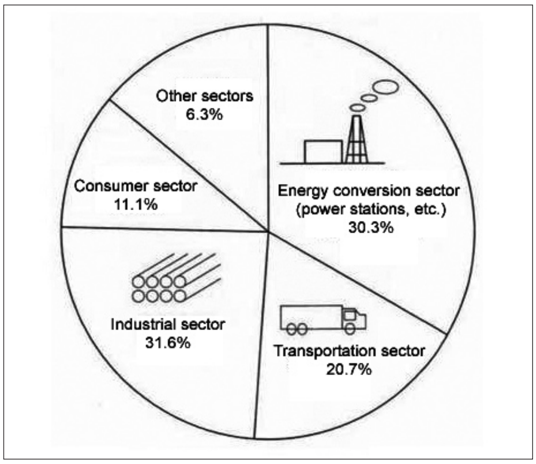
This report reviews the present status of the development of superheat-resistant metals that are indispensable for the realization of ultra-high temperature gas turbines and forecasts future trends in the technology.

2 Development of heat resisting materials as a measure to reduce CO_2 emissions

The necessity for developing measures against global environmental issues including global warming gave a strong impact on the circumstances surrounding heat resisting materials. The breakdown of the total CO_2 emissions in Japan by sectors, which is shown in Figure 1, indicates that the energy conversion sector including power stations accounts for the largest part of about 30%. In respect to power generation, thermal power generation that provides 55% of the total electric power supply is responsible for almost all of the CO_2 deriving from power generation as shown in Figure 2. Under such circumstances, various attempts to improve the operation of thermal power plants that play a central role in the electric power generation are being made. Such attempts include the improvement of generation efficiency by increasing the temperature and pressure, especially by using extra-supercritical pressure, use of natural gas that contains less carbon, and adoption of combined cycle power generation (as described later).

The present average thermal efficiency of thermal power generation using coal and petroleum is about 40% (HHVbasis*2). This means that more than half of the fossil fuels that have been burnt in large quantities are not effectively utilized, emitting a large amount of CO_2 into the atmosphere. Recently, LNG burning power generation that uses liquefied natural gas (LNG) and generates less CO_2 per unit heat quantity has been attracting attention. In particular, LNG combined cycle power generation, in which additional power is generated by driving steam turbines utilizing the steam produced by the waste heat from the gas turbine power generation, provides high thermal efficiency and emits the least amount of CO_2 among the various types of thermal power generation plants. As shown in Figure 3, about 47% of CO_2 per unit electricity generated (kWh) can be reduced by replacing coal-fired power plants with LNG combined cycle power generation plants. Since it is impossible to supply a large quantity of the required energy only with natural energy such as sunlight and wind power, LNG burning combined cycle power generation is now considered to be the last-resort measure to reduce CO_2 emissions in the power generation sector.

Figure 1 : Breakdown of the total CO_2 emissions in Japan[1]



The amount of CO_2 generated by a coal-fired power plant of the 1.2 million kW class accounts for 0.7% of the total emissions in Japan. If this plant is replaced with an ultra-high-efficiency LNG combined cycle power generation plant (gas temperature at the inlet of the turbine is 1,700°C and the thermal efficiency is 60%), the ratio of generated CO_2 is expected to be reduced to as low as 0.3%. The number of domestic major coal-fired power plants (with a capacity of 900,000 kW or more) is 12 and the total output is 17,135,000 kW [5] (as of the end of March 2001). This accounts for about 10% of the total CO_2 emissions in Japan. It should be noted that the introduction of ultra-high-efficiency power plants contributes greatly to the reduction of CO_2 emissions.

Generators of 1,100°C class (gas temperature at the turbine outlet) using the combined cycle were commercialized first. Since the latter half of the 1990s, ACC (Advanced Combined

Figure 2 : Share in electric power supply (left)[2] and CO_2 emissions by power generation methods (right)[3] in Japan

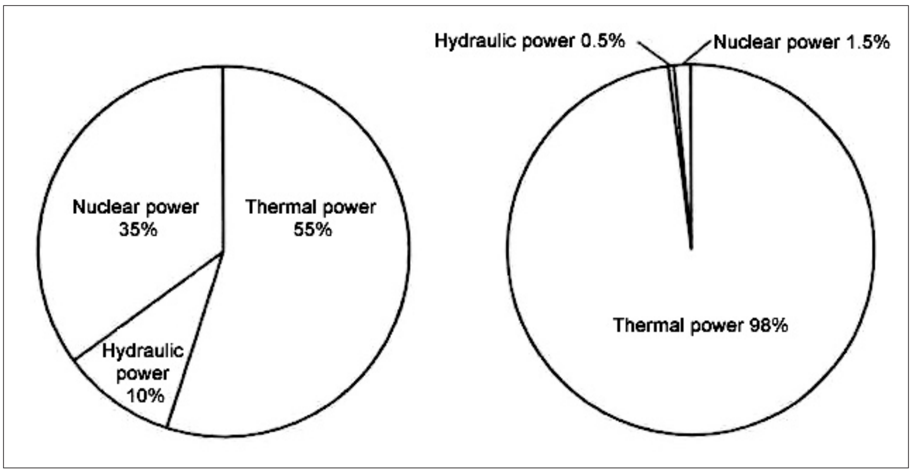
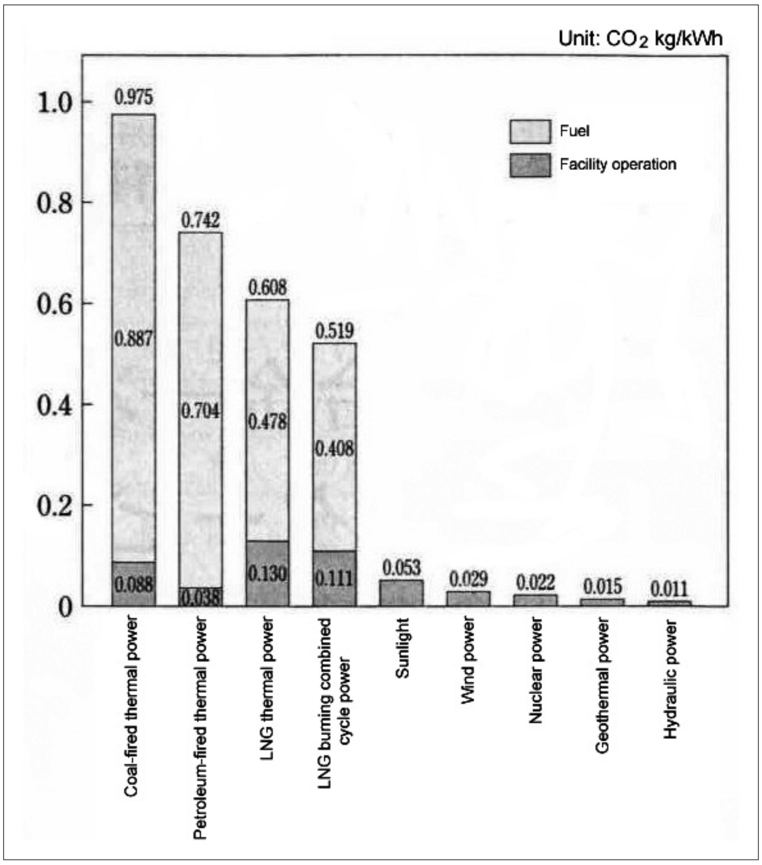


Figure 3 : Comparison of specific CO_2 emission by power sources in Japan[1]



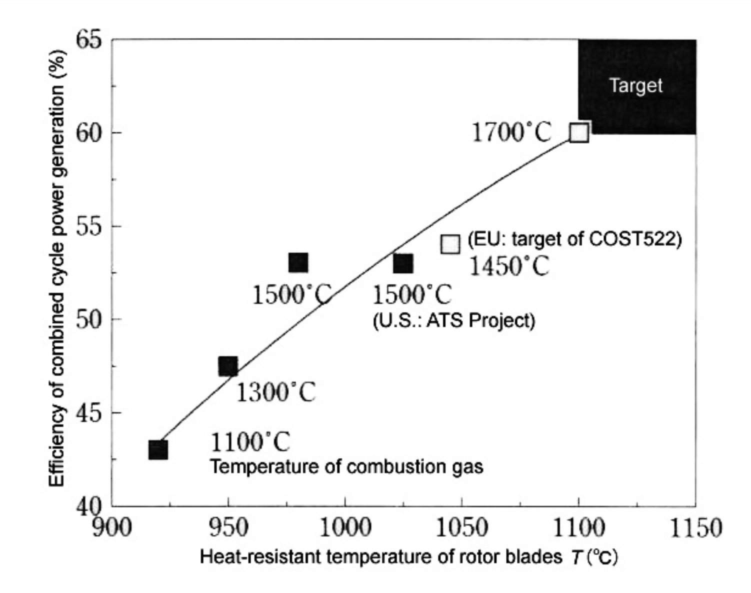
Cycle) generators of 1,300°C class with high thermal efficiency, environmental friendliness, and mobility have become the mainstream of LNG burning power generators. Furthermore, combined cycle power generators of 1,450°C to 1,500°C class, which provide a thermal efficiency of 52% to 54% (HHV basis), have entered the commercialization stage[6, 7].

In the course of the development of these most-advanced gas turbine generators, the heat-resistant temperatures of heat resisting metals including nickel-base superalloys have been improved by utilizing advanced techniques such as unidirectional solidification and single crystal solidification, which means that the development of materials has played an important role. Furthermore, together with the development of heat resisting metals, the cooling technology for turbine blades and ceramic coating material for the heat shielding of the outer surface have been developed.

Figure 4 shows the relationship between the heat-resistant temperature of heat resisting materials and the thermal efficiency of combined cycle generators for commercialized alloys and the target values of projects being carried out by various countries[4]. While the heat efficiency of popular LNG combined cycle generators with inlet gas temperatures between 1,100°C and 1,300°C is in the range between about 43% and 49%, that of 50% or higher has been achieved for generators of the 1,500°C class. It is estimated that a heat efficiency of as high as 60% can be attained when the turbine inlet gas temperature is raised up to 1,700°C. To realize the ultra-high-efficiency gas turbines as a practical solution for the reduction of CO_2 emissions, it is strongly required to develop new superheat-resistant materials for turbine rotor blades and stator vanes.

Referring to Figure 4, in the ATS project of the United States sponsored by DOE, which is a project aiming to develop an advanced turbine system (ATS), a gas turbine of the 1,500°C class has been already developed and commercialized with GE as the main developer. In Europe, the COST522 Project, which started in 1998, is progressing with a target to develop a turbine of the 1,450°C class. In Japan, it is being planned to develop a technology to realize 1,700°C for the inlet gas temperature in order to develop

Figure 4 : Relationship between the efficiency of combined cycle power generation and the heat-resistant temperature of materials used for air-cooled turbine rotor blades[4]



The value indicated as "Target" in the upper right corner of the chart is the target of development for the project being planned by the Ministry of Education, Culture, Sports, Science and Technology, the Ministry of Economy, Trade and Industry, and the National Institute for Material Science, etc.

high-efficiency gas turbines for the electric industry.

The development of heat resisting materials in the United States and Europe is being promoted aiming at the development of jet engines, which is a strategic technology[8, 9], through the cooperation among industry, academia, and government. Contrastingly in Japan, the background is quite different since heat resisting materials are being developed mainly for the development of gas turbines for nonmilitary applications.

In the 21st century, where energy and environmental problems are becoming still more serious, we believe that the strategic importance of heat resisting materials will increase not only from the viewpoint of aeronautical technology but also from the viewpoint of effective utilization of energy.

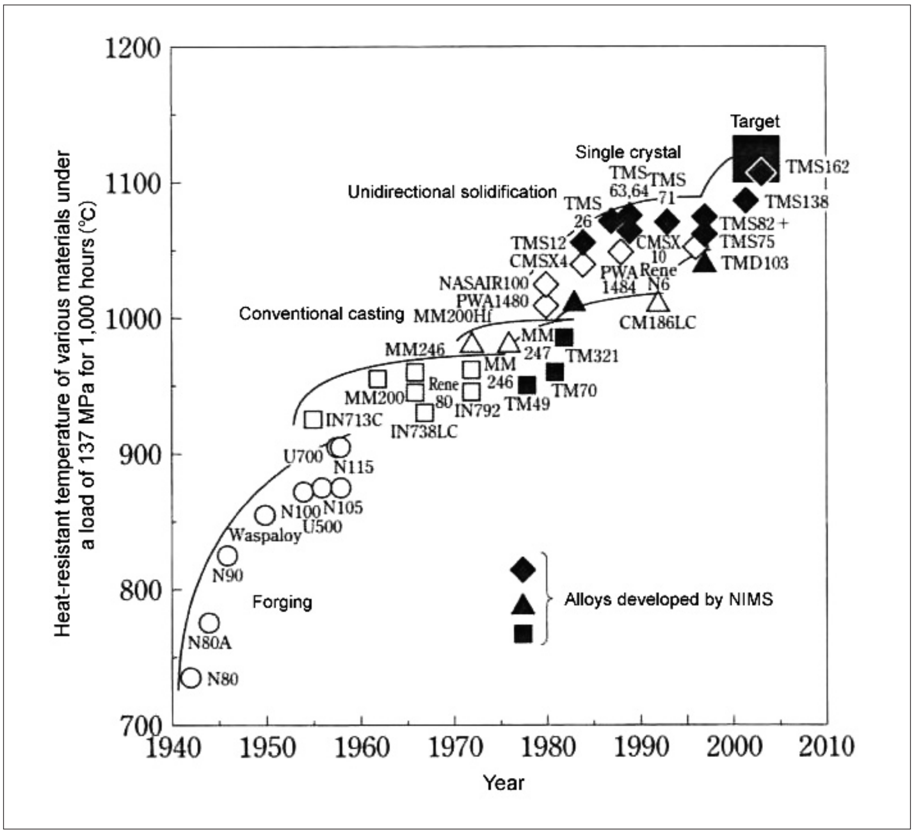
3 History of the development of nickel-base superalloys

The basic properties required for heat resisting materials are strength at elevated temperatures, oxidation resistance, and corrosion resistance. While there are nickel-base, iron-base, cobalt-base, and other alloys for superheat-resistant alloys (superalloys), nickel-base superalloys are being used mainly for the high temperature parts, particularly for combustors and high-pressure turbines that play an important role in improving the output and efficiency of gas turbines for industrial applications and jet engines. Figure 5 illustrates the history of the increase in heat-resistant temperature of nickel-base superalloys[10]. The ordinate axis indicates heat-resistant temperature expressed as the temperature at which creep rupture*3 occurs after 1,000 hours when a stress of 137 MPa is applied. In the gas turbine, there is a temperature difference of several hundred degrees centigrade between the high temperature gas and the heat resisting material, and if the heat-resistant temperature of the heat resisting material is increased, gas temperature of the turbine inlet can be raised correspondingly.

