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R&D and Protection of Intellectual Property

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There will be three major technological fields in the 21st century namely, IT, biotechnology and micro and nano technologies. In these fields of height technology, protection of intellectual properties is secured for the promotion of R&D activities in order to bring about further technological innovation. However, there are some problems to be solved in connection with intellectual property.

In the field of IT, the explosive spread of cellular phone use and the Internet is regarded as having triggered economic recovery. In addition to the rapid advances in technological fields such as communications, information processing, and image processing, which are often referred to as "digital revolution" fields, new business systems making use of the Internet as represented by e-commerce are further expanding the demand for the Internet. Under such circumstances, discussions and examinations are now under way to establish a range of reasonable patent protection for the business methods that have not been protected under patent law to date.

In the field of biotechnology, analysis of the human genome has almost reached completion as a result of competition between international joint research projects and private industries around the globe. The genetic information obtained from such analyses will advance the development of new medicines as well as the treatment of intractable diseases. However, the protection of such analyzed genetic information using patent functions has become a major issue.

In the field of micro-technology, MMC has been promoting The Industrial Science and Technology Frontier Program, "Micromachine Technology" since fiscal 1991. In this project, a wide range of R&D activities and basic research conducted by universities, colleges, and national institutes/laboratories have successfully resulted in the reported achievements which include the developments of new manufacturing techniques, constituent technologies covering the identification of functions, and development of system formation technologies. The project has helped industry to discover new seeds that are expected to contribute greatly to the advent of new industries as they go into practical use in various applications. With regard to the intellectual properties to be protected in this field, more than 500 cases have been filed for patents related to this project as the MITI and MMC have also been actively promoting and supporting the trend. The number of applications is much higher than that recorded for any ordinary national projects to date. The number of applications in Japan including those mentioned above and others totals more than 2,000, which is clearly higher than in the U.S.A where some 500 applications have been made. The problem with such circumstances in Japan is that the number of patent applications by universities, colleges, and national institutes/laboratories is far below the number of research papers (only a few percent).

For nano technology in particular, Japan is now planning a new national project to counter the intensified research projects on nano technology being promoted by the U.S. government. Since the project is expected to focus on basic R&D by universities, colleges, and national institutes/laboratories, the protection of related intellectual property will have a major influence on the R&D strategy.

On the other hand Japanese national universities and national institutes/laboratories are in the process of being reorganized into independent administrative agencies. In this sense, they will have to secure their income through the protection of intellectual property as they are required to reinforce the respective financial foundations.

"The Law Promoting Technology Transfer from Universities to Industry (TLO Act)" (jointly enacted in 1998 by Ministry of Education and MITI) is intended to facilitate the protection of intellectual property related to the results of research projects conducted by universities and/or colleges and also to promote technology transfer to private industry for commercialization of relevant technologies. The following paragraphs summarize the background of the TLO Act.

Japanese universities and colleges have been rich in the resources of scientific and technological researches. However, such achievements have not been sufficiently utilized in industry. For example, little more than one-third (250,000) of the total population of Japanese researchers is registered in universities or colleges. With 20 % of the research fund (3.1 trillion yen) in Japan spent on the research projects conducted by universities and colleges, patent applications by such organizations account for only 0.04% of the total number of applications in Japan. On the other hand, in the U.S., a system for promoting technology transfer from universities and colleges to the industrial sectors was established in the 1980s. As a result, the number of cases where companies employ the achievements of universities or colleges on a commercial basis and further, the number of new companies that are purely associated with such new technologies has increased, resulting in the creation of an impetus to boost country-wide economic recovery. Taking Stanford University and MIT as examples, both have obtained a large number of patents so that the funds from the royalties can be fed back into their research thereby improving it. The TLO Act is modeled on this successful American system.

TLO stands for Technology Licensing Organization and refers to an organization that takes charge of applying for patents for the results of research projects conducted by the universities or colleges and coordinating technology transfer to industry. It serves as the "Patent Division" in a university or college, allowing researchers to concentrate on their research while increasing research funds from patent royalties and commercialization processed by the TLO.

The income at the beginning of a technology transfer transaction is usually very small and the expenses for the patent right applications substantial. Under such circumstances, the TLO Act stipulates special supporting arrangements for the TLOs designated by the Ministers of Education and MITI, including grants for research, guarantee of obligation, supply of information, reduction or exemption of patent application fees, dispatch of technology transfer experts, assistance to venture businesses or small-and-medium size companies that receive the technologies, special permission for the teaching staff of a national college or university to also serve as executive members of a TLO or private company that accepts the technology from the college or university in particular. So far 15 institutes, including national and private colleges and universities. have established TLOs, with some more expected to be established in the near future.

Thermal Management Devices Utilizing Micro Grooves and Micro Channels

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Introduction

This Research Laboratory, which belongs to the "Department of Information & Systems" of Institute of Industrial Science, the University of Tokyo, is conducting research on thermal management engineering. Based on the conviction that the academic engineering in universities should be centered on three fields, namely the element phenomena, technological elements and technological systems, we are specifically conducting the following research projects. As for the research on element phenomena, we are working on phenomena including (1) liquid phase changes such as evaporation, boiling, solidification, freezing, etc.; (2) heat transport excited by the oscillation of a fluid; and (3) thermal hydraulic phenomena occluded in a narrow space. As a part of the research on technological elements, we are developing (4) heat pipes, (5) heat sinks, (6) refrigerators and (7) soft engines. As a part of the research on technological systems, we are developing (8) materials processing systems such as steel products, (9) cooling systems for electronic devices, and (10) freezing systems for storage of foodstuffs.

Outlined below are the research projects to which the word "Micro" can be prefixed.

Meniscus evaporation phenomenon and micro-groove evaporators

Firstly, we would like to introduce the research projects concerning (1) and (5). When the lower end of a wettable plate is immersed in a liquid as shown in Fig. 1, a liquid surface having a curvature, i.e. meniscus, is formed. When the plate is heated beyond its boiling point, evaporation occurs at the meniscus. Such evaporating meniscus can be divided into three regions as shown in Fig. 1. Evaporation does not tend to occur in the thin film region because the molecules in the liquid film are subject to constraint by the atoms constituting the plate. On the other hand, in the intrinsic meniscus region, intensive evaporation does not tend to occur because the thickness of the liquid film constitutes a thermal resistance. Thus, intensive evaporation only tends to occur in the intermediate interline region.

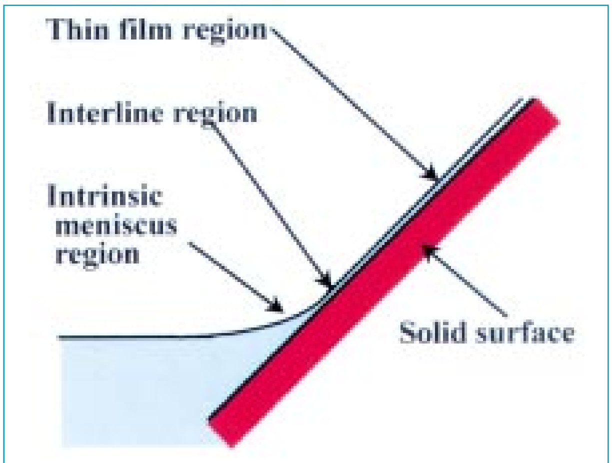

Fig. 1 Three regions in meniscus

If the interline region where intensive evaporation tends to occur can be closely arranged on the surface of a solid substance, it would become possible to develop an extremely small-sized evaporator, which could then be utilized as an evaporator for energy equipment, space heat sinks, etc.

The width of the interline region is said to be less than 1 μm, so that the above-mentioned conditions may be realized by, for example, arranging a large number of micro grooves on the surface of a solid substance in the vertical direction; in other words, forming interline regions along the grooves by siphoning the liquid, utilizing the capillary action that is generated by the grooves, thus confining the meniscus in the grooves. The problem lies in the fact that the volume of liquid that evaporates in the grooves will be drawn up by means of the capillary action. When the width of the grooves is reduced, the capillary action increases, but the flow resistance increases simultaneously. Therefore, when the grooves are made extremely narrow, a phenomenon known as "dry out" occurs in which the liquid at the upper end of the solid substance runs short even at low heats.

Accordingly, there must be an optimum groove width that produces the maximum dry out heat flux. Currently, the optimum groove width based on the experiments using ethanol is in the order of 100 μm; unfortunately, the above-mentioned region cannot be realized.

Heat transport phenomenon excited by vibration and micro heat pipes

Next, we would like to introduce our research concerning (2) and (4). Heat conduction exists as a principle of heat transfer. The amount of heat transferred by the heat conduction per unit area and unit time can be obtained by multiplying the temperature gradient by the coefficient of thermal conductivity (Fourier's law). When the heat flux is replaced by the current density, the temperature gradient is replaced by the electric potential gradient and the coefficient of thermal conductivity is replaced by the electric conductivity, the Fourier's law becomes the Ohm's law. As such, the heat conduction and the electric conduction are analogous.

However, there are large differences in heat conduction when compared to electric conduction; super-conductors, perfect insulators and diodes do not exist. If, in theory, it is difficult to develop super-conductors or diodes of heat, it is desirable to realize a similar function mechanically. The element that achieves the quasi-super conduction of heat is known as "Heat Pipe (HP)". A representative example is the wick type HP, in which the grooves (wicks) that generate the capillary action are provided on the inner surface of a pipe in which both ends are closed and a small quantity of liquid is charged. When one end of this HP is heated and the other end cooled, the charged liquid evaporates at the heated end. This vapor condenses at the cooled end and the heat is transported via a cycle whereby the condensate is returned to the heated end by the capillary action on the inner surface of the pipe.