In the "New Millennium Heat Resisting Material Project," which started in fiscal year 1999, an aim is to realize an ultra-high-efficiency gas turbine of the 1,700°C class by increasing the heat-resistant temperature of the material by 100°C, thus allowing the gas temperature to be raised by 200°C.

Nickel-base superalloy products have come through a process of development beginning with forged alloys through ordinary castings and

Figure 5 : History of improvement in the heat-resistant temperature of nickel-base superalloys[10]

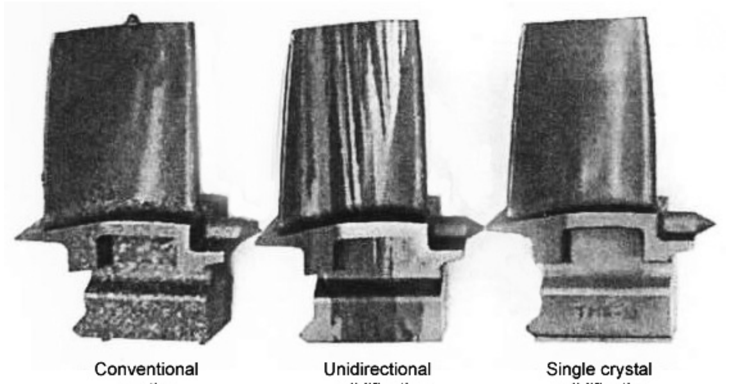


Heat-resistant temperatures are those at which creep rupture life is 1,000 hours under a load of 137 MPa.
○ :Forged (wrought) alloys, □ : Conventional castings (CC) alloys, △ :Directionally solidified (DS) alloys, ◇ : Single crystal (SC) alloys. Black marks indicate alloys that were developed by the National Institute for Material Science (former National Research Institute for Materials).
"Target" shown in the chart indicates the target of development for the New Millennium Heat Resisting Materials Project.

directionally solidified alloys, and finally to single crystal alloys. In the 1940s, forged (wrought) alloys such as N80 were developed and applied to rotor and stator blades of turbines. However, as the materials were strengthened by precipitation strengthening and other techniques, it became increasingly difficult to fabricate by forging. In the middle of 1950s, the vacuum melting technology was developed and precision casting of conventionally cast (CC) products of alloys containing large amounts of active elements such as aluminum and titanium was made possible using cores*4. This further promoted the development of precipitation strengthening and solid-solution strengthening. However, the problem was that the alloys obtained by such process had a structure containing a large number of crystal grains and the grain boundaries caused the start of fractures. In the case of turbine rotor blades, in particular, cracks were caused along the grain boundaries after a long period of use due to the centrifugal force resulting from the high-speed rotation of blades at high temperature.

To solve this problem, attempts were made to eliminate grain boundaries perpendicular to the longitudinal direction, in which fatigue and creep rupture were apt to occur, from turbine rotor blades using directionally solidified alloys and single crystal alloys that were prepared by controlling the crystal structures. Around 1970, application of the directionally solidified (DS) process was started, and the creep strength, ductility, and fatigue properties in the longitudinal direction of turbine rotor blades were significantly improved by arranging the direction of grain boundaries approximately parallel to the centrifugal force generated in the longitudinal direction. Furthermore, single crystal (SC) alloys were developed around 1980, in which all the grain boundaries were eliminated so that high temperature strength

Figure 6 : Turbine rotor blades fabricated by conventional casting, unidirectional solidification, and single crystal solidification[12]



was largely improved. Figure 6 illustrates turbine rotor blades produced by conventional casting, unidirectional solidification, and single crystal solidification processes. The preferred orientation of crystal growth obtained by the unidirectional solidification provides high creep strength and thermal fatigue resistance[11].

In addition, oxide-dispersion-strengthened (ODS) superalloys that have creep strength higher than that of single crystal superalloys have been developed[11, 12]. These alloys are produced by a series of processes–mechanical alloying → extrusion → unidirectional recrystallization. These alloys have excellent high temperature creep strength particularly at temperatures higher than 1,000°C, because fine particles of oxide such as yttrium oxide (Y_2O_3) that are stable when used at high temperatures for a long time are uniformly dispersed. Alloys of this type that can be forged or rolled into sheets are used for high temperature components such as combustors, but full-fledged application to turbine rotor blades has not been realized because the ductility is insufficient and it is difficult to fabricate air-cooled blades. A subject also to be pursued is to produce stable and uniform material and reduce the cost of manufacturing.

While the heat-resistant temperature of alloys was about 730°C immediately after development in the beginning of 1940s, those of present alloys have been raised to 1,100°C. The improvement of 350°C to 400°C in the heat-resistant temperature took almost 60 years, which is a typical example of the development of structural materials that requires a long period of time for the gradual progress in the improvement of properties.

Table 1 shows compositions of typical nickel-base superalloys for turbine blades[12]. All the alloys have complicated compositions containing approximately 10 component elements. The alloying elements are added to improve various characteristics including strength, corrosion resistance, oxidation resistance, casting characteristics, and heat treating characteristics. The alloys are classified into four groups according to their compositions: alloys of the first generation from the initial stage of development, alloys of the second generation that contain about 3 mass % of rhenium (Re), alloys of the third generation that contain 5 to 6 mass % of rhenium, and the newest alloys of the fourth generation that contain precious metals such as ruthenium (Ru).

It is particularly notable that all the alloys except for TMS developed by the former National Research Institute for Materials have been developed by private companies. PWA, Rene, and CMSX have been developed by U.S. manufacturers, MC by a French manufacturer, and MDSC by a Japanese manufacturer. Particularly in the United States and Europe, since the development of engines for the aerospace industry was prevalent, the governments supported the development of private companies, and, as a result of collaboration between government and industry, development was accelerated[9].

Table 1 : Compositions of typical nickel-base superalloys for turbine blades (mass %, Ni: remaining)[12]

Type	Name of alloy	Alloy composition														Remarks
		Co	Cr	Mo	W	Al	Ti	Nb	Ta	Hf	Re	C	B	Zr	Others	
CC	IN738	8.5	16	1.7	2.6	3.4	3.4	–	1.7	–	–	0.17	0.01	0.1	–	–
	IN792	9	12.4	1.9	3.8	3.1	4.5	–	3.9	–	–	0.12	0.02	0.2	–	
	Rene' 80	9.5	14	4	4	3	5	–	-	–	–	0.17	0.015	0.03	–	
	MarM247	10	8.5	0.7	10	5.6	1	–	3	–	–	0.16	0.015	0.04	–	
	TM-321	8.2	8.1	–	12.6	5	0.8	–	4.7	–	–	0.11	0.01	0.05	–	
DS	GTD111	9.5	14	1.5	3.8	3	4.9	–	2.8	–	–	0.1	0.01	–	–	1st
	CM247LC	9	8	0.5	10	5.6	0.7	–	3.2	1.4	–	0.07	0.015	0.01	–	1st
	TMD-5	9.5	5.8	1.9	13.7	4.6	0.9	–	3.3	1.4	–	0.07	0.015	0.015	–	1st
	PWA1426	12.0	6.5	1.7	6.5	6	–	–	4	1.5	3	0.1	0.015	0.03	–	2nd
	CM186LC	9	6	0.5	8.4	5.7	0.7	–	3.4	–	3	0.07	0.015	0.005	–	2nd
	TMD-103	12	3	2	6	6	–	–	6	0.1	5	0.07	0.015	–	–	3rd
SC	PWA1480	5	10	–	4	5	1.5	–	12	–	–	–	–	–	–	1st
	Rene' N4	8	9	2	6	3.7	4.2	0.5	4	–	–	–	–	–	–	1st
	CMSX-2	4.6	8	0.6	8	5.6	1	–	9	–	–	–	–	–	–	1st
	MC2	5	8	2	8	5	1.5	–	6	–	–	–	–	–	–	1st
	MDSC-7	4.5	10	0.7	6	5.4	2	–	5.4	–	0.1	–	–	–		1st
	TMS-26	8.2	5.6	1.9	10.9	5.1	–	–	7.7	–	–	–	–	–	-	2nd
	PWA1484	10	5	2	6	5.6	–	–	9	–	3	–	–	–	–	2nd
	Rene' N5	8	7	2	5	6.2	–	–	7	0.2	3	–	–	–	–	2nd
	CMSX-4	9	6.5	0.6	6	5.6	1	–	6.5	0.1	3	–	–	–	–	2nd
	TMS-82	7.8	5	3.4	8.7	5.2	0.5	–	4.4	0.1	2.4	–	–	–	–	2nd
	YH61	1	7.1	0.8	8.8	5.1	–	0.8	8.9	0.25	1.4	0.07	0.02	–	–	2nd
	Rene' N6	12.5	4.2	1.4	6	5.75	–	–	7.2	0.15	5.4	0.05	0.004	–	0.01Y	3rd
	CMSX-10	3	2	0.4	5	5.7	0.2	0.1	8	0.03	6	–	–	–	–	3rd
	TMS-75	12	3	2	6	6	–	–	6	0.1	5	–	–	–	–	3rd
ODS	MA6000	2	15	2	4	4.5	2.5	–	2	–	–	0.05	0.01	0.15	1.1Y203	–
	TMO-20	8.7	4.3	1.5	11.6	5.5	1.1	–	6	–	–	0.05	0.01	0.05	1.1Y203	–

In the Type column; CC: conventional casting, DS: directional solidification, SC: single crystal solidification, and ODS: oxide-dispersed-strengthening.
In the Remarks column, 1st, 2nd, and 3rd indicate the generations of alloy development.

4 Development of new materials expected to be commercialized in the future[12]

Attempts are being made to develop new materials far superior to nickel-base superalloys in heat-resistant temperature. So far, the materials that have been developed are not yet reliable enough to substitute nickel-base superalloys, but it is hoped that innovative heat resisting materials that are satisfactory for practical use will be developed in the future.

• **Ceramics**

Ceramics are expected to become heat resisting materials superior to metals. Particularly, silicon nitride ceramics are already being used for mechanical parts such as those for automobile engines. They are appreciated as reliable materials with corrosion resistance, strength, and toughness in the temperature range of 1,000°C or lower. However, they cannot be used for gas turbines because the strength decreases in the temperature range higher than 1,000°C. Recently, it has been reported that a material whose strength was maintained up to 1,500°C was developed by improving heat resistance through control of the composition of the grain boundary phase, which caused the decrease in strength at elevated temperatures. It is strongly hoped that the reliability of these materials at elevated temperatures will be improved by enhancing toughness and other properties.

• **Intermetallic compound alloys**

TiAl intermetallic compounds have a specific gravity that is about half the specific gravity of nickel-base alloys, the specific strength and specific creep strength comparable to those of nickel-base alloys, and higher specific rigidity than that of nickel-base alloys. Although intermetallic compounds are generally poor in ductility at ambient temperature, TiAl-base alloys are considerably ductile at ambient temperature having characteristics of high specific strength and lightness; so it seems that they are very close to practical use. Although cost effectiveness still remains a problem, it is intended in the "Research and Development of Environmentally Compatible Propulsion System for Next-generation Supersonic Transport (ESPR)" sponsored by the Ministry of Economy, Trade and Industry to use these intermetallic compounds for the blades of low-pressure turbines and stationary parts. Successful results including the combination of excellent creep strength and tensile ductility at ambient temperature have already been achieved through controlling the crystal orientation by unidirectional solidification as well as the metallographic structure. At present, studies to establish forming technologies that enable the fabrication of complicated shapes and improve strength at elevated temperature[11] are being carried out.