Now, whilst the heat generating density of the semiconductor device is increasing steadily, the size of the equipment mounted with semiconductor devices is becoming smaller and smaller. Under such circumstances, thin thermal diffusion plates that effectively diffuse the heat generated by the devices as well as heat sinks that transfer the heat effectively to ambient air are essential. A thin thermal diffusion plate cannot diffuse the heat effectively even if a copper plate having the highest coefficient of heat conductivity among the various materials currently available is used. Therefore, it is necessary to develop a heat diffusion plate equipped with HP. However, the wick type HP, which has an outer diameter in the unit of sub-millimeters, cannot transfer sufficient heat because of its limited capillary action. Thus, a new micro HP is required. One such HP is the COSMOS-HP developed in our laboratory. While the wick type HP utilizes phase changes, this HP is of the non-phase change type that utilizes the enhanced heat diffusion effect obtained by the reciprocating motion (oscillating flow) of the liquid charged in the snaking flow channel. When the amplitude and frequency of the oscillating flow in this HP is increased, the apparent heat conductivity becomes far superior to that of copper. This HP appears promising as a micro HP because it does not have the internal structure found in the wick type HP, except for a vibrator to turn the liquid to the oscillating flow. For your information, Fig. 2 shows the heat diffusion plate equipped with a diaphragm type vibrator and a COSMOS-HP, in which 17 rectangular flow channels of 0.5mm width are arranged in parallel to constitute the closed channels. Further, the COSMOS-HP functions as a thermal diode by on-off vibration.

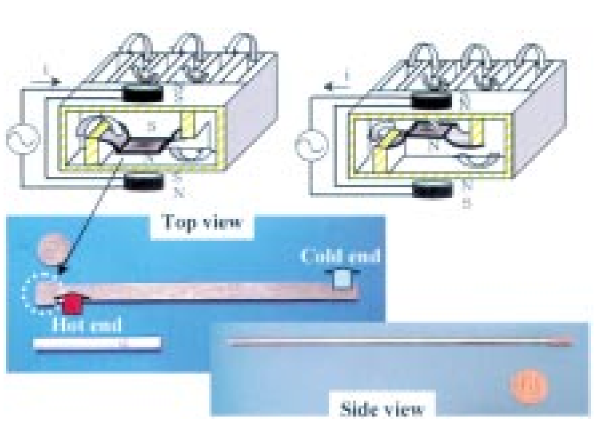

Fig. 2 COSMOS heat pipe

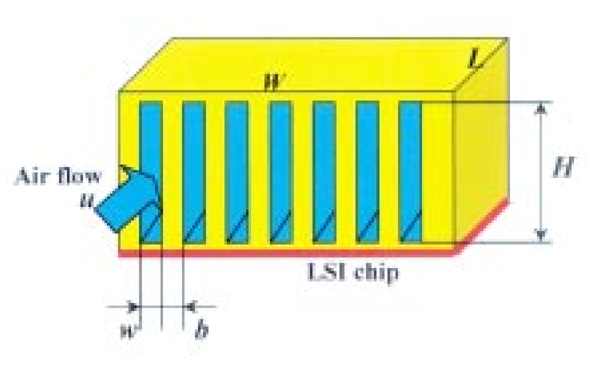

Fig. 3 Micro channel heat sink

Field constraint phenomenon and micro channel heat sink

Finally, we would like to introduce our research concerning (3) and (5). As mentioned above, with the progress of semiconductor devices, the development of a high-performance air-cooled heat sink is required. However, the development of such heat sinks is highly difficult because the thermal conductivity of air is extremely low.

Now, according to knowledge in the field of heat transfer, heat transfer performance is in reverse proportion to the thickness of the layer having temperature distribution in the air (the boundary layer thickness). For example, in a rectangular flow channel, the thermal boundary layer cannot be thicker than half the width of the flow channel, so that if the width of the flow channel is reduced, the heat transfer performance increases. However, if the width of the flow channel is reduced, the driving force to propel the fluid also increases; accordingly, there optimum dimensions must exist, as in the case of the micro groove evaporator.

According to the optimization calculation conducted in our laboratory, when several 10W/cm^2 (heat generating density which the semiconductor devices will reach in the near future) is treated in a heat sink measuring, 10 mm wide, 10 mm long and 3 mm high (refer to Fig. 3), the optimum width of the flow channel in the heat sink will be approx. 0.1 mm. A heat sink having such a narrow flow channel is known as a micro channel heat sink. The heat flow in the micro channels remains unaccounted for however, and research is in progress to develop this type of heat sink.

Reference
1) S.Nishio, Attempts to apply micro heat transfer to thermal management, Keynote Lecture in Engineering Foundation Conference: Heat Transfer and Transport Phenomena in Microsystems, Banff, 2000. 10.

Research on the Application of Sprout Technologies in other Fields to Micromachine Technology for Fiscal 1999 (Part I)

Since 1992, the Micromachine Center has taken up various seeds of technology as themes for joint research by academic, governmental and industrial sectors, aiming to reinforce basic technologies by searching for technology seeds, especially in the scientific and technological fields, that are necessary to build various micro systems. In fiscal 1999, research has been carried out on nine themes. The following articles are summary reports on four themes among them.

Investigative Study of a Mechano-sensor and Signal Transduction in the Mechanisms of Various Plant Responses to Environmental Stimuli

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The response of a plant to a mechanical stimulus, which can generally be observed, is an important factor by which a living plant adapts itself to various environmental stresses. However, the mechanism whereby a plant perceives mechanical stimuli remains almost unresolved. However, those stimuli working on membrane systems on a cell level play an important role not only in thigmomorphogenesis but also in various responses to environmental factors, including water, temperature, and gravity. This has led to the discovery of the presence of a mechano-sensor or a mechano-receptor that perceives those stimuli.

In this investigative study, the responses of a plant to the environment, in which a mechano-sensor is thought to take part, were all-inclusively investigated along with the detailed analyses of mechano-sensors of plants, including an investigation of the literature, verification experiments, and the development of the methods of study in terms of the cystoskeleton, membrane physiology, gene expression, and hormonal control.

A plant cell grows as a cell wall extends due to turgor pressure. Accordingly, each cell in a growing plant tissue shrinks and expands individually due to differences in the rate of growth. In this manner, plant cells are constantly receiving mechanical stimuli as they grow. This in turn serves as a means to control their own growth. In the pith of cultured cells of tobacco, the plane of cell division, controlled by a preprophase band of microtubules (PPB), is positioned perpendicular to the direction of shrinkage. Again, the direction of cell expansion is also thought to be controlled by the change in the orientation of a cell's cortical microtubules. Very significantly, this study also verified that this change in the direction of the microtubules is concerned with the expression of hydrotropism, gravitropism, gravimorphogenesis, and thigmotropism. It is also proposed that, in the gravitropism of a *Chara rhyzoid*, sedimentation of statoliths stimulates mechanically the microfilaments connected with the plasma membrane or endoplasmic reticulum, thus activating the stretch-activated calcium channel. It will be necessary in the future to prove the relationship between the statoliths and microfilaments for common gravity-sensitive cells of roots.

The cytoplasmic movement indigenous to the active material transport system in the cell plays a very important role physiologically in the joint action with its control mechanism. The calcium ion, Ca^{2+}, is known to play the leading role in this control mechanism. Investigation and analysis, therefore, suggested the possibility that the cytoplasmic movement responsible for the active transport system in the cell and its control mechanism along with the calcium channel sensitive to mechanical stimuli are concerned with this control. The findings have led to a concept that an increment of calcium in the cell necessitates the source of calcium inside and outside the cell with a mechano-sensor taking part in both cases. In *Nitella flexilis*, belonging to a family of fresh water green algae, the flow of water into the cytoplasm increases the concentration of calcium in the cell. This water flow into the cytoplasm was found to activate the calcium channel present in the intracellular membrane system, a small calcium-accumulating organ in the cell. Furthermore, it was found highly likely that this calcium channel works as a mechano-sensor.

This advance in the research of a plant mechano-sensor is supported by the following findings:

1) A gene induced by touch (thigmostimulation) was identified and found related to calmodulin.
2) The way calcium ions participate in the plant responses to environmental stimuli was clarified.

As a result, evidences are being collected that the stretch-activated ion channel and MAP kinase system play an essential role as plant mechano-sensors. It has been made clear that the molecules of a plant, in which gene expression is induced by various stimuli, including mechanical ones, contain a multigene family, closely related to the protein kinase, associated with the signal transduction in the cells as previously pointed out in the case of animals, and its second messenger, calcium.

On the other hand, very few reports are available in the case of animals that a stress induces the transcription of genes associated with the signal transduction. It is generally known that the genes in the path of signal transduction, always present in the cells in definite quantity, transfer various stimulative signals via the post-translation modification, such as the phosphorylation of protein. Plants differ greatly from animals in those respects. In this investigative study a method was devised not only for isolating a gene that codes the calcium-dependent protein kinase, considered to be an important molecule in the above processes, but also for isolating and identifying all-inclusively the mechano-sensor-related genes including the one described above.

As described, a mechnao-sensor is universally present in all organisms. It appears that a plant has mechano-sensors in both the plasma membrane and the intracellular membrane. In future studies, it will be necessary to prove this hypothesis as well as to elucidate the mechanism whereby such mechanosensors can induce multiple responses of a plant to the environment.

Investigative Research on Power MEMS Technology

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Micromachines enable high-sensitivity and high-accuracy sensing or high-accuracy and high-resolution actuation. It is generally considered difficult, however, for them to produce large energy, work, force or displacement.

On the other hand, there is a big demand for large power from the smallest possible volume. To meet this demand, power microelectromechanical systems (power MEMS) are under study. As a comparison between a gasoline car and an electric one clearly shows, higher output density can be realized from chemical energy using combustion engines than batteries.

Generally, thermal engines, including gas turbine or gasoline engine, attain a one-order higher output density and energy density than high-performance batteries. This has led to the study of the power MEMS for extracting the desired kinetic or electric energy from chemical energy using means such as combustion engines.

At the Massachusetts Institute of Technology (MIT), a large-scale project is under way to study and develop a micro-gas turbine with a rotor less than 10 mm in diameter by silicon micromachining. In comparison with a small battery, even with a high-performance battery such as lithium one a micro-gas turbine attains a one-order higher output density and energy density. In contrast with a secondary battery, which takes a long time for charging, a micro-gas turbine can be used readily simply by supplying it with fuel.

Several prototypes and test machines have been manufactured thus far, and offered for rotation and combustion tests. However, a self-sustaining micro-gas turbine has not yet been realized.