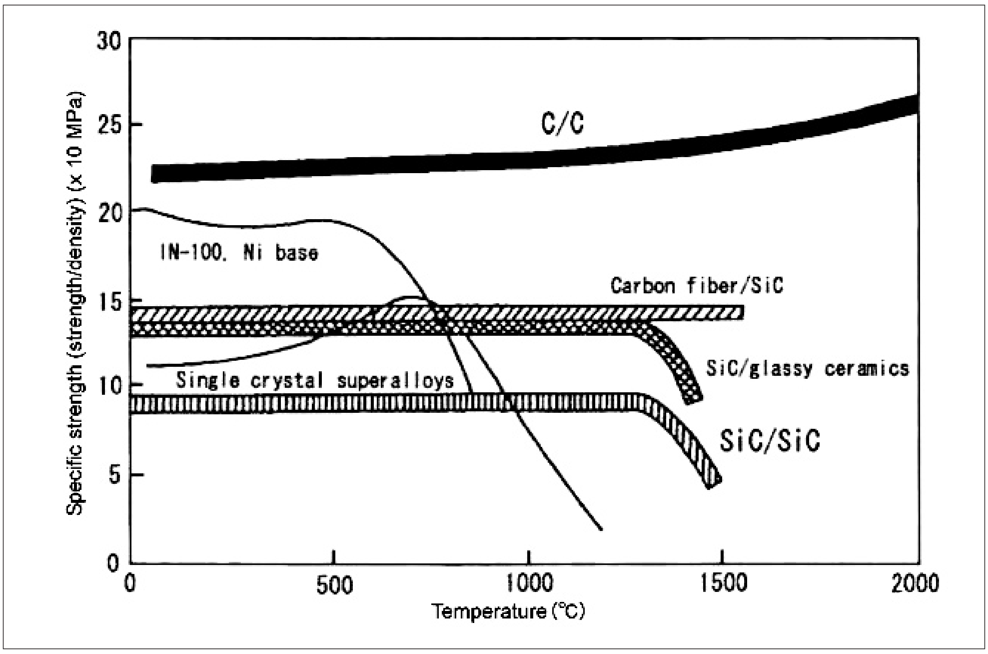
• **Refractory metals**

Refractory metals are expected to be used for uncooled blades. Among the refractory metals, niobium (Nb) has a specific gravity comparable to that of superalloys and excellent ductility in addition to the high melting point of 2,468°C. It has high temperature strength that enables its use at as high as about 1,500°C. The only problem for practical use is its poor oxidation resistance. However, it has been found that oxidation resistance is improved up to about 1,200°C by adding silicon to niobium, thus providing the complex structure of niobium solid solution and niobium silicide. This oxidation resistance is comparable to that of nickel-base superalloys. Niobium alloys are also being developed in the "Advanced Fabrication Technology for Refractory Metal Parts" project sponsored by the Ministry of Economy, Trade and Industry, and significant improvement in high temperature strength has been reported. However, the combination of oxidation resistance and strength has not yet been achieved.

Refractory superalloys using refractory metals other than niobium alloys have also been developed and have similar structures to those of nickel-base superalloys. Iridium alloys based on iridium, a platinum group metal having a melting point of 2,447°C, have a high melting point and very high elastic modulus at ambient temperature so that they have possibilities for heat resisting materials. In addition, these alloys have an improved oxidation resistance compared with conventional refractory metal alloys. However, they have not reached a practical level because other required characteristics such as specific gravity and cost are not yet satisfactory. Other platinum-family-base superalloys using rhodium and platinum have been developed[13]. Although these alloys have reached the level of practical use, the know-how obtained from the experience of these alloys is being utilized for the effective addition of alloying elements to nickel-base superalloys and the coating materials of nickel-base superalloys.

Conventional chromium alloys have a problem in that they are lacking in ductility, and strength decreases when attempts are made to improve ductility. However, they are now attracting attention once more because it has been reported that excellent ductility and workability at ambient temperature were obtained together with strength comparable to or better than conventional chromium alloys by applying an ultrahigh-purity melting process. It has also been reported that high temperature strength superior to nickel-base single crystal

Figure 7 : High temperature strength of various composite materials[14]



Both IN-100 and Single crystal superalloys are nickel-base superalloys.

superalloys was obtained in the temperature range exceeding 1,100°C by chromium-tungsten alloys or chromium-rhenium alloys prepared by a conventional melting process. Since chromium alloys suffer from embrittlement caused by the intrusion of nitrogen at high temperature, it is hoped that this problem will be solved in the future.

• Composite materials

It is hoped from the viewpoints of heat resistance and weight saving that composite materials such as metal matrix composites (MMC), ceramic matrix composites (CMC), and carbon carbon composites (C/C) will be developed.

Research on metal matrix composites (MMC) is being conducted from the viewpoints of weight saving and improvement in specific gravity, and materials based on aluminum, titanium, and intermetallic compounds have been developed. While research on the fabrication of parts using these materials is being conducted in the "Research and Development of Environmentally Compatible Propulsion System for Next-generation Supersonic Transport (ESPR)" project, it is also necessary for practical use to establish a database for designing as well as to reduce production cost.

Figure 7 shows the relationship between temperature and specific strength for SiC-base composites and carbon-base composites compared with the relationship for nickel-base superalloys. It is seen from the chart that these composite materials, in contrast to nickel-base superalloys, retain strength even in the high temperature range exceeding 1,000°C.

Ceramic matrix composites (CMC) consist of ceramics that have a specific gravity about one-third to a quarter that of nickel-base superalloys as well as a heat-resistant temperature exceeding 1,200°C, and reinforcing fiber such as SiC. They have fracture resistance far greater than that of conventional ceramics and they are expected to be used for combustor liners, stator vanes of high-pressure turbines, shrouds, etc., as ultra-light heat resisting material applicable to ultra-high temperature ranges. Since excellent SiC fiber materials are available in Japan, the technological level of Japan is high in this field. Although reduction of production cost is the most important issue for commercialization, development of process technologies including the structure control of the interface between the fiber and matrix and coating for the improvement of environmental resistance is also required.

Carbon carbon composite (C/C) is considered to be a promising light-weight, heat resisting material because it retains strength up to the ultra-high temperature of 2,000°C, However, oxidation resistance in high temperature gas atmosphere is an obstacle to commercialization, and it is an important issue to increase reliability in practical environments by developing such technologies as coating.

All of these composite materials are still in the stage of development and have not been put to practical use. There remain problems to be solved such as the fabrication of complicated shapes and environmental resistance in high temperature. In addition to the improvement in material characteristics, therefore, it is desired to establish process technologies and improve reliability.

• **Thermal barrier coating (TBC)**

As the operating conditions of gas turbines become severer due to the higher gas temperature, most of the parts made of nickel-base superalloys that are exposed to particularly high temperature such as the turbine blades and combustors are coated with coating materials from the viewpoints of corrosion resistance, oxidation resistance, thermal barrier, etc. Above all, the importance of thermal barrier coating is increasing as a result of increasing gas temperature. Yttria-stabilized zirconia is coated on the alloy surface by spray coating or electron-beam physical vapor deposition (EB-PVD), and at the same time the inside of rotor blades and stator vanes is cooled by forced cooling. By doing so, a large temperature gradient is created across the coating layer so that the rise of the temperature of the metal is suppressed. Materials that have a relatively large thermal expansion coefficient (close to that of metals) and small thermal conductivity are desirable for the oxides to be coated. Materials that do not deteriorate or exfoliate during a long period of use are being explored and developed.

Directionally solidified (DS) nickel-base superalloys, single crystal (SS) materials, thermal barrier coating (TBC) materials, etc., are now being used for the most-advanced turbines and are contributing, together with the development of the cooling technology, to the significant increase in gas temperature and generation efficiency. New materials including ceramics are also being used for some parts such as combustion chambers on a trial basis, but it has not yet been established which of these new materials will be used practically in the future. Under such circumstances, it is necessary to continue comprehensive research and development of new materials on a wide range, and, at the same time, it also seems necessary to conduct research on system design conforming to the characteristics of new materials with a perspective on full-scale application in the future. Therefore, development of material technologies must be carried out in cooperation with system designers taking structure stability and reliability in the long period of service under severe conditions into consideration.

5 Conclusion

In this report, trends in technical development of heat resisting materials have been reviewed from the viewpoint of measures for the reduction of CO_2 emissions. Heat resisting materials are key materials that significantly affect the heat efficiency of advanced heat engines such as gas turbines and jet engines, and their development is a very important cross-sectional subject that covers a wide range of fields including environment, energy, and materials from the viewpoint of saving energy and resources.

Originally, heat resisting materials started as strategic materials used for military applications such as jet engines, they were developed for military purposes in Europe and the United States, whereas the background is completely different in Japan because these materials have been developed for use in the civilian sector. In Japan, the former National Research Institute for Materials (present National Institute for Material Science) led the research and development of heat resisting materials. Globally, however, private companies have played important roles in the research and development of high-efficiency gas turbines and superheat-resistant materials. In Europe and the United States, the governments have helped private companies to develop heat resisting materials in line with the national policy relating to the development of jet engines. In this sense, it may be said that governments played a significant role in the development of heat resisting materials in all the countries of Japan, Europe and the United States.

Today, heat resisting materials have become strategically important from the viewpoint of advanced utilization of energy. In order to dispel environmental problems on a global basis, Japan must enhance international competitiveness in the world market of heat resisting materials and gas turbines through the strengthening of technology. Currently, the heat-resistant temperature of Japanese turbines is at the highest level in the world, and it is expected that Japan will take the leadership in the development and commercialization of next-generation gas turbine systems by developing heat resisting materials that have still higher heat-resistant temperatures.

As a challenge to global environmental conservation, the Japanese government should promote research and development and help with the commercialization and industrialization of the results. However, the past history of the development of superalloys has proved that development of materials takes time. Although nickel-base superalloys are expected to be used for the next-generation gas turbines, it is possible that ceramics and refractory metals that have higher heat-resistant temperatures will be put into practical use thereafter. Therefore, it is necessary to promote the development of these materials in parallel, and, in addition, continuous government aid based on a long-term perspective is required for the lasting development of technologies.

The methodology and time schedule for achieving the target of the CO_2 reduction were proposed in the roadmap for the heat resisting material strategy prepared by the Materials Strategy Committee of The Japan Institute of Metals. In this roadmap, the necessity of developing high-efficiency turbines and superheat-resistant materials was pointed out. In order to put newly developed technologies to practical use, it is necessary to promote the development with close cooperation between the system sector and material sector. This means that industry, academia, and government must further collaborate in order to establish concrete plans for development. In this sense, planning to start from fiscal year 2004, the "Development of elemental technologies for commercialization of high-efficiency gas turbines" project sponsored by the Ministry of Economy, Trade and Industry and the "Development of commercial superheat-resistant materials" project should collaborate, keeping close relationship between the system sector and material sector so that ultra-high-efficiency thermal power generation technology is developed through collaboration among industry, academia, and government.

Today, when the collaboration among industry, academia, and government is advocated, what is expected of the government is to provide an environment that efficiently enables cooperation and appropriate division of roles in research and development through the establishment of a framework for interdisciplinary technical exchanges making use of academic societies and industrial associations as well as coordination of such exchanges. It is also necessary to establish technical bases such as the construction of databases relating to the material characterization technology and elemental technologies for system design.

As the severe economic situation continues, to enhance and maintain international competitiveness of manufacturing industries, which are expected to lead economic revitalization, it is required to continuously promote the development of materials that serve for the minimization of burdens on the environment. Therefore, a subject for investigation is how to provide private companies with incentives including preferential taxation that would activate research and development and practical applications of materials and manufacturing technologies effective for saving energy and resources.

Acknowledgement

This report has been compiled based on the lecture "Strategy for the commercialization of superheat-resistant materials and ripple effects on the energy industry-from jet aircraft to power engineering" given by Mr. Hiroshi Harada, director of the High Temperature Materials Group, National Institute for Material Science, on September 11, 2003, with the added results of investigation made by the Science and Technology Foresight Center. The author would like to sincerely thank Mr. Harada for his advice and provision of material relating to this report.

Notes

*1 A heat engine that makes a gas undergo isothermal expansion, adiabatic expansion, isothermal compression, and adiabatic compression. Its efficiency η is given by $\eta = 1 - T_L/T_H$, where T_L and T_H are absolute temperatures of the low temperature heat source and high temperature heat source, respectively.

*2 Higher heating value basis. This indicates a condition for expressing the energy (heating value) of a fuel. The higher heating value (HHV) includes the heat of condensation (latent heat of vaporization) of the steam deriving from the water contained in the fuel and generated by combustion, whereas the lower heating value (LHV) dose not include the latent heat of vaporization. Therefore, values of generation efficiency expressed on the higher heating value bases are lower than those expressed on the lower heating value basis.

*3 A phenomenon in which the material does not break instantaneously but deforms gradually over a long period of time, finally resulting in rupture when a certain constant stress is applied while the specimen is kept at a high temperature. This is the most important property for structural materials used for equipment such as gas turbines, jet engines, and boilers that is used for a long period at high temperatures.

*4 A mold that is inserted into the cavity of the main mold when a casting with a hollow is made.

References

[1] The Federation of Electric Power Companies of Japan website: http://www.fepc.or.jp/menu/kankyo/kankyo1.html

[2] Agency of Natural Resources and Energy website: http://www.enecho.meti.go.jp/energy/japan/japan02.htm

[3] A. Nitta, Memorial Issue for the 40th anniversary of The 123rd Committee on Heat Resisting Metals and Alloys, Japan Society for the Promotion of Science (November 1999), p. 157.

[4] H. Harada and T. Yokokawa, “Superalloys for the Next Generation Jet Engine and Advanced Gas Turbine Applications,” Materia Japan, 42 (2003), 621 (in Japanese).

[5] The Federation of Electric Power Companies of Japan website: http://www.fepc.or.jp/menu/hatsuden/hatsuden6.html

[6] T. Sakurai, “Contribution of Materials to the Increase in Efficiency and Durability of Electric Power Equipment,” Materia Japan, 41 (2002), 74 (in Japanese).

[7] T. Noda, “Heat Resistant materials Used for Automobiles and Turbines of Power Generators,” Materia Japan, 42 (2003), 271. (in Japanese)

[8] J. C. Zhao and J. H. Westbrook, MRS BULLETIN, 28 (2003), 622.

[9] T. Maema, “Why Japan Cannot Make Passenger Aircraft?”, Soshisha (2002) (in Japanese).

[10] H. Harada, Gas Turbine Society of Japan, 28, No. 4 (2000), 278 (in Japanese).

[11] “Advancing Jet Engines,” Ferrum, 8 (2003), 705 (in Japanese).

[12] H. Harada and T. Yokokawa, “Progress and Perspective of Heat Resisting Materials for Gas Turbines,” Descriptions of the history of gas turbines in Japan, Gas Turbine Society of Japan (2002), 147 (in Japanese).

[13] L. A. Cornish, B. Fischer, and R. Völkl, MRS BULLETIN, 28 (2003), 632.

[14] Y. Kagawa, New Materials, Vol. 2 (1991), No. 3, p. 48 (in Japanese).

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7

Notable Points of the US "21st Century Nanotechnology Research and Development Act"

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1 Introduction

After the US Senate and House of Representatives had passed the bill entitled "21st Century Nanotechnology Research and Development Act" (S.189; hereinafter, "NRDA") at the 108th Congress, the bill became an official legislation on December 3, 2003 when President Bush appended his signature. War with Iraq has delayed congressional debates on the NRDA bill, and, due to this, NRDA mirrors current public awareness and clearly stipulates the attitude to integrate research on societal, ethical, and environmental concerns with nanotechnology R&D activities as much as possible.

The United States is the first nation to enact a law regarding how to proceed with nanotechnology R&D activities. In this sense, NRDA will have impacts on the future directions in other nations as well. This article explains the notable points of NRDA and outlines NRDA in the attached Exhibit.

2 Notable points of "21st Century Nanotechnology Research and Development Act"[1]

2-1 Background information on NRDA

Lawmakers submitted the NRDA bill to the 107th US Congress in 2002, but they failed to enact it during the session. Following this, the new bill was submitted to the 108th US Congress again in 2003. (The US Congress treats a resubmitted bill as a new bill in the following year.)

Since Congress has significant influence over the budget amount for science and technology public administration affairs in the U.S., NRDA proposers originally aimed at securing stable long-term budget funds for nanotechnology R&D and at accelerating the reorganization of the currently rigid science and technology research framework. Although the US government has steadily increased federal budgets for nanotechnology R&D activities since President Clinton's directive in 2000, the interagency coordinator NNI (National Nanotechnology Initiative)[2] has held a relatively weak status and unstable budget fund, which has been dependent on the fiscal position of the overall federal government. NRDA has successfully secured R&D budgets and program frameworks at least leading up to 2008, and has also enabled relatively long-term nanotechnology R&D activities.

During one year and a half long congressional debates, the United States changed its viewpoints on nanotechnologies. As nanotechnology seemed to have much fewer ethical concerns than bioscience, the NRDA bill would have gone through Congress quite easily. However, while countermeasures for anthrax and other bioterror attacks, the SARS outbreak and war with Iraq delayed the debates on the NDRA bill, US lawmakers perceived that uncontrolled nanotechnology advancements would yield some risks. As a result, they dramatically revised the NDRA bill to put emphasis on societal, ethical and environmental concerns.

As other reports provide detailed information on NDRA bill's congressional debates, please refer to these reports for more information[3].

2-2 Features in NDRA

Roughly speaking, NDRA specifically stipulates federal nanotechnology R&D efforts in

Section 2 (National Nanotechnology Program), establishes and defines the roles of the National Nanotechnology Coordination Office and the National Nanotechnology Advisory Panel in Sections 3 and 4, triennial external reviews in Section 5, and authorization of appropriations in Section 6. Except for the budget, the National Science and Technology Council is to prepare strategic plans within 12 months after the enactment of NDRA and update it every three years thereafter. NNI and other existing committees should play leading roles in establishing the Coordination Office and the Advisory Panel. The National Research Council of the National Academy of Sciences will be in charge of external reviews of the Program.

As a core component of NRDA, the National Nanotechnology Program (Section 2) has the following purposes under presidential responsibility: 1) setting up goals, priorities, and assessment criteria, 2) providing investments to achieve these goals, and 3) carrying out interagency coordination. As mentioned in Paragraph (b)(10)(c), the Program ultimately aims at “ensuring that advances in nanotechnology bring about improvements in the quality of life for all Americans.” From this perspective, the government will establish goals and priorities for the Program based on “national needs for a set of broad applications of nanotechnology” (Paragraph (c)(1)) as mentioned in the first sentence in the “Program Management” section of NRDA.

Getting down to specifics, NRDA stipulates the Program as encouraging fundamental understanding of matters that enable control and manipulation at nanoscale, accelerating deployment and application of nanotechnology R&D activities in the private sector including startup companies, and advancing the US productivity and industrial competitiveness. As one of its interesting features, NRDA will encourage nanotechnology education and training “so that a true interdisciplinary research culture can emerge,” in Paragraph (b)(9). Facility installation, stable fund infusion, various projects and partnership formation are all methods for creating such a “culture.” As another features, NRDA describes in detail considerations for ethical, legal, environmental and other societal concerns (Paragraph (b)(10)). It does not provide specific solutions for nanotechnology-based adverse impacts, but does describe the US decision-making process through expert research programs (probably led by the American Nanotechnology Preparedness Center as stipulated in Section 9) and ongoing public discussions, such as citizens’ panels, consensus conferences, and educational events. With these backgrounds, Americans have already started nationwide discussions on societal implications for nanotechnology. Of course, NRDA also aims at “ensuring United States global leadership in the development and application of nanotechnology” as mentioned in Paragraph (b)(5). However, unlike the common perception for Japanese people, NRDA does not give a strong impression that the US would countervail against excellent nanotechnologies in foreign nations (including Japan). Although US lawmakers might have intended to incorporate such propaganda into the NRDA bill to some extent in the year 2000, the current situation is totally different. NRDA also calls for identifying critical research areas where the United States should be the world leader in terms of comparison with other nations (Section 5, Paragraph (a)(12)).

As specific measures for the Program, NRDA sets some criteria for establishing “interdisciplinary nanotechnology research centers,” “networks,” and “interdisciplinary projects and collaborations.” When selecting these facilities, NRDA pays attention to past actual results and competitiveness, and to utilize existing methods and techniques. NRDA recommends utilization of existing micrometer-level research facilities and idle capacities rather than creating new facilities. The US government seems to have started evaluating some facilities based on their applications. For example, NNIN (National Nanotechnology Infrastructure Network)[4] corresponds to such a center/network. When the NNIN was invited, three university consortia subscribed, which were “self-assembled” to meet the requirements specified in NRDA. One of them, consisting of 13 universities such as Cornell University and Stanford University, has won the long-term stable

NNIN funding.

On the other hand, NRDA has only a few descriptions on specific research fields. The White House press release regarding NRDA[5] included examples of nanotechnology research themes that seemingly brought about some misunderstandings, but NRDA itself basically does not stipulate specific research themes (There are some program examples of departments and agencies in Sections 8 and 9). As exceptions, NRDA requires to make early decisions for following two themes in Section 5, where are strong expressions of "one-time study" that the National Research Council is supposed to make decisions as a part of the first triennial review (June 2005) and will not reverse the decisions thereafter.

One of such "one-time studies" is on molecular self-assembly. In this study, the technical feasibility will be reviewed in the view point of manufacturing materials and devices at the molecular scale. Although the molecular self-assembly had been recognized as one of the important nanotechnologies[6] , it has become a more urgent matter for the US researchers to have to prove its technical feasibility as soon as possible. While it is not certain why NRDA exemplifies only this technology in its text, the US lawmakers might regard it as a primary model case that has promising feasibility.

Another study is on the responsible development of nanotechnology. The National Research Council will assess the needs for standards, guidelines or strategies especially on the following six research targets: 1) self-replicating nanoscale machines or devices; 2) the release of such machines in natural environments; 3) encryption; 4) the development of defensive technologies; 5) the use of nanotechnology in the enhancement of human intelligence; and 6) the use of nanotechnology in developing artificial intelligence. In a sense, the US lawmakers recognize that these research programs would yield some risks that would also bring about some adverse impacts without proper control frameworks. Recent terrorism and infective disease outbreaks have forced US citizens to acknowledge risk awareness that some able researchers could turn SF horror movie stories into reality if they had such intention to do so.

When the House of Representatives passed the NRDA bill in May 2003, the bill stipulated a longer duration for the technical feasibility study on molecular self-assembly (for three years after the enactment of NRDA) and for the study on responsible nanotechnology development (for six years). However, the final text of NRDA specifies a shorter period (1.5 years) for these one-time studies.

In terms of authorization of appropriations (Section 6), NRDA authorizes the total $3.7 billion budget fund for nanotechnology programs for 2005 to 2008. The fund will gradually increase over a relatively long run. (Congress separately discusses the nanotechnology federal budgets leading up to FY 2004.) However, it should be noted that this authorization of appropriations does not include DOD (Department of Defense) and NIH (National Institutes of Health), which occupy large shares in the US science and technology federal budget (These two funding will also support nanotechnologies, but they will have their own separate programs; please see Section 2, Paragraph (c)(3)). In this sense, NRDA does not provide enough information on the correct amount of the entire nanotechnology federal budget; however, the overall US nanotechnology budget is estimated to be at least twice as much as $3.7 billion. During debates in the House of Representatives in May 2003, some congress members submitted an amended bill that defined specific allocation percentages in the budget for addressing societal implications, but Congress decided not to incorporate such specific percentages in the final text. In addition, the original NRDA bill also described the budget amounts for NIH, Department of Justice, Department of Agriculture, and Department of Transportation when it was submitted in January 2003, but Congress did not adopt them.

The last section (Section 10) defines the specific terminologies. "Nanotechnology" is defined as "the science and technology that will enable one to understand, measure, manipulate, and manufacture at the atomic, molecular, and supramolecular levels, aimed at creating materials, devices, and systems with fundamentally new molecular organization, properties, and functions." This definition is almost the same as the common understanding of nanotechnology here in Japan. In addition, the "Program" covers all projects and activities mentioned in Section 2, which is a vague expression in order to encompass a broad spectrum.

NRDA will be effective at least until 2008. In particular, as shown in Section 4, Paragraph (f), only the Advisory Panel is exempted from the Sunset law (which means automatic abolishment of rules and regulations after a certain duration). From this viewpoint, the Advisory Panel would play a key role after 2008. The National Science and Technology Council will be in charge of overseeing interagency coordination with DOD and NIH that have their own separate programs as described in Section 2, Paragraph (c)(3). (While DOD has the Defense Nanotechnology Research and Development Program, NIH also has the Nanomedicine Centers establishment program). Since their budgets will also play important roles in advancing nanotechnologies, it is necessary to pay attention to how well the Council will function as an interagency coordinator.

By and large, NRDA calls for some important strategic planning and decision-making to be completed in 2005 at the latest. In this sense, US nanotechnology advancement will surely see its turning point in the coming one to two years.

Translation into Japanese

The National Institute of Science and Technology Policy worked with the Nanotechnology Researchers Network Center of Japan for the translation of the NRDA text into Japanese, and posted it on the Center's website[1] for Japanese reader.

Acknowledgement

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References

[1] Nanonet: http://www.nanonet.go.jp/japanese/info/overseas/index.html (in Japanese)
[2] NNI: http://www.nano.gov/
[3] NEDO Overseas Reports, No. 907 (May 19, 2003) and No. 923 (January 14, 2004) (in Japanese)
[4] NNIN: http://www.nnin.org/
[5] The White House: http://whitehouse.gov/news/releases/2003/12/20031203-7.html
[6] Science & Technology Trends, December 2003, topics on nanotechnology and materials (in Japanese)

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8

Using of Power Electronics for the Development of Energy Infrastructures

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1 Introduction

The environment that surrounds electrical energy is reaching a turning point due to the growth of power demand mainly in the civilian sector, promotion of electrification, and the increase in electrical demand in developing countries involving in China.

Power electronics is a basic technology for energy infrastructures that contributes to the efficient utilization of electrical energy. A familiar example is the inverter control that provides smooth control of the output of electrical equipment such as air conditioner and motor enabling the reduction of power consumption, which is consequential technology for solving energy and environmental problems not only in Japan but also on the global scale.

It has been reported[1] that if ultra-low-loss power electronics devices currently being developed become widely used, which is estimated that electrical power totaling 29.78 TWh ($T=10^{12}$) will be saved in the fields including fuel cell vehicles and inverters for dispersion type power sources in Japan at 2020. This saving energy efficiency is equal equivalent of the annual power generation by four million kW class nuclear power plants.

The "Strategy for the Development of the Energy Sector (September 2001)" at Council for Science and Technology Policy announced that aims at practical applications of new materials such as ultra-low-loss power device (power semiconductor devices) etc is key research field for the promotion of energy infrastructures.

The industry has taken a major role in the construction of energy infrastructures using power electronics in Japan. However, it is currently difficult for a single business enterprise to actively work on such technical development because of the costs required under the flagging economy. Universities also have problems in this field especially for the personnel training education. On the other hand, the United States and European countries have realized the importance of this area and are actively conducting research activities by establishing research centers in collaboration between the industry and academia.

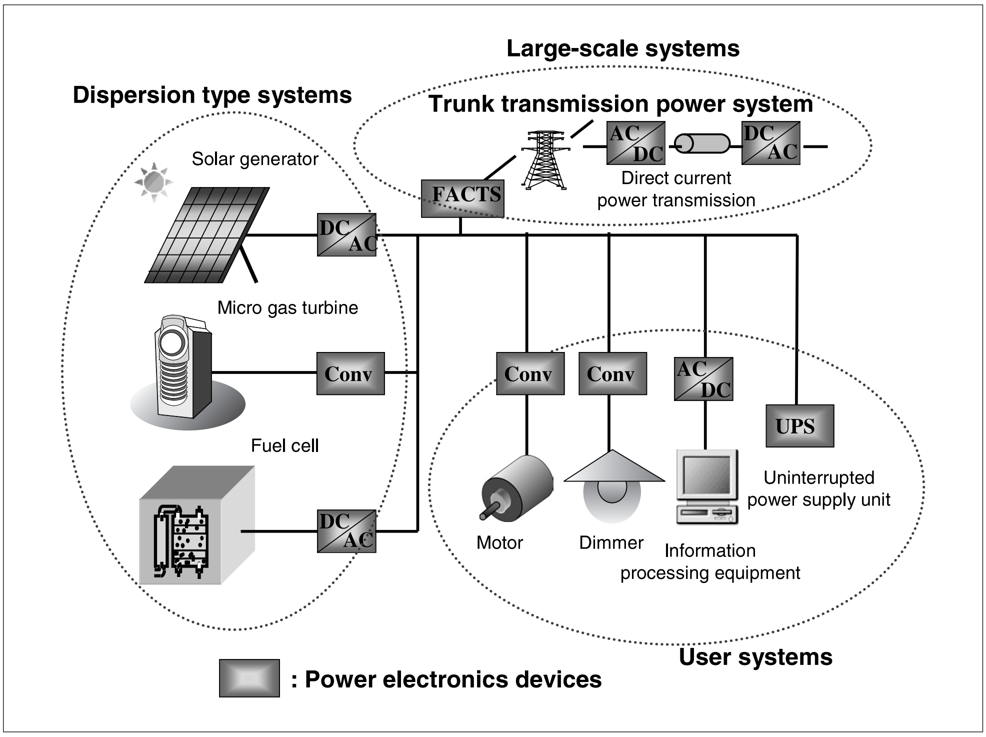
Based on such circumstances, this report will review that should be taken in order to maintain and develop the power electronics technology in Japan.