A group led by Tohoku University is also studying independently a micro-gas turbine, and has carried out so far the trial manufacture of a micro-rotor made of sintered silicon carbide, the trial manufacture and rotation test of a micro-air turbine, and numerical analysis of the internal flow of a micro-turbine by computational fluid dynamics (CFD).

The National Aeronautics and Space Administration (NASA) and Jet Propulsion Laboratories (JPL) of the U.S. are leading the research and development of a micro-thruster for the attitude control of a micro-satellite. Because of the long developmental period and the enormous amount of money required for launching a gigantic satellite exceeding 1 ton in weight, it has become almost impossible to maintain the required frequency of launching.

With the background described above, a project led by the U.S. is under way to uniquely miniaturize a satellite and a planet prober weighing 1 to 10 kg. A thruster to be mounted on such an extremely small satellite for attitude control, for instance, should be super-miniaturized to several centimeters square, thus making it impossible to manufacture it by merely extending conventional techniques.

It, therefore, becomes essential to manufacture a thruster by micromachining technology. Up to this time, various engines have been manufactured on a trial basis, including cold-gas-jet, resist-jet, and solid-fuel engines.

A wearable information terminal is a small device that can be attached to the body. In the future, the wearable information terminal with its sensor attached to the body will enable the monitoring of health or position when it is equipped with the functions to automatically sense, process and transmit various information. Other applications may be found in investigative tracking of animals or simultaneous multiple-point measurement of chemicals for the preservation of the global environment by attaching wearable information terminals to animals or artificial objects.

A key factor in the above case is how to supply energy to a wearable information terminal. In the applications described above, in which replacement or recharge of batteries is impossible or inconvenient, a micro-generator becomes necessary. A proposal was, therefore, made for a system of power generation from vibration, and this system was manufactured on a trial basis. However, the energy generated by this system was insufficient and unstable, and it will be necessary to combine this system with a circuit so that its limited power can be utilized to the full.

Concrete examples of techniques for effective use of energy and its conservation include a switched-capacitor voltage-boosting circuit for the automatic generating system (AGS) of a wrist watch, and a self-sustaining digital signal processor (DSP) driven by vibration power generation. It is highly desirable that those systems will be combined with the power MEMS.

Investigative Research on the Merger of Micromachine Technology with Biometric Technology

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The merger of the medical field with micromachine technology is one of the most desirable applications of micromachine technology, and its study is going on ardently. Unfortunately, however, commercialized instances are quite few up to this time. It will therefore be necessary to clarify the demand from the medical site and the present state of micromachine technology.

(1) First, the hope and request for the development of micromachines from the medical site are under investigation in terms of diagnosis and therapy.

From the standpoints of diagnosis and therapy, the following can be cited:

(a) miniaturization of examination instruments, (b) non-invasive diagnosis and trace sample, (c) bed-side inspection, (d) microcapsules, (e) more precise examination, (g) medical treatment at home, and (f) electronic clinical charts and optomagnetic cards.

(a) Less-invasive or non-invasive therapy (b) therapy using microcap-sules, and (c) therapy on a microlevel.

(2) The following five points now attracting public attention are under investigative research.

2.1 DNA chips

Now under investigation is an entirely new technology for DNA analysis, a micro- and nano-chip technology, that enables the extraction, separation, and detection necessary for DNA analysis on a single chip. This technology takes advantage of semiconductor integration technology for fine processing, enabling analysis of even tens of thousands of samples in a few seconds. Also under investigation is a trend toward the development of syringe pumps, fine processing pumps, and electrophoretic technology.

2.2 Capillary electrophoresis

Capillary electrophoresis is one technique of chromatography. Research to apply chip electrophoresis with a glass capillary formed on the planar substrate to DNA analysis is energetically going on. A major feature of the analytical system using this capillary electrophoresis, i.e., a micro/miniaturized total analysis system (mTAS), is that no mechanical moving part is required because of the possibility of sending liquid by an electroosmotic phenomenon. This enables the control of fluid merely by applying voltage, and is advantageous for simplifying the chip mechanism as well as for miniaturizing the total system. This section describes capillary electrophoresis and the mTAS by making use of the former.

2.3 Liquid elements

The mTAS can broadly be divided into the following three systems:

1) A micro electro mechanical systems (MEMS) with a mechanical fluid control mechanism
2) A flowing system in which analysis is carried out in a continuous flow with a capillary electrophoresis system formed on the planar substrate
3) A batch system in which reaction and analysis are carried out in an extremely small chamber formed in a matrix state.

The flowing system is characterized by micronizing each element constituting the system, giving it a two-dimensional structure in which micro passes connecting the elements are arranged on the planar substrate. The properties of a fluid, which are expected to become particularly important for the flowing system, a mixer that takes those properties into consideration, and micro fluid control elements, including a micropump and a microvalve, will be introduced relative to their present states. Also, the CAD system and its application samples useful for designing the micro analytical system and micro fluid elements are described.

2.4 Optical measurement

The field of a biochemical analysis, particularly that of clinical chemical analysis can be considered best-suited for the application of micromachine technology related to optical measurement in biometry.

For clinical biochemical analysis using light, the following three items are necessary:

1) Separation for detection of only the object material
2) Labeling for optical detection of the object material
3) Quantitative measurement by appropriate spectrophotometry

In this section, the recent trend toward biochemical analysis using light will be outlined in terms of micronization.

2.5 Sensors

This section will describe, in particular, the following biometric sensors that can be realized by fine processing technology utilizing micromachine technology:

(a) catheter-mounting sensors, (b) mTAS, and (c) wristwatch type pulse measurers.

(3) As examples of application of the above techniques, the following less-invasive or non-invasive biometric instruments are introduced:

Application to (a) vital sign measurement, (b) biometric instruments, and (c) therapeutic instruments.

Investigative Research on Enhancing the Functions of Artificial Organs by Merging with Micromachine Technology

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In recent years organ transplantation following brain death has come to be accepted in our country. However, the current situation still faces many unresolved problems, such as the controversy of ethics, the legislative system, and the absolute deficiency on the supply side.

Artificial organs are technological products designed to circumvent the problems associated with brain-death organ transplantation as described above. However, the technology is not yet mature enough to replace organ transplantation. This report deals with the current state of research and development, the problems involved, and the possibility of accelerating the development of artificial organs by applying micromachine technology. The techniques of genetic engineering and histological engineering are being introduced for the development of artificial organs. In this context, micromachine technology is expected to play an important role now and in the future. This has led to the investigation of the relationship between the biotechnology, deemed essential for the development of artificial organs with biocells, and micromachine technology.

This investigative report emphasizes several items closely connected with micromachine technology, particularly in the development of artificial organs.

1) Small, dispersible artificial organs

The organs of a living body, particularly internal organs, including the heart, lung, liver, gall bladder, pancreas, kidney, and digestive organs are clustered in the living body. On the other hand, the skin, blood vessel system, lymphatic system, and bone and muscle system are widely present throughout the whole body. Additionally, there are also other forms of existence as seen in the nerve system with its branches stretching through the entire body despite the presence of the central system. Aside from the forms of the above organs in a living body, an investigation was made into the advantages to be gained from arranging artificial organs in a living body and related technical problems when the emphasis is placed on small dispersible artificial hearts. Those small artificial organs represent an important subject for development in inducing organs from biocells outside the body and maintaining them.

2) Microsensing technology in artificial organs

Various sensors to measure the state of a living body are required for actuating artificial organs in harmony with the living body. Attempts have been made in the past to miniaturize those sensors by making use of micromachine technology. For instance, a micro pressure sensor, pioneered in the medical application of micromachine technology, constitutes a very important part indispensable to modern medicine. The conditions to be sensed by artificial organs include physical quantities, such as a blood pressure, blood flow volume, airway pressure, and temperature, and chemical quantities, such as insulin concentration, blood sugar level, and oxygen partial pressure. Every sensor measures physical and chemical quantities while keeping contact with a living body in some form or other. What matters most in this connection is the stability at an interface between a living body and an artificial object. The problem for physical sensor is maintaining prolonged stability in measurement and that for chemical sensor is service life.

3) Artificial nerves and artificial sensors

The artificial nerve is an organ that receives and sends information by connecting the nerve system of a living body with an electronic circuit. Various nerve electrodes have been developed by applying micromachine technology to gain electric signal from the nerve system of a living body. Coding rules are also being clarified gradually, though still in the exploratory stage, so that information can be received from and sent to a living body using electric signals. The technique developed here has attained a level so high that products in an early stage can be marketed, including an artificial cochlear implant and a cerebral auditory implant as solutions to auditory problems. Although those products have enabled hearing to some extent, they are much inferior to healthy people in sensing quality. This is because the coding rules are not yet fully understood for the exchange of information with a living body, resulting in a failure to transfer appropriate signals to the living body. For high-quality signal transfer, the application of micromachine technology is indispensable, including the techniques of developing devices constructed with the steric integration of a multitude of nerve electrodes and the microsensing techniques of selecting object nerve fibers.

4) Hybrid tissues using intercellular substances

Cells in each organ tissue are arranged with their own structures. An intercellular substance between them not only maintains those tissue structures, but also constitutes two systems: one is to transport various materials to and from the cells, and the other is to transfer intercellular information through chemical factors. The intercellular substance with such a structure is not produced by simply cultivating cells alone. As one approach to the development of an artificial organ using biocells, an attempt was made to structure cultured cells similar to bio-tissue using an artificial intercellular substance so that the functions of an organ could be realized. Micromachine technology has been applied to the modification and formation of high-molecular compounds from which intercellular substances are formed, and to the control of the configuration of cells.

5) Control of the forms and functions of cells by mechanical stresses

It has been revealed that cells, in reaction to mechanical stresses, undergo changes in form, cell function, and gene expression. It is highly likely that an appropriate application of mechanical stresses in the development of artificial organs using biocells may promote the induction of cellular substances and the formation of tissue structures. The possibility was therefore probed of applying micromachines to the measurement and control of cell forms against mechanical stresses and the control and measurement of cell membranes on a molecular level.

Fukui Mciromachine Seminar

Fukui Micromachine Seminar was held in the afternoon of September 22 (Friday), 2000 at the Industrial Technology Center of Fukui Prefecture in Fukui City, sponsored by Micromachine Center, Fukui Association of Industry Technology and Industrial Technology Center of Fukui Prefecture and supported by Center for Cooperative Research in Science & Technology, Fukui University and Research Center for Advanced Technology, Fukui National College of Technology.