2 What is power electronics?

"Electrification ratio," which is the ratio that the primary energy such as petroleum and coal is used for electricity as secondary energy after conversion, is increasing year by year, and recently it has become higher than 40% in Japan[2]. As the informatization and aging of society progress, it is expected that the electrification ratio will become still higher due to the convenience and safeness of electricity.

Power electronics is a technology that converts the form of electricity from alternating current to direct current or from direct current to alternating current, or changes the frequency making use of power semiconductor devices. The IEC (International Electrotechnical Commission) defined power electronics as the "technical field related to electric power conversion and switching in which technologies of electrical power engineering, electronics, and control

Figure 1 : Interfaces between electrical power systems and power electronics devices



FACTS: Flexible AC Transmission Systems
C o n v: Converter; usually AC-DC-AC power conversion equipment.
Source: Authors' compilation based on data provided by the Power Electronics Research Center of the National Institute of Advanced Industrial Science and Technology.

engineering are comprehensively integrated". The targets of power electronics are the conversion and handling of electrical energy, whereas those of electronics are the conversion of electrical signals and information processing.

As the use of dispersion type power sources such as fuel cells with direct current output and information devices using direct current expands in the future, more and more electrical power systems and power electronics devices will be used to form interfaces in various fields as shown in Figure 1. It is expected that power electronics, which utilizes power semiconductor devices for the conversion and control of electricity, will be key technology and an important role in the promotion of efficient utilization of electric energy, which is expected to increase by the electrification ratio increases.

In Japan, elemental technologies for new power semiconductor devices used for electrical power systems and fuel cell electric vehicles have been developed aiming at ultra-low-loss, downsizing, and weight saving. Investigation on the Commercialization of the Next-generation of power semiconductor Devices Committee for the Development of Ultra-low-loss Power Device Technology Project (1998 to 2002) expected that ultra-low-loss power devices including silicon carbide (SiC) and gallium nitride (GaN) would be applied to automobiles, motor control inverters, CPU power sources[*1], UPS (uninterrupted power supply), inverters for dispersion type power sources and transmission elements of communication base stations, and estimated the effects on energy saving and reduction of CO_2 emissions in Japan at 2020 (see Table 1). The annual reduction of CO_2 emissions of 10.93 million tons corresponds to 0.98% of the total CO_2 emissions of 1,119 million tons in Japan at 1990. This fact indicates that the introduction of ultra-low-loss power devices will be able to an important role as a measure against global warming as well as contributing much to energy saving.

3 Applied technologies of power electronics

As shown in Table 2, power electronics is applied to large-scale and dispersion type electrical power systems, and further to traffic and transportation systems, household electric

Table 1 : Examples of the estimation of effects brought about by the introduction of new devices (SiC, GaN) in 2020

Application	Quantity (2020)	Energy saving (TWh/y)	Reduction of CO_2 emissions: (10 thousand tons CO_2/y)
EV/FCEV	5 million vehicles	6.25	229
Motor control	41 million units	9.96	366
CPU power source	65 million units	2.73	100
UPS	23 million units	4.71	173
Dispersion type power source	20.02 million kW	3.83	141
Communication base station (GaN)	500 thousand units	2.3	84
Total		29.78	1,093

(Unit CO_2 emission: 0.367 kg-CO_2/kWh)

* An example of the calculation for EV/FCEV (electric vehicle/fuel cell electric vehicle):
Assuming that the average output is 50 kW, the annual running time is 500 hours, and the devices are introduced into 5 million vehicles (2020: by the Fuel Cell Commercialization Study Group). If the inverter loss is improved by 5% (Si: 7% → SiC: 2%), the amount of energy saving/reduction of CO_2 emissions=50 (kW)×500 (h/year)×0.05×5 (million vehicles) =6.25 (TWh/year)= 2.29 (million tons CO_2/year)

Table 2 : Major application fields of power electronics

Field		Current major application fields (Major technical needs in the future)	Expected new application fields
Electrical power system	Large-scale	- Direct current power transmission (low-loss, downsizing)	-Flexible AC Transmission Systems (FACTS)
	Dispersion type	- Inverters for dispersion type power sources (low-loss)	-Loop controller -Direct current power supply system
Traffic and transportation system (Transport sector)		- HEV (downsizing, weight saving) - Electric railroad system (downsizing, weight saving)	-EV / FCEV
Household and office appliances (Civilian sector)		- Electromagnetic range - Air conditioner - Refrigerator - Personal computer - Illumination	
Industrial equipment (Industrial sector)		- Elevator - FA equipment - Uninterrupted power supply unit	

appliances, office equipment, and industrial equipment. In this chapter, the current major application fields, future needs for technical development, and the application fields that will appear in the future relating to electrical power systems and traffic and transportation systems are described.

3.1 Application technologies of power electronics in electrical power systems

(1) Large-scale systems

In the Japanese trunk transmission power systems, in addition to the alternating current transmission systems, direct current transmission systems of "Hokkaido-Honshu" and "Honshu-Shikoku" as well as frequency conversion facilities between "50 Hz and 60 Hz" are provided. In these systems, many thyristor elements, which are power semiconductor devices, are utilized by being connected in a series according to the operating voltage. This results in the large size of equipment, thus requiring the realization of small-size low loss power electronics devices that use high-efficiency power semiconductor devices. In the United States, power transmission systems are so complicated so that a particular transmission system has limited operation therefore consequently, the Electric Power Research Institute (EPRI) has proposed the concept of FACTS (Flexible AC Transmission Systems) which is increasing of the transmission line utilization factor (power flow control) and stabilize the system. This concept involves electrical power control systems to improve the weak of alternating current transmission systems using power electronics, and, self-exciting SVC (static var compensator), UPFC (unified power flow controller), etc., have been developed mainly in the United States.

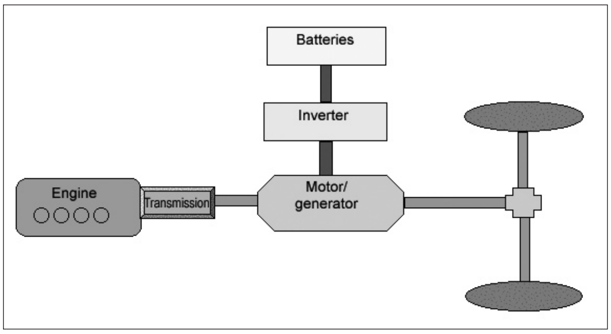
(2) Dispersion type systems

Recently, the number of new energy systems and cogeneration systems installed in the neighborhood of consumption areas (power distribution systems) is increasing. Since the dispersion type power sources such as solar generators and fuel cells generate direct current electricity, the generated electric power is supplied to electrical power systems after being converted to alternating current using inverters that are power electronics devices. It is estimated that the loss caused by inverters for dispersion type power sources is 6% for Si and 2% for new power semiconductor devices of SiC. As for new energy, it is expected by 2010 that 2.2 million kW will be generated by fuel cells, 4.82 million kW by solar generators, and 3 million kW by wind power generators[3]. Electrical power of 6.5 million kW is already being generated by cogeneration systems[4], and still more systems are expected to be built as the ESCO projects are promoted. Therefore, it is necessary to reduce the loss from power electronics devices which form the interfaces between these dispersion type electrical power sources and electrical power systems.

When a large number of dispersion type power sources are introduced, we must concern that the quality of electrical power is affected by the variation of output, making it necessary to develop measures to reduce the effects on the total system. Those researches enhanced the optimization of the system voltage and accidental current controlling using a device which called a loop controller, that consists of power semiconductor devices is being conducted with the Central Research Institute of the Electric Power Industry as the hub of research activities in Japan[5].

Although the electrical power systems in Japan are based on alternating current, with the increase of equipment and devices using direct current power sources such as routers and servers, and dispersion type power sources such as solar generators and fuel cells that provide direct current in principle, a practical idea is to construct power supply systems mainly of direct current within buildings (homes and offices) or consumption areas. DC/DC converters are indispensable for the conversion of direct current also a type of power electronics device.

Figure 2:An example of a hybrid electric vehicle (HEV)[6]



3.2 Application technologies for power electronics in traffic and transportation systems

Recently, the electric motors are attracted for the purpose of fuel saving, low noise, and low exhaust gas emissions as well as for the application of hybrid electric and fuel cell vehicles. Hybrid electric vehicles (HEV) which combined with gasoline and electric motor have already been developed and introduced into the market. Also the development of fuel cell electric vehicles is keen and leasing and has started competition. Furthermore, the development of electric vehicles (EV) had been suspended by most of the automobile manufacturers by 1990, then it has been restarted because of the increasing concerns over global environmental problems and the enforcement of ZEV (zero emission vehicle) regulations of the state of California in the United States[6]. Thus, while most of the present automobiles use gasoline as the energy source, future automobiles will use electric energy that is stored in batteries using inverters, which are power electronics devices, to drive the motor (see Figure 2).

In addition, recent automobiles are equipped with many complicated in-vehicle electric systems in order to provide safety, amenity, and convenience. As a result, the current 14V power supply system is reaching the limit of voltage source capacity, and it is now being investigated to raise the system voltage to 42 V. Power electronics is the key of the next-generation automobile power source systems which using 42 V*2.

In the electric railcar systems, power regenerative braking is widely used in order to return the braking energy to the overhead wire system. Power regenerative braking is a system in which the motor is used as a generator when the brake is operated to convert the kinetic energy of the railcar to electric energy and to return the generated electric energy to the overhead wire system so that the recovered energy is used to run other railcars. In the regeneration process, generated electric power is returned to the overhead wire system through the inverters for electric railcars, which are also power electronics devices.

For the sake of fully-fledged dissemination of hybrid electric vehicles and fuel cell electric vehicles, and further energy saving of electric railcars, downsizing, weight saving, and cost reduction of power semiconductor devices used for the inverters are required.

As has been described above, power electronics is not only the basic technology that supports the energy infrastructures in various fields including the industrial, civil, and transport sectors, but also it is indispensable for future prospective electrical power systems such as dispersion type electrical power supply systems that use loop controllers and direct current power supply systems.

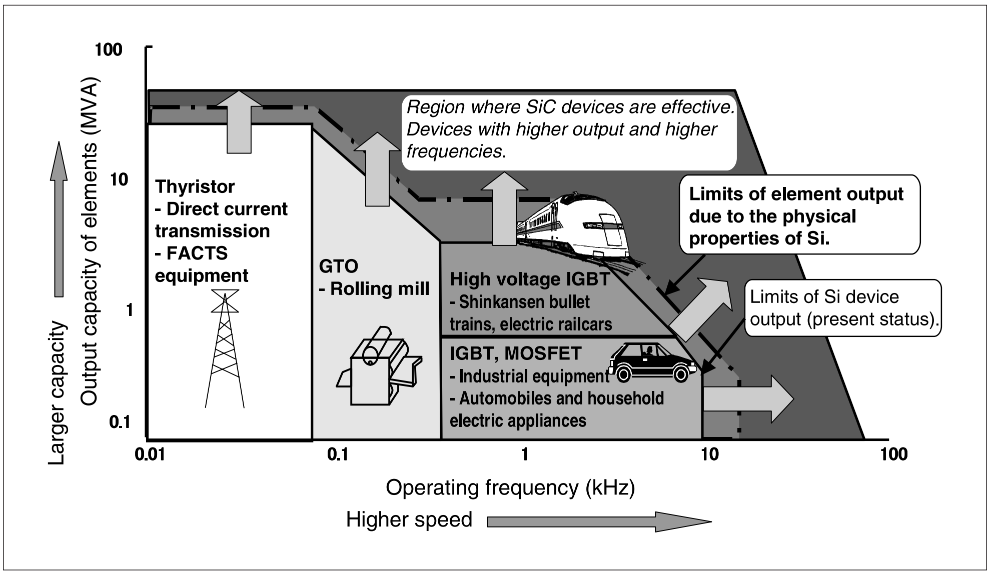
4 Trends in the development of power semiconductor devices

4.1 History of the device's development

Power semiconductor devices which are used for switching between "On" and "Off," are the most important component of power electronics equipment that consists of filters, cooling devices, etc. The less the conducting loss and the loss in on-off switching (the switching speed is faster), the electrical power conversion is much effective.

Most of the present power semiconductor devices are made of silicon (Si). General Electric in the United States was the trigger of the development and commercialized the thyristor which enhancement of power electronics in 1956[7]. Although Japan was behind the United States and Europe in the development of power semiconductor devices, that having a high capacity was successfully developed around 1970 in a project relating to automobiles, and, as a result, catapulted Japan to the top level of the world in the power electronics technology[8]. Afterwards to the latter half of the 1980s, GTO(Gate Turn-Off Thyristor), the optical trigger thyristor, MOSFET (metal oxide semiconductor field effect transistor), IGBT (insulated gate bipolar transistor), etc., were rapidly developed making it possible to meet the diversified needs in electrical power conversion ranging from small capacity to large capacity[9] (see Figure 3).

Figure 3 : Application fields of power semiconductor devices



Source: Data of Power Electronics Research Center of the National Institute of Advanced Industrial Science.

From the 1990s to now, research and development aiming at high performance has been conducted by utilizing the fine processing technology for LSIs.