In this seminar, cutting-edge micromachine technologies were explained and the Industrial Science and Technology Frontier Program Project, “Micromachine Technology Research and Development”, which is now being conducted mainly by Micromachine Center, was outlined. Further, four concrete achievements were reported.

During recess, the portable exhibits of micromachine technology, “1mmØ SMA Micro Actuator” (OLYMPUS OPTICAL CO., LTD.) and “A Small Ladybug Actuator” (SANYO Electric Co., Ltd.) that had been brought to the venue were displayed and explanations were given by Mr. Kazuhiro Honma. In addition, Mr. Tomohiko Kawai introduced a micro ultra-precision machining trial product, giving the audience a precious opportunity to learn about micromachine technology.

Mr. Mitsuyasu Matsuo, Staff Researcher of Creative & Advanced Research Department of Industrial Technology Center of Fukui Prefecture acted as MC and presided at the meeting.

During the seminar, after an address by Mr. Masami Maeda, General Manager of Creative & Advanced Research Department of Industrial Technology Center of Fukui Prefecture, Mr. Takayuki Hirano, Executive Director of MMC, Professor Tokio Kitahara of Shonan Institute of Technology and Mr. Kazuhiro Honma, General Manager of Research Department of MMC delivered lectures “MMC Activities”, “Features of Micromachines” and “Outline of the Second Phase of Micromachine Project”, respectively.

In addition, during the presentation of achievements of the Industrial Science and Technology Frontier Project, the following lectures were delivered:

“A Control Method for Gathering Patterns of Distributed Micromachines” by Mr. Yoshiki Shimomura, Technical Group of KAWASAKI HEAVY INDUSTRIES, LTD.

“Micro Optical Scanning Sensor with Multilayer Stacked Device Structure” by Mr. Hiromi Totani, Central R&D Laboratory, Corporate Research and Development H. Q. of OMRON Corporation.

“Development of a Flexible Shaped Battery” by Mr. Kensuke Muraishi, Research Laboratory of MITSUBISHI MATERIALS CORPORATION.

“Ultra-precision micro structuring by means of mechanical machining” by Mr. Tomohiko Kawai, Basic Research Laboratory of FANUC LTD.

Many people showed a considerable interest in this seminar and a total of 100 people attended, including 55 people from 32 companies involved in the precision machinery industry, textile industry, eyeglasses frame producing industry, semiconductor processes and materials for them in Fukui Prefecture, Nara Prefecture and Ibaraki Prefecture, as well as 45 people from the universities, research laboratories and public institutions. Lively discussions took place after the lectures and enjoyed a meaningful seminar.

A scene from the Fukui Micromachine Seminar

Display of the portable micromachine technology exhibits

The 6th Forthcoming International Micromachine Symposium

The 6th International Micromachine Symposium, an annual event held in the autumn, will be held as usual on November 9 (Thursday) and 10 (Friday), 2000 at the Science Hall of Science Museum located in Kitanomaru Park in Tokyo.

This year's symposium has been planned by the organizing committee (committee chairman: Professor Naomasa Nakajima, Graduate School of The University of Tokyo) and the specific programs and the guest speakers have now been finalized by the program committee (committee chairman: Professor Hiroyuki Fujita, The University of Tokyo). Furthermore, an advisory board has been established, comprising 9 chief representatives from Europe and the United States who participated in the 6th Micromachine Summit held in Hiroshima this year, in order to reflect international perspectives and to enrich the content of the symposium.

Guest speakers will deliver lectures on the first day. During **Session 1 "Opening"**, guest speakers from the Ministry of International Trade and Industry, Agency of Industrial Science and Technology, and New Energy and Industrial Technology Development Organization will give opening speeches, followed by a special lecture to be given by Professor Shinichi Nitta, Vice President of Tohoku University, entitled "Advances in micromachines and artificial internal organs". It is expected that he will give a valuable lecture on micromachine technology and artificial internal organs based on his wide-ranging viewpoints.

During the morning of the first day, the following four lectures concerning the industrialization will be delivered:

Session 2 The Path to New Industries in the 21st Century

International Collaboration in MEMS:
Prof. Dominique COLLARD, IEMN

MEMS Standardization Course:
Dr. Michael GAITAN, NIST

Challenge to MEMS Commercialization:
Prof. Kyoichi IKEDA, Tokyo University of Agriculture & Technology

MEMS Opportunities in Photonic Communication Networks: Prof. Ming C. WU, UCLA

After lunch, three sessions are planned for the afternoon.

Firstly in the afternoon, the session "Thinking of Micromachines" is scheduled. This session has been planned in order to consider the future of micromachine from broader perspectives and has enjoyed a good reputation every year. This year, the relation between micromachines and health will be considered in this session; the keyword is "Health". We plan to invite three persons both from Japan and abroad who are conducting cutting-edge research in this field.

Session 3 Thinking of Micromachines – Health Care & Micromachine –

Approach to Common Diseases – How can new useful genes and/or polymorphisms be found? – :
Prof. Mitsuo ITAKURA, Tokushima University

Telehealth and ICT Industries:
Prof. Masako MIYAZAKI, University of Alberta

Future in Robotic Surgery: Lessons learned from "da Vinci":
Prof. Makoto HASHIZUME, Kyushu University

We will then invite four persons from abroad to report on the most recent trends in foreign countries.

Session 4 Overseas Activities

From Reseach to Applications : Experiences of HSG-IMIT: Prof. Hermann SANDMAIER, IMIT

Recent Activities in Italy:
Prof. Paolo DARIO, Scuola Superiore San't Annna

Activity in Canadian MEMS Research and Commercialization: Mr. Dan GALE, Canadian Microelectronics Corporation

Recent Micromachine Research and Development Activities in Korea:
Dr. Young-Ho CHO, KAIST

For the finale of the first day, four persons will introduce new research activities in which major new developments are expected.

Session 5 Innovative R&D

Power Microelectromechanical Systems (Power MEMS): Prof. Shuji TANAKA, Tohoku University

Micro Thermodynamics: Prof. Takayoshi INOUE, Tokyo Institute of Technology

New Approaches to Chemistry and Biochemistry through Microchip Technology:
Prof. Teruo FUJII, University of Tokyo

MEMS for Microwave/MM-wave Applications:
Prof. Koji MIZUNO, Tohoku University

On the second day, the state of progress of the Industrial Science and Technology Frontier Project, "Micromachine Technology" of Agency of Industrial Science and Technology, Ministry of International Trade and Industry, will be reported.

Firstly, Mr. Yoshikazu Yamaguchi, Director of Agency of Industrial Science and Technology will make a general speech on this subject, and then persons from three national research institutes (Mechanical Engineering Laboratory, Electrotechnical Laboratory and National Research Laboratory of Metrology) will deliver lectures on the present state of their research efforts and the future prospects for micromachine technology. The chief of Research and Development Department of our Center and four working group leaders will then give a summary of the second phase of the research and development of the Industrial Science and Technology project, and report on the trend survey of the technology. After that, researchers from among the supporting members of the R&D project will report on the details of the latest results of the Industrial Science and Technology project. The speakers and the titles of their lectures are as follows:

Session 6 Current Status of Micromachine Technology Project in ISTF Program

Overview of ISTF Program:
Mr. Yoshikazu YAMAGUCHI,
Director for Machinery and Aerospace R&D,
AIST, MITI

Research and Development on Micromachines at Mechanical Engineering Laboratory:
Dr. Shigeru KOKAJI,
Mechanical Engineering Laboratory AIST, MITI

Research on Micromachine Technology at Electrotechnical Laboratory:
Dr. Shigeoki HIRAI,
Electrotechnical Laboratory, AIST, MITI

Precision Measurement Standards & Micromachine:
Dr. Mitsuru TANAKA,
National Research Laboratory of Metrology,
AIST, MITI

The Outline of the Micromachine Project:
Mr. Tatsuaki ATAKA,
R&D Committee, Micromachine Center

Experimental Wireless Micromachine for Inspection on Inner Surface of Tubes:
Dr. Nobuaki KAWAHARA, Micromachine Center

Experimental Chain-type Micromachine for Inspection on Outer Surface of Tubes:
Mr. Munehisa TAKEDA, Micromachine Center

Experimental Catheter-type Micromachine for Repair in Narrow Complex Areas:
Mr. Ryo OHTA, Micromachine Center

Experimental Processing and Assembling System (Microfactory):
Mr. Kazuyoshi FURUTA, Micromachine Center

Development of Micro Coating Device:
Mr. Koichi IRISA, Aisin Cosmos R&D Co., Ltd.

Development of Microconnector Utilizing Deep X-ray Lithography Technique:
Mr. Tomohiko KANIE,
Sumitomo Electric Industries, Ltd

Wafer Level Three-dimensional Integration Technology for MEMS:
Mr. Akinobu SATOH, Fujikura Ltd.

Micro Force/Torque Measurement for Micromachines:
Mr. Yasushi ONOE, Yokogawa Electric Corp.

Development of a Microfine Active Bending Catheter:
Mr. Hideyuki ADACHI, Olympus Optical Co., Ltd.

Ultra-high Precision Machining Technology of Micro Structure:
Mr. Hiroya TERASHIMA, Fanuc Ltd.

The Micro-parts Conveyance Unit with Coil Module:
Mr. Yasumasa WATANABE,
Fuji Electric Corp. R&D , Ltd.

For your information, the 11th Micromachine Exhibition will be held on the ground floor of the Science Museum from November 8, 2000. A wide variety of companies, universities, and organizations involved in micromachine technology, including the supporting research members of our center will exhibit their products. The supporting member companies and three national research institutes will be displaying the specific results of their micromachine technology mainly achieved via the Industrial Science and Technology project. We believe that this symposium and the micromachine exhibition will provide a great opportunity to effectively obtain a comprehensive picture of cutting-edge micromachine technology. The participants of this symposium can freely gain admission to the micromachine exhibition by simply showing the participation cards.