However, it seems that the technology is reaching the limits of Si material, so long as the conventional technologies are applied for achieving high performance. It is required for the development of prospective fuel cell electric vehicles to improve fuel consumption by downsizing and weight saving as well as by simplifying the cooling system. It is also hoped for the motor control to develop inverters integrated with the motor by improving heat resistance. Under such circumstances, the “Development of Ultra-low-loss Power Device Technology” Project aimed at developing new materials such as SiC and GaN, considering the needs of the technical development described above. According to the post-project evaluation report[1], among the achievements relating to basic technology development are large-diameter crystals and high performance of the products. As for the production technology of elements, it has been demonstrated that the “on-resistance” of SiC basic elements is less than one tenth that of Si elements and that the power density is ten times or higher than that of Si elements. However, it remains that many problems need to be solved for commercialization such as cost reduction of substrates, mounting technology, and development of peripheral technologies.

4.2 Application effects of SiC power semiconductor devices

SiC semiconductors have excellent indices performance for power semiconductor devices with a band gap at about three times that of Si semiconductors, dielectric breakdown electric field at about ten times, and thermal conductivity at about three times. SiC semiconductor elements would enable the realization of high withstanding voltage, high-speed operation, low loss in power conversion, and high temperature operation. For example, high temperature operation at 400°C or more higher will become possible because the characteristics of a semiconductor can be retained up to 1,500°C or higher due to the broad band gap[10]. Probable merits of the use of SiC semiconductors for power semiconductors including downsizing are as follows:

(1) High withstanding voltage

The withstanding voltage of conventional power electronics devices is between 6 and 8 kV at the highest, and when higher withstanding voltage is required, as in the case of Kii Suido HVDC (High Voltage DC) whose rated direct current voltage is 250 kV, devices are connected in series to obtain the equivalent of devices with a high withstanding voltage. Since the dielectric breakdown electric field of SiC semiconductors is approximately ten times of Si semiconductors, it is expected that the dielectric withstanding voltage of SiC semiconductors will also become ten times of Si semiconductors. If the dielectric withstanding voltage of a device becomes higher, the number of devices connected in series can be decreased so that devices are downsized and conducting loss and switching loss are reduced resulting in a low total loss.

(2) High speed operation

To increase the operation speed of switching device means to operate with higher frequencies. A high dielectric breakdown electric field enables a reduction in the layer thickness so that the length of the device (running distance of carriers) can be decreased, thereby making it possible to operate at high speed. In addition, when magnetic parts such as a transformer are involved, power electronics devices can be downsized in inverse proportion to the switching frequency. Furthermore, high-speed operation improves controllability, waveforms of input/output voltage and current, suppression of higher harmonic waves, and then it is enabling the elimination or downsizing of filter devices.

(3) Low loss of power conversion

Reduction in the loss of power of devices significantly contributes to reducing the loss of power of electronics devices. The loss of power conversion of SiC semiconductors is theoretically one 100th to 300th that of Si semiconductors. Since a higher dielectric breakdown electric field enables a reduction in the layer thickness, electrical resistance will be significantly reduced and result in low loss.

(4) High temperature operation

If devices can be operated at high temperature, a high degree of freedom will be provided for the cooling design of power electronics devices. Conventional devices require a certain amount of surface area due to the thermal restriction. The use of air cooling instead of water cooling will also contribute to the downsizing of devices. For example, hybrid automobiles are equipped with a cooling system consisting of many parts including a radiator, so downsizing will bring about an improvement in fuel consumption.

5 Current status in Japan

5.1 Structural transformation of industries

The development of power electronics technology in Japan has been supported by industries, particularly by the heavy electric machinery industry. However, the heavy electric machinery industry is in a severe business environment while the Japanese economy is suffering from a recession.

The power electronics is much sought after in the amenity-oriented fields such as automobiles and household electric appliances in order to attract consumers' attention, but at the same time it is utilized for energy infrastructures such as electrical power systems having an important meaning as a social infrastructure type technology. Currently in Japan, dichotomization of the heavy electric machinery manufacturers is proceeding as a result of reduced orders due to the domestic suppression of investment particularly by electrical power companies (Toshiba Corp. + Mitsubishi Electric Corp. → TMT & D, Hitachi, Ltd. + Fuji Electric Co., Ltd. + Meidensha Corp. → Japan AE Power Systems).

Although the Japanese heavy electric machinery industry has grown keeping pace with the rapidly increased domestic electrical power demand, it now stands at a turning point because new domestic businesses have decreased due to the saturation of electrical power demand in Japan, whereas the demand for electrical power in developing countries particularly in China is increasing.

While it is an objective of companies as to how to maintain the business within the country, being unable to actively invest in the development of power semiconductor devices that require additional costs, another problem is how to expand international business in order to carry on global price competition.

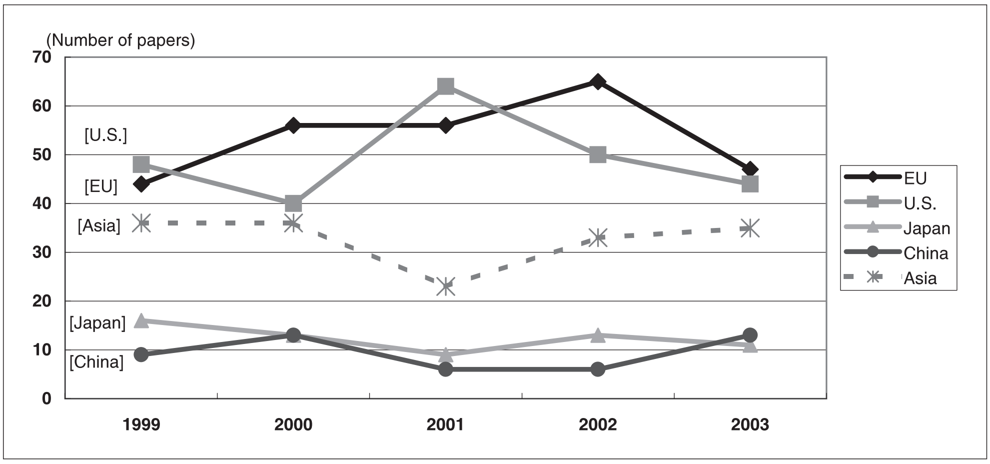
5.2 Development of human resources in universities and the efforts of The Institute of Electrical Engineers of Japan

Fewer students are interested in the hardware-oriented semiconductor industry (power electronics) than in the semiconductor industry (electronics). Newell of the United States defined power electronics in 1973 as a technology in which three technical fields-power (electrical power and electrical equipment), electronics (devices and circuits), and control-are completely combined. As this definition indicates, power electronics is progressing, being supported by the development of these technical fields, and the areas that it covers are getting more and more diversified and complicated[11].

In the field of education, the following questions are being discussed: "what are the fundamentals of power electronics?", "how should lectures be improved to induce students' interest?", and "how can the expansiveness and importance of power electronics be communicated?".

The Institute of Electrical Engineers of Japan has established the "Collaborative Study Committee on the Education of Power Electronics" (April 2000 to March 2002) and the "Collaborative Study Committee on the Education of Power Electronics in the IT period" (October 2002 to September 2004)[12]. The objectives of these committees are to carry out investigation on the methods of education in power electronics including field research and to obtain guidelines for improvement. In these committees, the following issues have been and are being discussed in pursuit of the measures that should be taken to make the education of power electronics more attractive: i) choice and arrangement of curriculum and syllabus, ii) effective utilization of multimedia that induce the interest of students, iii) optimum balance between hardware and software, iv) effective application of simulation, and v) comprehensive training of students with a view to international

Figure 4 : Comparison of the numbers of papers on power electronics



Source: Database of Thomson ISI on papers.

activities.

6 Trends in research

In order to analyze the domestic and international trends in the research on power electronics, the numbers of papers reported on power electronics were compared by countries (regions) (see Figure 4). The database of Thomson ISI was searched for papers that include any of the keywords-"power electronics," "power electronic," and "power semiconductor"—in the title, abstract, or keywords. The term searched was five years from 1999 to 2003. When authors of a paper belong to two or more countries, the paper was counted for each country.

EU was top in the number of papers reported during the five years, which was 268; the United States comes next with 246; Japan reported 62; and China 47. Although not shown in the chart, Canada 30, Taiwan 22, and Australia 20 respectively. Judging from the numbers of papers, the United States and Europe are leading the research on power electronics, and Japan and China are following on almost the same level (Hong Kong was included in China for 1999). The dotted line in the chart shows the total of Asian countries including Japan and China, indicating that the Asian group can become the third power that follows the United States and Europe.

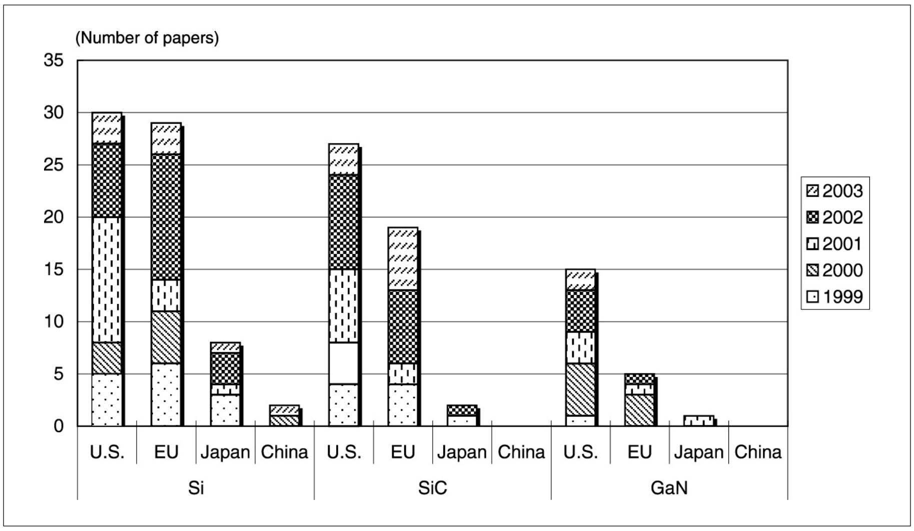
Among the papers reported by Japanese researchers, the number of papers involving industrial companies was 37 and that of universities was 35, which indicates that the numbers are comparable. The fact that the number of papers reported by the industry is comparable to that reported by universities, where much importance is published papers, shows that industrial circles have contributed much to the development of power electronics.

And then, analyzing the domestic and international trends in research on power semiconductor devices, which are important components of power electronics devices, the numbers of papers that include any of the keywords relating to the materials of devices-Si ("Si" or "Silicon"), SiC ("SiC" or "Silicon Carbide"), and GaN ("GaN" or "Gallium Nitride")- in the title, abstract, or keywords of the papers are shown in Figure 5. The numbers are in the order of the United States, EU, Japan, and China for all of Si, SiC, and GaN, which indicates that research on power semiconductor devices using new materials such as SiC and GaN is being actively conducted in the United States as compared to other countries (regions).

In the United States and Europe, collaboration between universities and industry is being promoted in the field of power electronics.

In the United States, CPES (Center for Power Electronics Systems) was established in August 1998 as one of the research centers of the National Science Foundation (NSF)[13]. A consortium consisting of five universities was organized, allocating special technical fields to each university. Its integrated system program provides a strong interdisciplinary approach with collaboration of more than 80 companies through an industrial cooperation program. In Europe as well, ECPE (Engineering Center for

Figure 5 : Comparison of the numbers of papers on semiconductor power semiconductor devices



Source: Database of Thomson ISI on papers.

Power Electronics) has been established with the objective to promote research, education, and technology transfer to the industries[14].

7 Conclusion

Power electronics is a basic technology for energy infrastructures and, at the same time, an important technology that helps to solve environmental problems because it can provide measures to realize low loss, downsizing, and weight saving of various equipment and devices used for electrical power systems and automobiles.

In the past, we, in Japan succeeded in the development of power semiconductor devices having high capacity by Si and climbed to the top level in the world. Recently the “Development of Ultra-low-loss Power Device Technology” Project has been finished and the next step of development is being investigated. In the future, it is necessary to plan a project that aims at the practical applications of the results of material development on which the past project placed emphasis. Based on the standpoint that the research results for new materials that have been obtained should be put to practical use, a series of research and development activities covering a wide range from device development to system applications must be continued.

Power electronics covers a lot kind of diversified areas including electrical power systems, traffic and transportation systems, and household electric appliances; therefore, it is necessary to establish a roadmap based on the needs for technical development required by each field and to promote research and development. Since the recent expansion of the use of dispersion type power sources has brought about concerns the electric power quality of Japanese electric power systems, it is particularly important to quickly realize the practical application of power electronics devices that contribute to the stabilization of electric power systems when dispersion type power sources are used in large quantities.

Although power electronics has been developed primarily by industry, particularly by heavy electrical machinery manufactures, it is now difficult for a single company to actively invest in the development of new power semiconductor devices. In the universities as well, which have the responsibility to supply human resources to the industry, there are problems in the education of human resources. Furthermore, judging from the numbers of papers, research on power electronics is being conducted more actively in the United States and Europe than in Japan, and collaboration between industry and academia is being promoted steadily there. Also in China, where demand for electrical power is expected to grow rapidly and the technology is considered to bring about significant ripple effects, the number of papers on power electronics is already comparable to that of Japan. Projects that aim at practical applications of power electronics must be promoted with a view that the industry, academia, and government should cooperate in fostering researchers and engineers who will play a major role in the development of next-generation technology.

Acknowledgements

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Notes

*1 When power is supplied to the CPU, alternating current is converted to direct current using power semiconductor devices and, then, the required voltage is obtained by direct current to direct current conversion (DC/DC converter).

*2 The value of 14 V (42 V) is a nominal value of the circuit voltage during the operation of the electric system of a vehicle, and the voltage of batteries used is 12 V (36 V).