The deadline for applications to the symposium is October 27, 2000. If seats are available, applications will be received on the day so that as many people as possible are able to attend this symposium.

SANYO Electric Co., Ltd.

Fusao Terada
Officer
General Manager
R&D Headquarters

1. The Challenge of Micromachine Technology

With the 21st century close at hand, Information Technology (IT) as typified by the Internet and the technological innovation to cope with environmental protection movements around the world are progressing rapidly. In order to be prepared for such technological innovation, SANYO Electric Co., Ltd. has long promoted research and development activities by formulating two major technological strategies, namely, user-friendly “Multi-media” and environmentally-friendly “Clean Energy”, under the corporate slogan of “We love people and the planet earth”. Among others, we have identified micromachine-related technology as a fundamental technology that may facilitate innovations in this business field in the 21st century, and have also participated in an Industrial Science and Technology Frontier project in an attempt to promote the development of device technology.

2. Development of Micromachine Technology

Regarding the development of micromachine technology under the Industrial Science and Technology Frontier project, we have been engaged in the development of photon energy transmission system technology that transmits energy wirelessly using light, and which is designed to be installed in the “Wireless micromachine for inspection on inner surface of tubes” that moves wirelessly in the piping of the power generating facility and transmits environmental information on the internal surface of the piping to the outside.

To date, we have developed a high-voltage micro photovoltaic device (which generates a voltage of 207 V/cm^2, the world’s highest) and a micro photovoltaic device to be mounted on a curved surface (which can be mounted on surfaces with a curvature radius up to 2 mm). (Refer to Fig. 1.)

Based on these micro photovoltaic device forming technologies, we are now engaged in the development of an advanced technology that will enable higher voltage and higher output, as well as system technologies such as sophisticated energy supply technology that enables a multiple voltage supply that may be utilized in light energy transmission devices equipped with new optical communications functions.

The recent results of our research and development efforts include “Advanced integrated micro wiring formation technology” and “Multiple voltage supply technology”. The former technology realizes the high speed formation (approx. 10 µm/s) of high step coverage micro wiring, by selectively forming tungsten deposits by means of the direct drawing type laser CVD method with 2 wavelength excitation that may be used to make the electrical connections at any places in the micro structures. (Refer to Fig. 2.) Utilizing the latter technology, photovoltaic devices have been developed that can be mounted in the self-propelled environment recognition system in the piping, and can supply voltages of 80 V and –7 V in piping 10 ϕmm in diameter. (Refer to Fig. 3.)

3. Future Stance

We would like to further evolve the device technologies such as the high-precision micromachining technology and photon energy transmission technology for micromachines that we have accumulated while participating in the Industrial Science and Technology Frontier project, and apply them to our new business fields, thereby developing totally new, market-creating products.

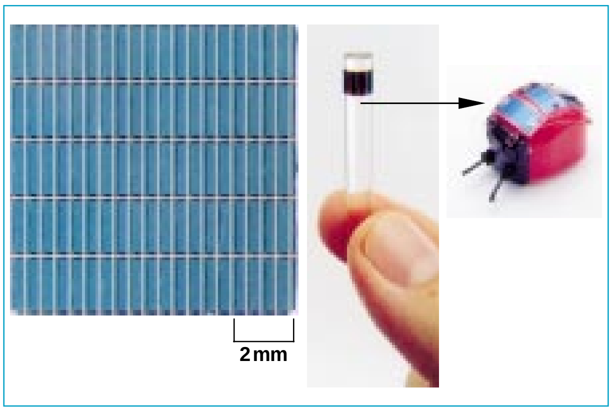


Fig. 1 High-voltage micro photovoltaic device (left) and micro photoelectric conversion device that can be mounted on a curved surface

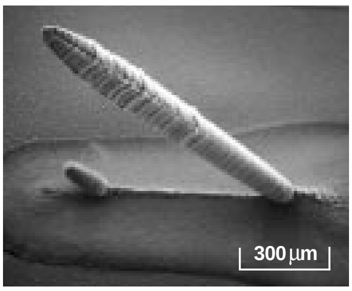


Fig. 2 Tungsten micro wiring

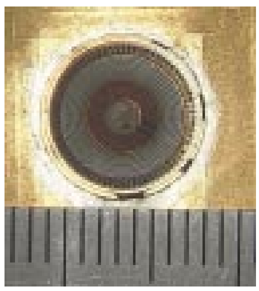


Fig. 3 Micro photovoltaic device

SUMITOMO ELECTRIC INDUSTRIES, Ltd.

Hiroshi Takada
General Manager,
Harima Research Laboratories

1. The Challenge of Micromachine Technology

The rapid growth of information and telecommunications technology offers immeasurable business opportunities to our company, since our main products are the electric wires and cables that support this technology. In order for our company to take advantage of current trends and to make rapid progress, it is essential not only to further develop our accumulated technologies, but also to integrate them with new, innovative technologies. We are engaged in R&D activities, aiming at LIGA technology based on our synchrotron radiation (SR) technology.

2. Development of Micromachine Technology

We have been participating in a government-sponsored R&D project and conducting element technology development for the LIGA process and its applied researches. During the 1st phase of the national R&D project, we have developed a high sensitivity resist and high transparency mask, that enables deep lithography with an industrial small-sized SR, conventionally carried out using a medium-sized SR. Furthermore, we have developed a technology that casts and bakes a slurry with the resist mold, thereby improving the ceramic's micromachining limit from 100 µm to 20 µm or less (refer to Fig. 1). This technology has contributed to the realization of the composite piezoelectric devices, an underwater signal oscillating device whose development had long been hoped for, in which a large number of micro piezoelectric ceramic rods stand close together in the resin sheet. This device has many strong points such as high resolution, high S/N ratio, broad band, etc. We have developed and commercialized the mass-production process because this device can break through the problems involved in ultrasonic examination.

During the second phase of the national R&D project, we were engaged in the development of micro connectors to be used for inspection on outer surface of tubes. This connector is equipped with an electromagnetic actuator for automatic insertion and removal. The combination of the actuator's structure and the terminal structure shown in Fig. 2 has realized a connector system having a large alignment tolerance. We believe it is highly likely that these connectors will be put into practical use in the field of electronic components packaging, where densification is expected to accelerate.

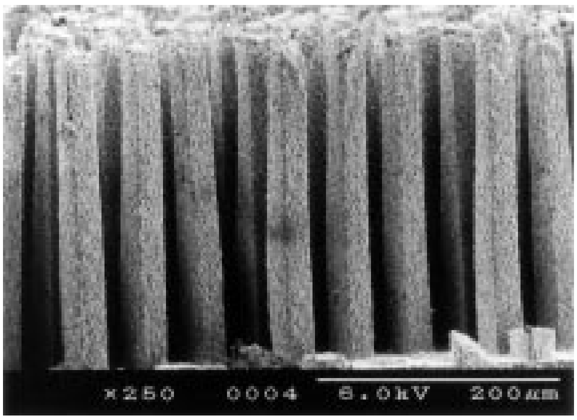


Fig. 1 Ceramics rod array (25 µm square, 250 µm in height)

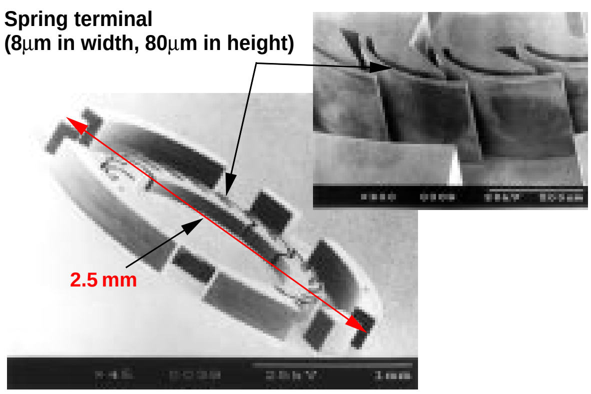


Fig. 2 Micro-connector (receptacle)

3. Future Stance

Since LIGA technology will help realize an aspect ratio of more than 30 and machining accuracy of ± 0.5 µm, and will also be applicable to machining of various types of materials such as metals, resins or ceramics, it is a highly promising micromachine technology. We would like to expand the fields of its application by seeking integration of the LIGA technology and other micromachine technologies, while striving for cost reductions. We are committed to producing the unique products toward the 21st century.

The 2000 Micromachine Mission to Europe

In conjunction with the holding of micromachine seminars in Europe, Japanese mission members visited some local research institutes.

Industrial Institute of Electronics (PIE)
Location: Warsaw, Poland
Date: Tuesday, Sept. 5
Parties met with: Dr. Jerzy Kern, Prof. Marek Genera, and others

The wide-ranging scope of research conducted by PIE includes work in mechatronics, automation, and machine processing.

Institute of Electronic Materials Technology (ITME)
Location: Warsaw, Poland
Date: Tuesday, Sept. 5
Parties met with: Prof. Dr. Andrzej Jelenski, Mr. Tadeusz Zero, and others

The Institute of Electronic Materials Technology (ITME) consists of 280 employees and 12 professors. Funding for its operations is drawn from three sources: 40% from government-subsidized academic research, 40% from technology and product development projects, and 20% from sales-generated income. ITME researchers devote much of their effort to such research topics as (1) special single-crystal materials, such as silicon and high-temperature superconductors, (2) glass materials, including fiberscopes and optical filters, and (3) epitaxial technology. ITME reportedly sells products in some of these areas, such as glass materials (filters and image guides), single-crystal materials, and masks.