References

[1] New Energy and Industrial Technology Development Organization, National Institute of Advanced Industrial Science and Technology, "Post-project Evaluation Report on the Development of Ultra-low-loss Power Elements Technology Project," August 2003. (in Japanese)

[2] Comprehensive Energy Statistics, Agency for Natural Resources and Energy, 2001 Edition. (in Japanese)

[3] New Energy Subcommittee of the Advisory Committee on Natural Resources and Energy, "Nature of the Measures for New Energy in the Future," June 2001. (in Japanese)

[4] Japan Cogeneration Center, website: http://www.cgc-japan.com/japanese/info/info01.html

[5] For example: Kobayashi, Nanahara, Ishii, "Electrical Power Systems in the 21st century-Construction of demand region systems-," OHM, March 2002. (in Japanese)

[6] Japan Automobile Research Institute, website: http://www.jari.or.jp/ja/denki/denki.html

[7] Y. Akagi, "Prospects and Expectations of Power Electronics in the 21st Century," Journal of The Institute of Electrical Engineers of Japan, No. 1, Vol. 121, 2001. (in Japanese)

[8] "Report of Special Committee for Research and Development of Solid Devices for High Electrical Power," Japan Society for the Promotion of Science, March 1999. (in Japanese)

[9] H. Ohashi, "Recent Power Devices Trend," Journal of The Institute of Electrical Engineers of Japan, No. 3, Vol. 122, 2002. (in Japanese)

[10] Y. Sugawara, "Trends in the Development of SiC Power semiconductor Devices of the Next Generation," Electrical Review, April 2003. (in Japanese)

[11] Ueda, Oguchi, Matsui, "Discussion on Power Electronics Education in the 21st Century," IEEJ Transactions on Industrial Applications, No. 6, Vol. 122, 2002. (in Japanese)

[12] Matsui, Oguchi, "Present Status and Problems of Power Electronics Education," OHM, April 2003. (in Japanese)

[13] CPES, website: http://www.cpes.vt.edu/

[14] ECPE, website: http://www.ecpe.org/en/index.html

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9

Evaluation of R&D Projects
– European Practice –

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1 Introduction

There are two types of governmental R&D projects: the “open-type” project, and the “closed-type” project. In the past, Japan heavily depended on the “closed-type” R&D project via negotiated contracts, but there have been an increasing number of “open-type” R&D projects that select proper proposals after accepting a wide variety of proposals from researchers.

In line with its reports from the “Competitive R&D Fund System Reform Project,” the Cabinet Office’s CSTP (Council for Science and Technology Policy) submitted its opinion paper to the prime minister and other related ministers in April 2003. As the competitive R&D fund has already reached ¥349 billion, or about 10% of the total S&T expenditures in the FY 2003 government budget, the opinion paper provides specific policy recommendations for further expanding such R&D fund[1],*1.

In addition, the opinion paper points out the reason for expanding such competitive R&D fund as follows.

“In order to yield top world-class R&D outcomes, it is necessary to selectively provide funds to R&D activities proposed by motivated researchers.... The United States has competitive R&D funds about ten times as much as Japan. In the US, an independent fund allocation entity allocates R&D funds to universities and other institutions based on a fair and transparent evaluation process. Under such competitive R&D environments, the United States has been creating top world-class R&D outcomes and bringing about technological innovation for revitalizing its economy.”

The expansion of a competitive scheme surely requires a proper evaluation system. As the opinion paper points out, there are four important factors for establishing a proper system: Excluding stakeholders from the evaluation process; involving competent researchers and technical experts in the initial evaluation process; disclosing evaluation results to applicants; and establishing proper interim and ex post valuation processes after adopting a R&D project.

While Japan’s competitive fund system reform initiative is based on the corresponding fund scheme in the US, Europe also has its own competitive R&D fund scheme. Since I had an opportunity to participate in the initial evaluation process in Europe, I would like to explain the European practice as compared to Japan’s scheme.

2 Framework Program

Since 1984, the European Union has been promoting an R&D program called the “Framework Program[2].” The Framework Program is a five-year-long program (practically, one term is four years long). The Sixth Framework Program covers the period between 2002 and 2006. The previous fourth and fifth Programs covered the 1994-1998 term and the 1998-2002 term, respectively.

The fourth and fifth Program had a fund amount of €13,215 million and €14,960 million, respectively. The current sixth Program has a fund amount of €17.5 billion. If converted into Japanese yen at an exchange rate of ¥130/€, the sixth Framework Program represents about €2,275 billion. This means the EU has a competitive R&D fund capability larger than that of Japan on a yearly basis.

The EU carries out the Framework Program because the EU recognizes the importance of R&D activities in enhancing industrial competitiveness as well as protecting consumers and the environment. While the EU has been forming its own monetary union in accordance with the Maastricht Treaty of 1993, the new Amsterdam Treaty became effective in May 1999. This new treaty has one chapter covering R&D activities and emphasizes the importance of such activities.

Table 1 shows the fund allocation for each R&D field based on the sixth Framework Program[2]. Japan selectively allocates funds to four priority fields. The EU similarly sets out priority fields such as life science, information society, nanotechnology, and environmental technologies. Unlike Japan, the EU sets out aerospace as an independent priority field, which suggests that the EU puts more emphasis on the aerospace industry, including Airbus.

The Framework Program is an open-type program. Researchers must solicit for research institutions in at least three different EU member states when submitting their proposals to the European Commission, which serves as the Framework Program secretariat. The secretariat then evaluates these proposals to identify those deemed appropriate.

3 Initial evaluation of proposals

The initial evaluation process consists of two steps: peer review by experts; and the subsequent coordination by the secretariat.

As described in detail later, experts evaluate whether or not a submitted proposal carries academic value. Since researchers are allowed to submit more than one project, two or more R&D projects submitted by a same researcher might pass this expert evaluation. In this case, it is necessary to make some adjustments, including priority/timing adjustments in the projects and designation of an alternate researcher. Adjustment is also necessary if the expert evaluation does not approve the full amount of the budgetary request for the R&D project. The European Commission is authorized to make such adjustments.

The following statements explain the initial evaluation process by experts.

In parallel with soliciting for R&D project proposals, the European Commission appoints panel members who are in charge of the evaluation process. Basically, the panel members must be experts who do not have any stake in the specific proposal. Usually, three to five experts are involved in the examination of a project proposal. In this sense, if each expert evaluates ten project proposals, about 40 experts are needed to examine 100 project proposals*2.

Table 1 : Fund allocation plan in the sixth Framework Program

(Unit: € million)

Priority fields			13345
Items	Life science	2255	
	Information society	3625	
	Nanotechnology, materials	1300	
	Aerospace	1075	
	Food safety	685	
	Sustainable development, environment	2120	
	Citizens and governance in a knowledge-based society	725	
	Others	2060	
Mobilizing R&D staff			2605
Establishing research collaboration schemes			320
Others			1230
Total			17500

Source: Author's compilation based on European Commission documents.

On the other hand, since there are not so many experts available, it is difficult to always appoint the necessary experts who do not have any stake in the project. In order to solve this problem, the European Commission sometimes appoints experts from non-EU member European nations or non-European nations. If this solution does not provide the sufficient number of experts necessary, the European Commission will need to appoint experts who have some stakes in a specific proposal. In this case, the Commission temporarily excludes such interested expert from the evaluation process or orders the expert to leave his/her seat when other panel members are discussing the proposal.

The secretariat gathers all the evaluation panel members and instructs them to stay in a certain place for a week. It is prohibited to take out the document and to bring in PCs and mobile phones. The secretariat then hands over proposals to the panel members.

Due to their characteristics, R&D project proposals are divided into five categories as shown in Table 2. In addition to pure R&D activities, the EU intends to provide R&D funds not only to NOE and CA, which would strengthen collaboration among many existing research institutes in the EU member states, but also to SSA, which would be indirect activities (e.g., holding a symposium). While recently Japan aims at establishing the Center of Excellence (COE), the EU's NOE aims at forging closer ties among COEs. This represents an interesting contrast.

Each of these five categories has different evaluation items. The list is shown in Table 3. For each evaluation item, a perfect score is 5 points. A proposal will pass the expert evaluation if it gains 3 points or more for items marked with 3/5, and 4 or more points for items with the 4/5 mark. In addition, the proposal must at least receive a score at its qualifying criteria.

Each panel member independently evaluates the proposals. After that, they hold a panel meeting with the coordinator to draw up the tentative evaluation results, as a consensus of the panel consisting of three to five members.

Table 2 : R&D project categories

Name	Abbreviation	Description
Integrated Project	IP	A large-scale project to support objective-driven research.
Network of Excellence	NOE	A project that strengthen excellence by tackling the fragmentation of European research.
Specific Targeted Research Project	STREP	A R&D project designed to achieve a certain goal.
Coordination Action	CA	A continuous activity to promote and support the networking and coordination of research and innovation activities
Specific Support Action	SSA	A specific support activity, such as holding a symposium.

Source: Author's compilation based on European Commission documents.

Table 3 :List of evaluation items

Project category	IP	NOE	STREP	CA	SSA
Relevance	3/5	3/5	3/5	3/5	4/5
Potential impact	3/5	3/5	3/5	3/5	3/5
Science and technology excellence	4/5		4/5		
Quality of the consortium	3/5	3/5	3/5	3/5	
Quality of management	3/5	3/5	3/5	3/5	3/5
Mobilization of the resources	3/5		3/5	3/5	3/5
Degree of integration and joint program of activities		4/5			
Quality of the coordination				4/5	
Quality of the support action					3/5
Total threshold	24/30	20/25	21/30	21/30	17.5/25

Source: Author's compilation based on European Commission documents.

Then, panel members will have enough time to read the other proposals that he/she is not in charge of. After they grasp the total picture of the proposals, the secretariat gathers all the panel members together.

In the plenary panel session, the secretariat presents the tentative evaluation results for each category. Then, the panel members hold discussions to make the necessary adjustments in the initial conclusion. As already explained earlier, the secretariat orders any interested expert to leave his/her seat when other panel members are discussing the proposal. In this plenary session, the panel members evaluate and discuss the following points: "whether or not it is proper that this proposal would involve researchers from non-EU member states," "whether this project would intentionally exclude female researchers[*3]," and "whether this project would abuse personal information or other protected information."

For small-sized projects such as STREP, CA and SSA, the secondary evaluation results by experts are regarded as the final conclusion.

For relatively large-sized IP and NOE, the secretariat will hold a hearing session with the applicant of a successful proposal. Expert panel members will also attend this hearing session and ask the proposal applicant professional questions in line with a questionnaire that has been already prepared at the plenary panel meeting. The panel members have some discussions and draw their final evaluation results. The ratio of successful proposals usually ranges from 10% to 20%.

After being notified of the evaluation result, applicants may raise an objection over the evaluation result. The secretariat deals with the applicant's objection, paying due attention to document records of the initial evaluation process.

Referring back to my own experience in attending the evaluation process, the European Commission retained 40 experts for a week and paid their fees and traveling expenses just for evaluating 100 proposals. From this perspective, the EU probably spends 2% of its total R&D expenditures for this evaluation process.

4 Reasons for the strict initial evaluation process

Why does the Framework Program require such strict process for the initial evaluation? There are several reasons for this.

The most important reason is that each member state contributes funds for the EU to operate its activities. If the evaluation process disproportionately adopts many proposals from a certain nation, other member states will surely make objections. Impartial evaluation by expert panel members is necessary for the successful defense against such objections. In short, the initial evaluation process is very strict because the European Commission assumes and intends to fulfill its accountability to the EU member states.

The evaluation process is disclosed as a document format. Everyone is allowed to review this document. This, as well, is because the EU assumes accountability. On the other hand, the EU maintains secrecy on panel members' names in order to maintain neutrality in the evaluation process.

Similar to Japan, the EU obviously intends to adopt proposals submitted by motivated researchers. Researchers are working on their R&D activities in international competitions. If a panel exclusively consists of members from EU member states and makes the final decision, the evaluation process will yield a biased decision. To solve this potential problem, the European Commission invites experts from non-EU member states and respects their opinions.

The secretariat sometimes appoints panel members from non-EU member states in order to increase the number of experts who have appreciation of Europe. This is because these experts will spread European point of view to the rest of the world. The United States, Asia and Europe have been frequently pursuing initiatives in the R&D fields. The EU implicitly aims at giving positive impacts on this competition in its favor.

It should also be noted that all proposals are written in English. The EU usually designates all of its member states' official languages as

Table 4 : Statistics of external trades in telecommunications, audio, TVs and VCRs
(Unit: € million)

Year	1990	1996	1997	1998	1999	2000	2001
Export value	5969	20316	27272	28076	31282	44295	41879
Import value	14044	19665	22963	26475	32381	49294	48729
Balance	-8075	651	4309	1601	-1099	-4999	-6913

Source: Author's compilation based on European Commission documents.

its own official languages. However, so far as the Framework Program is concerned, all the proposals are written in English. This means English is the only "official language" in the science and technology field. By doing so, the EU intends to obtain objective evaluation results from many evaluation experts who have different nationalities.

5 Ex post evaluation in Framework Program

The committee in charge of the Framework Program's ex post evaluation was established outside the European Commission in order to maintain neutrality. The committee's evaluation results were published in July 2000[3]. This report commends project outcomes and strongly encourages the Program's continuity. It attaches high value to the Framework Program because the Program has encouraged R&D activities in industry-academic collaboration and provided SMEs with opportunities to join the Program. On the other hand, the report criticizes the European Commission's complex and time-consuming process management.

Let us use ACTS as an example to examine in detail the ex post evaluation. ACTS is an information/telecommunication project that took place from 1994 to 1998 as part of the fourth Framework Program[4].

ACTS covered a wide variety of R&D fields, such as interactive digital multimedia services, optical technologies, high-speed networking, mobile communication networks, more sophisticated networks and services, as well as quality and security in communication networks/services.