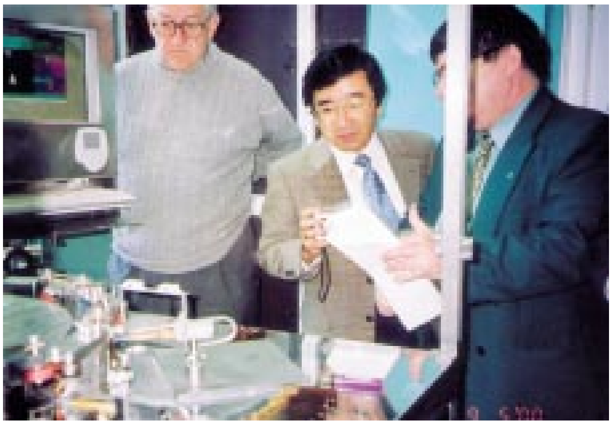
University of Mining and Metallurgy, Department of Electronics
Location: Krakow, Poland
Date: Wednesday, Sept. 6
Parties met with: Prof. Stanislaw Nowak, Prof. Tadeusz Pisarkiewicz, Dr. Andrzej Kolodziej, and others

The University of Mining and Metallurgy, which became an independent institution in 1919, has a faculty of 106 professors and a staff of 3,828. This engineering school consists of 14 departments specializing in such areas as mining, metallic materials, and electricity and electronics. The Department of Electronics, which welcomed the mission members, has just embarked on MEMS activities. It wants to develop this new undertaking as a core technology. At the time of the visit, researchers were exploring such themes as MEMS structural drawing using CAD and device evaluation techniques. While the department does not have a clean room, it has been undertaking μ TAS (micro total analysis system) manufacturing on a trial basis using foundry facilities in Europe.

Fachhochschule Wiener Neustadt
Location: Wiener Neustadt, Austria
Date: Thursday, Sept. 7
Parties met with: Prof. Helmut Detter, Dr. Gordana Popovic of the Technical University of Vienna, and others

Located in Wiener Neustadt, which is less than an hour's drive from Vienna, this Fachhochschule (FH) is a university that specializes in engineering and emphasizes practical educational research. One of six FH institutions in Austria, this school was established in 1994. Its student body totals 1,400. Prof. Detter, who serves as its president, is also a professor at the Technical University of Vienna (TU). Working jointly with TU, this FH is moving ahead with research in such areas as biosensors and microsensors, precision manufacturing, micromechanisms, simulations, and optical devices.

The two schools also take a proactive approach to spinning research results into business ventures. They have set up a venture company and are pursuing the commercialization of a micro-molding machine. The Technology and Research Center, a facility aimed at fostering the development of venture businesses, is located in an industrial park adjacent to this FH. The members of the mission from Japan toured this center, which is scheduled to open this autumn.



At the Industrial Institute of Electronics in Poland

At the Fachhochschule Wiener Neustadt in Austria

Micromachine Seminars in Europe

Seminars were held in Warsaw, Vienna, and Lausanne as part of an industry trade mission disptached to Europe by the Japan External Trade Organization (JETRO) from Sept. 2 to 13, 2000. The seminars were organized jointly with local research institutions and organizations involved in the field of micromachines in Poland, Austria, and Switzerland. The objective of the three seminars, which are described below, was to disseminate information about micromachine technology in Japan and to provide opportunities at each location for interaction with representatives of micromachine organizations and specialists in this field.

<Lectures by members of the Japanese mission>
"Future Prospect of Micromachine"
Takayuki Hirano, Micromachine Center

"Medical Application of Micromachines"
Oyo Ota, Olympus Optical Co., Ltd.

"The Microfactory in Japanese National R&D Projects"
Tatsuaki Ataka, Seiko Instruments Inc.

"Multiple Distributed Micromachine System"
Koji Naemura, Mitsubishi Electric Corporation

"In-pipe Wireless Inspection Micromachine"
Nobuaki Kawahara, Denso Corporation

"Micromachined Silicon Sensors"
Hideto Iwaoka, Yokogawa Electric Corporation

"Applications of Deep X-ray Lithography"
Yoshihiro Hirata, Sumitomo Electric Industries, Ltd.

<Seminar highlights>
1. Joint Seminar Poland-Japan on Micromachining
Date: Monday, Sept. 4
Location: Industrial Institute of Electronics, Warsaw, Poland
Attendance: 40 participants (primarily from universities and research institutes located in and around Warsaw, Krakow, and other Polish cities)

Organized jointly with Institute of Electronic Materials Technology, this seminar featured six lectures given by speakers from Polish university circles and the country's national research laboratory facilities. They addressed such subjects as biosensors and sensors for chemical analysis. A discussion open to all participants prior to the seminar's conclusion produced a lively exchange of views concerning the possibility of cooperation between the micromachine industry in Japan and research organizations in Poland.

2. Joint Japan-Austria Seminar on MEMS
Date: Friday, Sept. 8
Location: Technical University of Vienna, Austria
Attendance: 95 (from the Austrian business, academic, and research communities)

This well-attended seminar, which was held in cooperation with such local organizations as the Austrian Society for Microsystem Technology, was extremely well received. Nine presentations made by speakers from Austrian universities and companies focused on micromachine technology research and development activities that specifically target applications in such spheres as telecommunications networks, the utilization of outer space, automobiles, and materials science.

3. Swiss/Japan Micro-technology Seminar
Date: Monday, Sept. 11
Location: Ecole Polytechnique federale de Lausanne (EPFL), Switzerland
Attendance: 35 (primarily from universities and businesses)

This seminar was held in cooperation with such organizations as the Ecole Polytechnique federale de Lausanne (EPFL). The Swiss segment of the program included reports by representatives of the EPFL and the University of Neuchatel on four research initiatives, including projects related to piezo actuators, nano tools designed for utilization under microscopes, and GHz-range resonators.

Seminar in Warsaw

Seminar in Vienna

The Technical Report: "Measurement and Evaluation Methods of Micromachine"

Professor Kimiyuki Mitsui
Faculty of Science and Technology,
Keio University

Micromachine technology has engendered great hopes as a technology that will be the support and driving force of promising industrial fields in the future. This technology is a typical interdisciplinary technology that spans multiple fields including mechanical engineering, electrical engineering, physics, science, biology, medical science, etc. At present, it is in the basic research and development stage and concrete product images are not necessarily clear. However, the R&D efforts on individual element technologies are producing specific results, and it is expected that their applications will exert a major influence on a wider range of industrial fields. In order to facilitate the advancement of such micro-machine technology and to encourage its use across a wider range of industrial fields, standardization appears to be essential. To this end, the Measurement and Evaluation Method Working Group of The Committee on Micromachine Standardization in the Micromachine Center (Measurement and Evaluation Method WG) has conducted a research study with the aim of promoting the standardization of the measurement and evaluation method, in the hope that it will be used as the basis for micromachine technology.

Based on the results of a questionnaire survey conducted in fiscal 1993 that polled national research institutes and the R&D supporting members, the shapes and dimensions, forces and torques, fluid-related and material characteristics were selected as target fields since the necessity of conducting measurements using micromachine technology was deemed to be highest in these areas. The first to the third items shown above were started in fiscal 1994 and the item on material characteristics in fiscal 1995.

During fiscal 1999, the results of the research studies were compiled and published in June, 2000 as a technical report from the Micromachine Center.

The major objectives of the publication of the technical report are firstly to propose the items that require standardization of measurement technologies in the field of micromachining and to compile the contents of the reports on the research studies conducted from fiscal 1994 to fiscal 1998. This technical report describes the results of the literature researches in various fields, their sources as well as a summary of each document, so we believe it will be useful for the researchers and engineers who have an interest in this issue.

This technical report is an A-5 size booklet with 369 pages, with individual chapters compiled by each sub-working group (SWG) on "Shapes and dimensions", "Forces and torques", "Fluid-related" and "Material characteristics". In order to illustrate the overview of the contents, a summary (suggestions) of the results of research conducted by each SWG is described below.

"Shapes and dimensions"

It is necessary to promote the development of the general purpose measurement method and peripheral technologies that can be used in the measurement of various types of micro components. It is expected that, by accumulating the measured data on components of different specifications using such measurement methods, the specific items that require standardization will gradually be identified. According to the results of the needs survey, the demand for the non-contact measurement was strong.

In order to evaluate the measurement techniques, it will be necessary to measure the standard measuring specimen using each measurement instrument and compare the results. By doing this, the basic properties of each measurement technique, items that can be measured and evaluated, as well as the degree of accuracy will be clarified, and debate on common ground will become possible. Therefore, to promote the standardization of the measurement method, it is necessary to propose the shapes and dimensions and the materials of the standard measuring specimens, after identifying the measurement items to be evaluated.

It is necessary to review the dimensional tolerances of parts whose size is 3mm or less, which are not specified by current JIS (Japanese Industrial Standards). In order to fabricate the micromachine by combining parts, it is necessary to secure the interchangeability of parts and to clarify the range of allowable dimensional differences of these parts so as to facilitate automated assembling. From this viewpoint, it is necessary to conduct basic works in order to specify the dimensional tolerance of micro components.

The JIS that specifies the setting of datum affecting the measurement of micro holes and cylinders having a high aspect ratio, and the curvature radius at the tip of the gauge head of the roundness measuring instrument is not at present applicable to the measurement of micro components, so it is necessary to revise the JIS so that the evaluation of micro components is taken into account.

"Forces and torques"

When we review the results of the study and examination conducted this time from the viewpoint of standardization, it becomes evident that the testing methods and laboratory equipment include those converted from commercially available products sold on the market, laboratory equipment fabricated independently for specific purposes, test specimens in miniature size made of silicon, etc. Each test method is mainly worked out based on the ideas of individual researchers in order to achieve the utmost limit of the resolution (accuracy) or to widen the range of measurement.

In the future, it will be necessary to establish laboratory equipment, experimental conditions, methods for experiments, and methods for evaluation that will be common worldwide. At least in the field of measurement of forces and torques, it is necessary to adopt an evaluation method that is universally acceptable in order that discussions may be conducted on the same ground worldwide. A problem in the measurement of forces and torques when viewed in terms of measurement needs is that, as expected, there are cases where measurements below the measurable range of the measuring instrument sold on the market are required. In addition, it has been clarified that the measurement of a micro portion is required and that care must be exercised toward the influence by displacement on force and/or torque generated by the actuator.

The increased necessity for the measurement of micro portions is inevitable because the size of the micro actuator has been reduced. However, as the size of the actuator is made smaller, the absolute stroke (movable range) decreases, so that a corrective measure must be taken because, in the deflection method, the displacement of the measuring point due to the deformation of the measuring instrument by the generated force largely influences the apparent measured value, while on the other hand, in the measurement of torques, the accurate setting of the measuring point is required, including the accuracy of the measuring radius.

“Fluid-related”

For mechanical fluid control devices, we compiled a list of the existing methods for measuring the properties of the micro pumps, micro valves and flow rate sensors. While there are many studies utilizing electro-osmotic flow for non-mechanical fluid control devices, some other devices and control methods have also been proposed; such situation necessitates the establishment of a standard method for evaluating the properties. However, since it is difficult to evaluate the properties of a single device, it is necessary to develop simulation technology intended for fluid analysis and setup a proper database for that purpose.

In order to set up the database efficiently, unification of the measurement methods and the measurement data shared by the research organs is necessary. Therefore, in order to promote the standardization of the devices, normalization of the evaluation items and evaluation parameters are of urgent necessity.

Peculiarities of the micro fluids physical phenomena are gradually being elucidated, in the form of the coefficients of viscous friction and pressure distribution of the micro channel flow, however, on the whole, the experimental data are insufficient and contradictory data exist. In order to standardize the measurement of the physical quantities of pressure, etc., it is necessary to record accurate information on the measurement items, resolution, shapes of channels and their materials, working fluids and their properties as well as the measurement environment, in addition to the specifications for the measurement instruments. If the physical models in the micro regions are elucidated through the accumulation of experimental data, the numerical simulation will become key technology in designing and developing high performance micro fluid devices.

“Material properties”

Concerning the individual methods for testing the materials for micromachines: In the tensile test, the thickness of the test specimen is in the unit of sub-µm to several tens of µm, so that the flexural rigidity of the test specimen is extremely small; therefore, it is necessary to specify that the method for handling and attaching the specimen to the tester should not influence the system of measurement. Furthermore, due to the internal structures of the materials and the dimensions of the test specimens, handling similar to the conventional macroscopic material properties may be difficult.

For the bending test, there are large differences in the shape and size of the test specimens, the size of the support and the distance between supporting points, so that there are many points to consider when applying it to the testing of materials for micromachines. The test method using a cantilever seems to be a simple and easy measurement method because it is not difficult to produce and support the test specimen. With respect to this test method, there are many reports that the modulus of elasticity is measured instead of the flexural strength. The reason for this may be that since it is assumed that the moving part operates in the elastic region, the modulus of elasticity alone is the point of concern and other parameters are not so important in practical use.

Of the various hardness test methods, the Vickers hardness test has been widely used to evaluate the mechanical properties of membranes. However, in the field of micromachines, the indentation test using a micro indentator (nano-indentation) has come to be used, and ISO is considering standardization of the test method and certification of the tester.

One method for measuring the elastic modulus using the resonance method is the non-destructive and non-contact testing, which seems to be an appropriate method for measuring the material properties, provided that attention is paid to the measurement conditions such as the influence of air damping, etc., in order to secure a valid measured value.

JIS specify the fixed temperature loading test method and the fixed strain thermal cycle test method for the shape memory alloy coil springs as an example of the functional materials. The test method for the functional device is specified in addition to material properties.

Latest Micromachining Technology — Part 3

Miniaturization of Mechanical Processing — Precision Machining

Professor Kazuo Sato
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In the first and second issues, the technologies to produce microstructures using etching or thin-film formation based on the photolithography were explained. This issue describes cutting, grinding and polishing that have long been known as machining techniques, as well as the relatively new processes such as electro-discharge machining and beam processing, which are all categorized as "Precision Machining". Figure 1 shows the configurations of cutting, grinding, polishing, electro-discharge machining and beam processing.

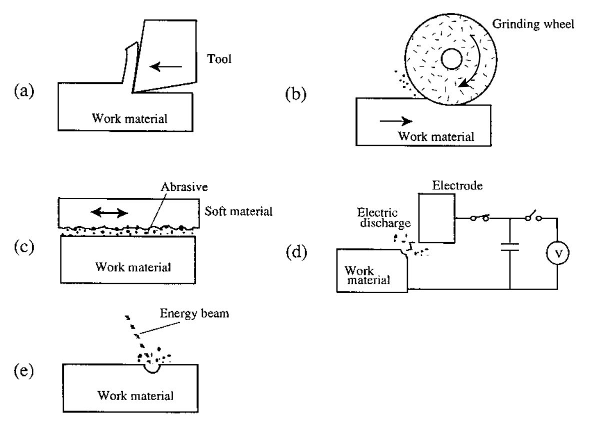

Fig. 1 Configuration of precision machining processes (a) cutting, (b) grinding, (c) polishing, (d) electro-discharge machining, (e) beam processing

1. Cutting, grinding and polishing

Cutting, together with grinding and polishing, has long been used to produce sophisticated 3-D shapes from metalic materials. In order to achieve micromachining using cutting, the following are prerequisite:

(1) The cutting edge of the tool is sharp; it cuts well.
(2) The relative movement of the tool and the work material is accurate.

To achieve (1), a small diamond chip that is hard and has a small friction coefficient is used for the tool. For (2), a mechanism that provides firm and precise rotational and linear motion to the tool and/or the work material as well as a mechanism that feeds the tool accurately are required. Figure 2 shows an example of a screw shaft of approx. 0.1mm in diameter fabricated using the micromachining lathe developed by Higuchi et al. of The University of Tokyo.

Grinding removes the work by rotating the grinding wheel made of fine abrasive grains at high speed. Since each of a large number of cutting edges removes the work little by little, the affected layer is generally less than that of cutting and the surface finish is relatively smooth. However, in the grinding method, it is assumed that the abrasive grains come off the grinding wheel, making it inadequate for the purpose of fabricating minute shapes. The grinding wheel wears drastically, so that making a small grinding wheel would be pointless, and therefore, grinding is rarely used for fabricating minute shapes.

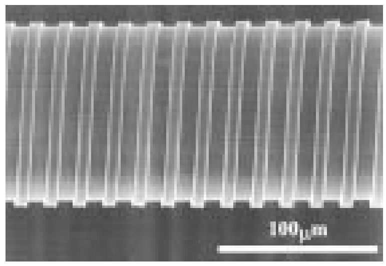

Fig. 2 Example of a screw fabricated by fine cutting (Courtesy of Dr. Y. Yamagata and Prof. T. Higuchi)

Polishing is generally used to obtain a fine surface with a less affected layer, or to obtain a flat surface on a relatively large area, rather than for fabricating shapes. In order to obtain a flat surface on a relatively large area, polishing is widely used, for example, for the processing of the surfaces of silicon substrates to be used as the substrates of LSI, and for the final finishing processing of the magnetic disc record heads, etc. With the surface processing application of the single crystal substrates in particular, polishing is essential for fabricating the SOI (Silicon-On-Insulator) substrates on the surface of which a thin single crystal layer of the order of microns thick is left and for the CMP (Chemical Mechanical Polishing) processing in which the irregular surface resulted from the fabrication of LSI is made flat in order to apply 3-D wiring onto the LSI surface. Even micromachines working on silicon substrates will benefit from a polishing technique that smoothes surfaces when utilizing the silicon-on-insulator substrates or adhering two substrates together, etc.

2. Electro-discharge machining

The principle of electro-discharge machining is as follows: a controlled discharge pulse is generated between the electrode and the work material, and its heat energy melts, spatters and removes the work material. Conventionally, this machining method was mainly used for machining of hard materials that were difficult to process; for example, machining of cemented carbide used for punches and dies for plastic forming of metals. The electro-discharge machining has attracted attention because, although its machining efficiency is low, it can achieve micromachining, and its application for fabricating micromachines is currently being studied. When the electrode is miniaturized, a new technical problem occurs where the vibration and wear of the electrode deteriorates machining accuracy. A machining system, in which the thin wire that constitutes the electrode is veered away and the vibration of the wire is prevented, was developed by Masuzawa et al. of The University of Tokyo and is in practical use. Figure 3 shows an example of the fabrication of miniature parts that is processed by micro electro-discharge machining. Electro-discharge machining can achieve processing of 3-D shapes equivalent to that achieved by turning, milling and drilling machines, so that 3-D machining with a high degree of freedom is possible. On the other hand, one of the disadvantages of the electro-discharge machining is the fact that the finished surface is coarse because the surface is covered by marks due to electro-discharging. In the event that a smooth surface finish is required, it is necessary to polish the surface afterwards. Other disadvantages or reasons why the application of the electro-discharge machining is limited include its low removal rate and the unclean machining environment.

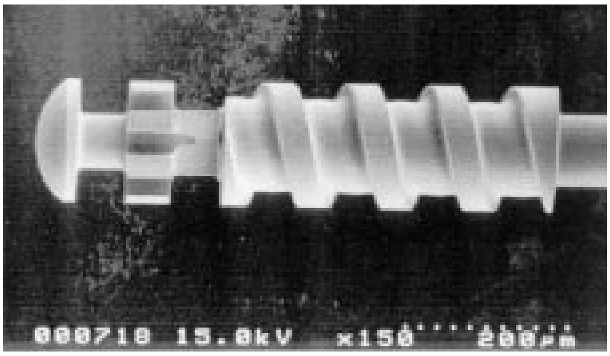

Fig. 3 Example of electrodischarge machining (Courtesy of Matsushita Electric Co. Ltd.)

3. Beam processing

The material can be partly melted, sputtered, evaporated and removed by irradiating an energy beam of a small diameter such as a laser beam, electron beam or an ion beam, etc. Any shape can be fabricated by scanning the beam or changing the irradiating positions by moving the work material.

The laser beam includes one that melts, sputters and evaporates the material using heat energy by means of long-wave length light sources such as CO_2 and YAG laser. and one that decomposes and evaporates the material by directly breaking the bonds between the molecules of the material by means of a short-wavelength light source, such as the eximer laser. Generally, laser beam processing is applied to the fabrication of holes in various types of materials such as metal, plastic, and ceramics.

Electron beams and ion beams are electrically charged particles that are accelerated by the electric field and strike the work material with a high energy force. While the electron beam removes the work material mainly by the agency of heat, the ion beam removes the material mainly by physical impact. The electron beam processing melts and evaporates the material, so that like the thermal laser processing, the molten materials may get re-deposited to the work surface. The ion beam processing does not inflict thermal damage to the work material, so that it is applied to the preparation of cross-sectional samples to be observed using an electron microscope.