The fourth Program also had other information/communication projects such as microelectronics-related ESPRIT and an educational project called TELEMATICS. The total research expenditures for the information/communication fields stood at €3,646 million, or 28% of the Program's total budget. Out of this research fund, the EU spent €671 million for ACTS.

Under ACTS, the EU adopted 89 proposals, and about 1,060 organizations participated in ACTS. Research institutions and universities accounted for 30% of the total participating organizations, while private corporations occupied 48%. In this sense, ACTS was a corporate-driven project.

ACTS website provides the results of a corporate survey, asking participating organizations the following question: "How would you evaluate your own research outcomes when based on a worldwide perspective?" According to this website, the projects that "successfully achieved top world-class" accounted for 55%, while a third of the respondents answered that their projects "exceeded the research levels in the US or Japan." In addition, almost half of the respondents gave favorable answers such as "investment risks have been lowering" or "Business strategies have been successfully narrowed down."

Based on the statistics of external trade, let us examine to what degree European industrial competitive edge has been successfully enhanced in the information/communication fields[5].

According to Table 4, some product items suffered from a significant trade deficit in 1990, recovered to a trade surplus in the late 1990s, and fell into significant adverse trade balances again thereafter.

The EU's import and export statistics against the United States and Japan also represent similar trends. The trends are shown in Tables 5 and 6. These charts show a gradual increase in trade deficit against the US. They also illustrate that the sectional trade deficit against Japan dropped by half in 1996 but has been suffering a gradual rise

Table 5 : Statistics of trade with the US in telecommunications, audio, TVs and VCRs
(Unit: € million)

Year	1990	1996	1997	1998	1999	2000	2001
Export value	705	1743	2646	3109	3802	5402	5437
Import value	1550	4436	5860	7033	8405	12366	10677
Balance	-845	-2693	-3214	-3924	-4603	-6964	-5240

Source: Author's compilation based on European Commission documents.

Table 6 :Statistics of trade with Japan in telecommunications, audio, TVs and VCRs
(Unit: € million)

Year	1990	1996	1997	1998	1999	2000	2001
Export value	86	995	912	645	1022	–	–
Import value	6579	4136	4307	4613	5793	8103	7335
Balance	-6493	-3141	-3395	-3968	-4711	–	–

– : No data

Source: Author's compilation based on European Commission documents.

thereafter.

The trade statistics only represent rough categories such as "telecommunication, audio, TVs, and VCRs." In this sense, the EU's trade deficit against Japan might represent adverse impacts of commodity products such as TVs and VCRs. However, the trade deficit against the US surely illustrates a gap between the United States and the EU in their competitive edges in high-tech fields such as the Internet.

Of course, there is a time lag between successful R&D activities and improvements in trade accounts. On the other hand, all the Framework Programs have recognized informat ion/communication as a priority area. From this perspective, the trade statistics shown in these charts would represent outcomes of the fourth Program as well as those of previous Framework Programs.

ACTS report optimistically shows successful improvements in the EU's industrial competitive edges. However, the EU still has trade deficits against other developed nations such as the US and Japan. This fact indicates that the EU suffers from deficits in overall external trades in the info rmation/communication fields.

Despite positive responses from participating organizations, what is the reason the trade statistics do not indicate the successful enhancement of the EU's competitiveness?

The answer is obvious. Usually, participating organizations would welcome receiving R&D subsidies and have no reason to refuse them.

Table 7 : Major communication equipment manufacturers' R&D expenditures in 1998
(Unit: € million)

Year	1998
Alcatel	1809
Siemens	4664
Ericsson	3143
Bosch	1778
Nokia	1150
Total	12550

Source: Author's compilation based on annual reports of manufactures.

If a fund allocation entity asks them about a Program's outcome, they would naturally answer the Program "went successful" or "gave positive effects."

However, actual subsidies do not represent significant amounts. Based on annual reports released by the top five European information/co mmunication firms, Table 7 illustrates these five major firms' R&D expenditures in 1998 when the EU carried out ACTS.

In total, these five corporations spent R&D expenditures 3.4 times as much as €3,646 million, the total information/communication expenditure under the Framework Program. Because the Program has also provided subsidies to other corporations during its five-year term, the Framework Program's R&D subsidies have probably pushed up corporate R&D expenditures only by a few percent.

A region-wide R&D program seemingly

provides a significant amount of total funds. However, as these funds are usually allocated and diluted to many entities, each firm receives a tiny R&D fund amount. From this viewpoint, it is difficult to expect that such regional R&D program would naturally enhance the industrial competitive edge.

Even in Japan, when the government announces R&D support measures, the business community supports it. However, sober perspectives are necessary to correctly judge whether or not such government measures would effectively yield positive results.

6 Conclusions

Focusing on the EU Framework Program, this paper has so far explained the evaluation process for the "open-type" R&D program.

As already mentioned at the beginning, Japan has been expanding its competitive R&D fund scheme. According to the CSTP document mentioned earlier, Japan's largest R&D support project (49%) is the "Grant-in-Aid for Scientific Research" provided by MEXT (Ministry of Education, Culture, Sports, Science and Technology) and JSPS (Japan Society for the Promotion of Science). The second largest project is the Basic Research Program by the Japan Science and Technology Agency.

The Japanese government grants subsidies for two types of scientific research activities: Large-scale special promotion research activity on one hand, and specific foundation research activity on the other. Special promotion research activity has an initial evaluation process in the sequence of third party's document review, panel-type examination, and, then, hearing session. If a proposal is rejected, the unsuccessful applicant will be notified of the reasons for rejection. The foundation research activities involve document review and panel-type examination. When the proposal is rejected, its applicant is able to know the rough position of the unsuccessful proposal, if he/she wishes[6].

Japan's scheme is more transparent than the EU Framework Program because it publishes the list of appraisers. On the other hand, there is no panel-type evaluation process in the document review phase. Although Japan's scheme has an advantage in cost reduction of the evaluation process, it is less transparent because appraisers have no chance to meet with each other to check on any possible conflict of interest.

As the government also incorporates document review, panel-type examination, and hearing session into many other projects, the Japanese government is making efforts, in a sense, to establish sound foundations for the initial evaluation process. In addition, notifying unsuccessful applicants of the reasons for rejection will surely contribute to fulfilling accountability.

Unlike the EU Framework Program, Japan's scheme does not have any evaluation process that involves foreigners. This is partly because foreigners are not able to read proposals that are all written in Japanese.

As Japan has not so many experts available, the possibility for some type of conflict of interest is quite high. There is no national border for R&D activities. R&D activities fall under the international competition arena, rather than domestic competition. If Japan successfully establishes a proper system for impartially evaluating R&D proposals based on global standards and worldwide perspectives, such an evaluation process will successfully select excellent R&D proposals.

In order to establish an initial evaluation process having an international perspective, it is necessary to require applicants to submit their proposals in English. Because able Japanese researchers frequently write their papers in English and submit them to international journals, a new requirement to write proposals in English will only impose a marginal burden on researchers. Japan should establish a proper competitive fund system that requires R&D proposals and reports to be written in English.

Comparing with the European system, Japan's scheme does not have enough objectivity in its ex post evaluation process. Japan needs to seek for a proper scheme that would properly maintain objectivity in the ex post evaluation process.

If establishment of a proper ex post evaluation process would take a long time, a secure framework for the initial/interim evaluation process is necessary. Narrowing down excellent R&D proposals will surely give positive impacts on the R&D project's actual performance. From this viewpoint, Japan should put more emphasis on improving its initial evaluation process.

Notes

*1 The opinion paper defines "competitive R&D funds" as follows: Competitive R&D funds mean "R&D funds allocated by a certain fund allocation entity that publicly solicits R&D proposals and selects proper R&D proposals based on a highly scientific and technical evaluation process that involves multiple panel members including experts."

*2 About 100 proposals were examined in the evaluation process that I was involved with. This is only a part of the Framework Program. Since I entered into a contract that prohibits me from disclosing the specific contents and evaluation results of proposals, I would like to refrain from stating such information in this paper.

*3 Fostering female researchers is one of the important political issues.

References

[1] Council for Science and Technology Policy, "Competitive Research Fund System Reform: Interim Opinion Paper," April 2003. (in Japanese)

[2] European Commission, "Participating in European Research," 2002.

[3] Independent Expert Panel, "Five-year Assessment of the European Union Research and Technological Development Programmes, 1995-1999."

[4] "ACTS - Advanced Communications Technologies and Services," www.cordis.lu/acts/home.html/

[5] European Commission, "External and intra-European Union Trade - statistical yearbook," 2000 and 2002.

[6] Website of MEXT's "Grant-in-Aid for Scientific Research," http://www.mext.go.jp/a_menu/shinkou/hojyo/main5_a5.htm

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About SCIENCE AND TECHNOLOGY FORESIGHT CENTER

It is essential to enhance survey functions that underpin policy formulation in order for the science and technology administrative organizations, with MEXT and other ministries under the general supervision of the Council for Science and Technology Policy, Cabinet Office (CSTP), to develop strategic science and technology policy.

NISTEP has established the Science and Technology Foresight Center (STFC) with the aim to strengthen survey functions about trends of important science and technology field. The mission is to provide timely and detailed information about the latest science and technology trends both in Japan and overseas, comprehensive analysis of these trends, and reliable predictions of future science and technology directions to policy makers.

Beneath the Director are five units, each of which conducts surveys of trends in their respective science and technology fields. STFC conducts surveys and analyses from a broad range of perspectives, including the future outlook for society.

The research results will form a basic reference database for MEXT, CSTP, and other ministries. STFC makes them widely available to private companies, organizations outside the administrative departments, mass media, etc. on NISTEP website.

The following are major activities:

1. Collection and analysis of information on science and technology trends through expert network

— STFC builds an information network linking about 3000 experts of various science and technology fields in the industrial, academic and government sectors. They are in the front line or have advanced knowledge in their fields.

— Through the network, STFC collects information in various science and technology fields via the Internet, analyzes trends both in Japan and overseas, identifies important R&D activities, and prospects the future directions. STFC also collects information on its own terms from vast resources.

— Collected information is regularly reported to MEXT and CSTP. Furthermore, STFC compiles the chief points of this information as topics for "Science and Technology Trends" (monthly report).

2. Research into trends in major science and technology fields

— Targeting the vital subjects for science and technology progress, STFC analyzes its trends deeply, and helps administrative departments to set priority in policy formulating.

— STFC publishes the research results as feature articles for "Science Technology Trends" (monthly report).

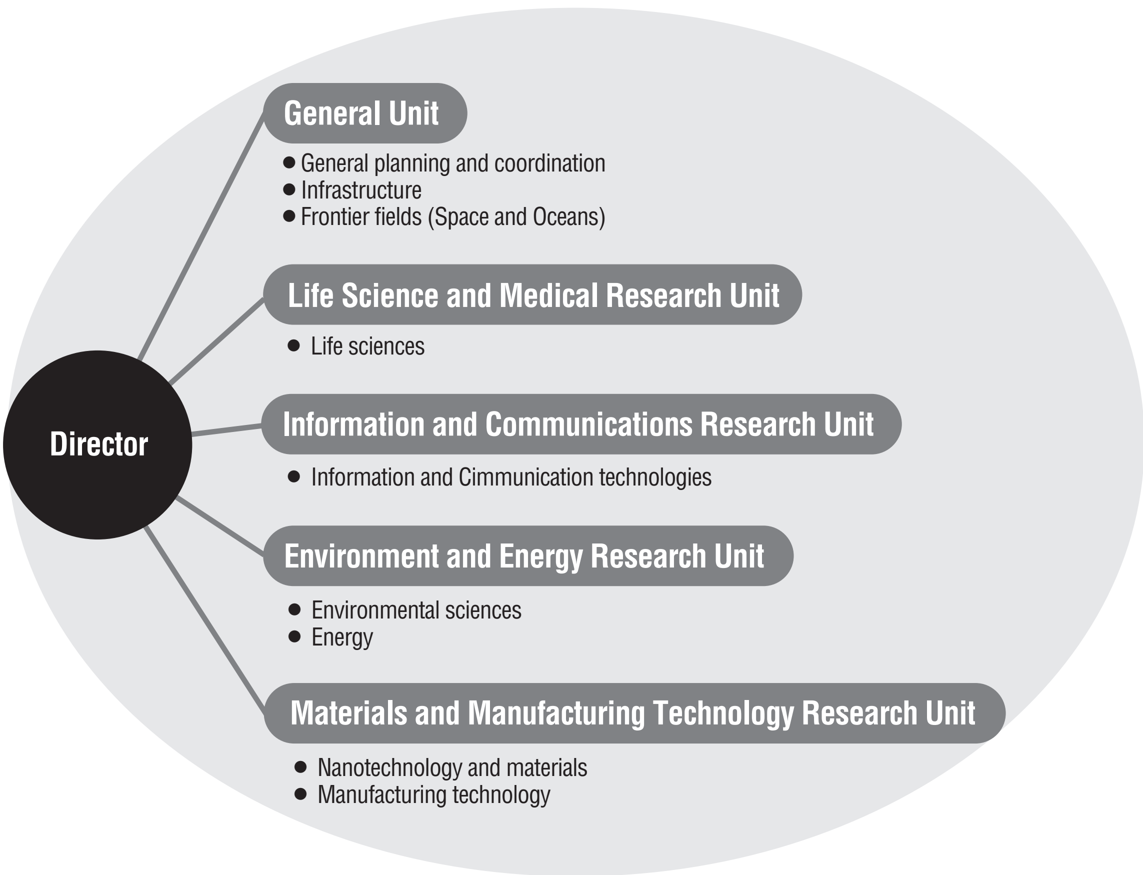
3. Technology foresight and S&T benchmarking survey

— STFC conducts technology foresight survey every five years to grasp the direction of technological development in coming 30 years with the cooperation of experts in various fields.

— STFC benchmarks Japan's current and future position in key technologies of various fields with those of the U.S and major European nations.

— The research results are published as NISTEP report.

Organization of the Science and Technology Foresight Center



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