On the other hand, when the electrically charged particles such as electrons and ions are irradiated on the surface of the insulating material, the surface is electrostatically charged and thereby the speed of the subsequent ion is decelerated, resulting in decreased machining efficiency. In order to avoid this problem, machining is executed by a beam electrically neutralized, which can be achieved by irradiating an electron beam to the accelerated ion beam. A device that conducts the micromachining using an argon atom beam has been developed on this priciple.

Table 1 shows the working principle, advantages and disadvantages of the precision machining processes described above.

Table 1 Working principle, advantages and disadvantages of precision machining processes

	Working principle	Advantages	Disadvantages
Cutting	Physical removal of work by cutting tool	Potential to fabricate arbitrary 3-D shapes	Track of tool marks, Difficult to fabricate small holes
Grinding	Physical removal of work by bound abrasive	Relatively smooth surface finish	Difficult to make a small abrasive wheel, Small holes cannot be fabricated
Polishing	Physical removal of work by dispersed abrasive particles	Excellent smooth surface finish	Difficult to control surface profiles
Electro-Discharge Machining	Splashing melted work by electric discharge	Applicable for hard materials	Coarsening of surface, Low removal rate
Beam Process-ing	Splashing melted, evaporated, or decomposed materials by irradiation	Applicable for hard materials	Deposition of splashed materials on the work surface

4. Consideration on the application fields

Machining can fabricate complex 3-D curved surfaces utilizing NC. In this respect, the flexibility of machining is far superior to the lithographic processing. However, its application is limited to small-lot production, implying that it can only be useful in limited fields of application, such as sophistication of endoscopes and catheters, prototyping scientific instruments, etc. In contrast, in the lithographic processing, a large number of small machine elements to be fabricated can be arranged in precise locations on the silicon chip, and up to one million machine elements can be fabricated on one silicon chip; it is far superior to machining in terms of its impact on productivity in industry. Such processing characteristics can be fully utilized in the fields of information and telecommunications, and household appliances. As mentioned above, the characteristics of machining and lithographic processing are different and consequently they are used in different fields. In the meantime, attention should be paid to the combination of machining and lithographic processing. Good examples are the technology for polishing the surfaces of silicon substrates and the mass fabrication of electro-discharge electrodes at one time utilizing lithographic processing.

THE SIXTH INTERNATIONAL MICROMACHINE SYMPOSIUM

Foundation of Industrial Technology in the 21st Century

Date: November 9-10, 2000
Venue: Science Museum, Tokyo
Organizers: Micromachine Center / Japan Industrial Technology Association
Supporters: Ministry of International Trade and Industry (MITI) / Agency of Industrial Science and Technology (AIST) / New Energy and Industrial Technology Development Organization (NEDO)
Cooperators: The Federation of Micromachine Technology / Micromachine Society / Research Committee on Micromechatronics / Japan Power Engineering and Inspection Corporation / Japan Robot Association / Japan Machinery Federation
Registration Fee: ¥15,000 (Including proceedings and reception party)
Application: Complete the symposium registration form and FAX to Micromachine Center by Oct. 27, 2000
Contact: Micromachine Center
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PROGRAM (Tentative, as of September 25, 2000)

November 9, 2000		
9:00 ~	Registration	
Session 1: Opening		**Chairman: Mr. T. HIRANO**
9:30	Opening Declaration	Mr. Takayuki HIRANO, Executive Director, Micromachine Center
9:30 ~ 9:35	Opening Remarks	Dr. Tsuneo ISHIMARU, Chairman, Micromachine Center
9:35 ~ 9:43	Guest Speech	Mr. Shinichirou OOTA, Director-General, Machinery and Information Industries Bureau, MITI
9:43 ~ 9:51	Guest Speech	Dr. Koji KAJIMURA, Director-General, AIST, MITI
9:51 ~ 10:00	Guest Speech	Mr. Hideyuki MATSUI, Chairman, NEDO
10:00 ~ 10:40	Special Guest Speech: Micromachines and Artificial Organs	Prof. Shinichi NITTA, Tohoku University
Session 2: The Path to New Industries in the 21st Century		**Chairman: Prof. I. SHIMOYAMA**
10:40 ~ 11:00	International Collaboration in MEMS	Prof. Dominique COLLARD, IEMN
11:00 ~ 11:25	MEMS Standardization Course	Dr. Michael GAITAN, NIST
11:25 ~ 11:45	Challenge to MEMS Commercialization	Prof. Kyoichi IKEDA, Tokyo University of Agriculture & Technology
11:45 ~ 12:10	MEMS Opportunities in Photonic Communication Netwoks	Prof. Ming C. WU, UCLA
12:10 ~ 13:15	Lunch	
Session 3: Thinking of Micromachines — Health Care & Micromachine —		**Chairman: Prof. H. MIURA**
13:15 ~ 13:35	Approach to Common Diseases – How can new useful genes and/or polymorphisms be found? –	Prof. Mitsuo ITAKURA, Tokushima University
13:35 ~ 14:00	Telehealth and ICT Industries	Prof. Masako MIYAZAKI, University of Alberta
14:00 ~ 14:20	Future in Robotic Surgery: Lessons learned from "da Vinci"	Prof. Makoto HASHIZUME, Kyushu University
14:20 ~ 14:40	Break	
Session 4: Overseas Activities		**Chairman: Prof. K. IKUTA**
14:40 ~ 15:00	From Reseach to Applications : Experiences of HSG-IMIT	Prof. Hermann SANDMAIER, IMIT
15:00 ~ 15:20	Recent Activities in Italy (tentative)	Prof. Paolo DARIO, Sscuola Superiore San't Annna
15:20 ~ 15:40	Activity in Canadian MEMS Research and Commercialization	Mr. Dan GALE, Canadian Microelectronics Corporation
15:40 ~ 16:00	Recent Micromachine Research and Development Activities in Korea	Dr. Young-Ho CHO, KAIST
Session 5: Innovative R&D		**Chairman: Prof. H. FUJITA**
16:00 ~ 16:20	Power Microelectromechanical Systems (Power MEMS)	Prof. Shuji TANAKA, Tohoku University
16:20 ~ 16:40	Micro Thermodynamics (tentative)	Prof. Takayoshi INOUE, Tokyo Institute of Technology
16:40 ~ 17:00	New Approaches to Chemistry and Biochemistry through Microchip Technology	Prof. Teruo FUJII, University of Tokyo
17:00 ~ 17:20	MEMS for Microwave/MM-wave Applications	Prof. Koji MIZUNO, Tohoku University
18:00 ~ 20:00	Reception Party at KKR Hotel Tokyo	
November 10, 2000		
9:00 ~	Registration	
Session 6: Current Status of Micromachine Technology Project in ISTF Program		**Chairman: Mr. K. HOMMA**
9:30 ~ 9:45	Overview of ISTF Program	Mr. Yoshikazu YAMAGUCHI, Director for Machinery and Aerospace R&D, AIST, MITI
Researches and Future Prospects on Micromachine Technology in National Research Laboratories		**Chairman: Mr. K. HOMMA**
9:45 ~ 10:00	Research and Development on Micromachines at Mechanical Engineering Laboratory	Dr. Shigeru KOKAJI, Mechanical Engineering Laboratory, AIST, MITI
10:00 ~ 10:15	Research on Micromachine Technology at Electrotechnical Laboratory	Dr. Shigeoki HIRAI, Electrotechnical Laboratory, AIST, MITI
10:15 ~ 10:30	Precision Measurement Standards & Micromachine	Dr. Mitsuru TANAKA, National Research Laboratory of Metrology, AIST, MITI
10:30 ~ 10:40	Break	
R&D in Micromachine Center		**Chairman: Mr. K. HOMMA**
10:40 ~ 11:10	The Outline of the Micromachine Project	Mr. Tatsuaki ATAKA, R&D Committee, Micromachine Center
● Systems		**Chairman: Mr. K. HOMMA**
11:10 ~ 11:30	Experimental Wireless Micromachine for Inspection on Inner Surface of Tubes	Dr. Nobuaki KAWAHARA, Micromachine Center
11:30 ~ 11:50	Experimental Chain-type Micromachine for Inspection on Outer Surface of Tubes	Mr. Munehisa TAKEDA, Micromachine Center
11:50 ~ 12:10	Experimental Catheter-type Micromachine for Repair in Narrow Complex Areas	Mr. Ryo OHTA, Micromachine Center
12:10 ~ 12:30	Experimental Processing and Assembling System (Microfactory)	Mr. Kazuyoshi FURUTA, Micromachine Center
12:30 ~ 13:30	Lunch	
● Elements		**Chairman: Mr. T. ATAKA**
13:30 ~ 13:50	Development of Micro Coating Device	Mr. Koichi IRISA, Aisin Cosmos R&D Co., Ltd.
13:50 ~ 14:10	Development of a Microconnector Utilizing Deep X-ray Lithography Technique	Mr. Tomohiko KANIE, Sumitomo Electric Industries, Ltd.
14:10 ~ 14:30	Wafer level Three-dimensional Integration Technology for MEMS	Mr. Akinobu SATOH, Fujikura Ltd.
14:30 ~ 14:50	Micro Force/Torque Measurement for Micromachines	Mr. Yasushi ONOE, Yokogawa Electric Corp.
14:50 ~ 15:00	Break	
15:00 ~ 15:20	Development of a Microfine Active Bending Catheter	Mr. Hideyuki ADACHI, Olympus Optical Co.,Ltd.
15:20 ~ 15:50	Ultra-high Precision Machining Technology of Micro Structure	Mr. Hiroya TERASHIMA, Fanuc Ltd.
15:50 ~ 16:10	The Micro-parts Conveyance Unit with Coil Module	Mr. Yasumasa WATANABE, Fuji Electric Corp. R&D, Ltd.
Session 7: Closing		**Chairman: Mr. T. HIRANO**
16:10 ~ 16:20	Closing Address	Mr. Hikaru HAYASHI, Managing Executive Director, Japan Industrial Technology Association

Pictures on the cover: Winning artworks in the Micromachine Drawing Contests
Rescue machine for mountaineering accidents, Mr. Drain-pipe Cleaner, Landmine detector, Little MM nurses, Pichi and Minya (from top to bottom)

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