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MICROMACHINE

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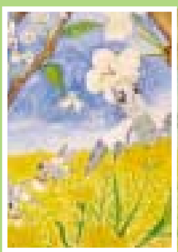
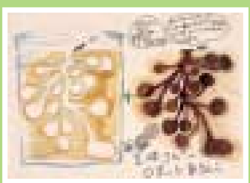
MICROMACHINE CENTER





Commenting on the Micromachine Drawing Contest

Ryoze Yamashita
Associate Professor,
Tokyo National University of Fine Arts and Music

This marks my third to participate in the screening of the Micromachine Drawing Contest. This contest is quite intriguing with a considerable number of entrants attending, classified into school children from primary and junior high schools.

For those school children, the micromachine is not a real device, but a future or imaginary one. This contest, therefore, aims at screening imaginary pictures. This screening emphasizes not on the excellence of a little artist expresses or tries to express his or her idea, suggestion or hope in the picture, that is, how he or she thinks about the micromachine.

It is widely known that a picture enriches our inner selves in a broad sense, particularly when we draw imaginary pictures. Drawing imaginary pictures is quite effective for training our minds to nurse flexible thinking.

What we envisage is fragmentary like a jigsaw puzzle. By drawing a picture, however, our imagination works to fill up what is vague, enabling us to expand our imagination.

The sense of filling up and the energy to expand activate our brains.

On finding that it is easier to understand what we think if we draw a picture, I was beside myself with joy as a fifth-year-grade boy. I disliked schooling except for drawing and manual arts, which I liked best, physical education, which made me feel happy, and science, which I liked a little bit. One day, however, our teacher wrote an arithmetic problem on the blackboard saying "This problem is hard to solve. Solve it, the lot of you". On it, a picture flashed into my mind.

I drew the picture in the notebook, and I readily solved it.

After that, I became able to solve a problem much faster than any other classmates if the problem allowed me to develop my imagination into a picture. That was the only occasion when I felt schooling to be quite fun.

Now, I'm teaching students while working on my art using the technique of dyeing.

The world of art is divided into various fields (or genres), such as paintings, sculpture, craft, and design. However, every field is based on drawing a picture.

It is very rare that a work is finished straight from an inner imagery itself.

First, I draw a picture. The picture is not for showing to others, but for making a decision on my own whether the image can be made into a work after seeing it with my own eyes. The picture does not have to be complete. It suffices if I can draw to an extent where I can determine on my own. This stage is called "Idea sketch" or "Image design", and is most important process of making.

I draw pictures on one sheet after another until the picture comes close to the image. The image changes, however, while drawing on one sheet after another. The image may change since it is vague in my mind. The image gets going after I see the picture I drew for activating my mind to work.

My hand keeps chasing an image in the beginning until finally the image chases my hand, a condition most desirable. When I draw a picture, it propels what is in my head rather than depicts/illustrates what is in my head.

A student often says "I've not drawn a picture yet, but an image is in my head". However, this is mistaken. He is in a state where an image which should be vague and mobile has been fixed as an illusion, because of the image being unmoved. This state does not lead to a final piece. An image could be real when visualized by using your hands.

When screening in the "Micromachine Drawing Contest", I have come across many pieces of work that induce me to think that "Brains and senses work flexibly by drawing a picture".

It may not be a dream that a Leonardo da Vinci in the 21st century may emerge from among them.

Probing the Micro-World through Tactile Sensors

Associate Professor Masahiro Ohka

Faculty of Science and Engineering, Shizuoka Institute of Science and Technology

1. Introduction

This laboratory, called "Intelligent Sensing Laboratory", is conducting scientific research chiefly to tactile sensors, tactile information processing, and tactile display systems. As a micromachine-related theme, it is setting about dealing with "Tactile Microsensors", an effort to minimize a tactile sensor to the utmost limits.

2. Tactile Microsensors / Display Systems

A microscopic type microrobot often contacts tube walls. It is therefore considered effective to mount a tactile sensor on the robot for the protection of the robot itself as well as for the prevention of tube wall damage. Generally, a tactile sensor indicates a sensor by which the distribution of contact-induced pressure can be measured. For the control of the attitude of a microrobot moving along the wall tube, however, it appears necessary not only to measure the pressure distribution but also to detect shearing stress that works in the direction of friction.

In addition, more dexterous operation of the microrobot can be realized if the tactile information, obtained by the microrobot on contact, could be effectively displayed to the operator. Since the tactile information the microrobot acquires is minute, it becomes necessary to enlarge it for display instead of displaying it as it is. In the master-and-slave-mode control as shown in Fig. 1, it is easy to enlarge a display as desired because of the presence of a computer between the master and the slave.

The system shown in Fig. 1 is an ultimate goal of this research. Research and development of the important technology is under way now for the realization of this ultimate goal. With the subsidy granted by the Foundation Micromachine Center, a tactile sensor could be developed for mounting on a microrobot. In addition, a master manipulator is also being manufactured on a trial basis for mounting on a tactile information display unit, the details of which will be described below.

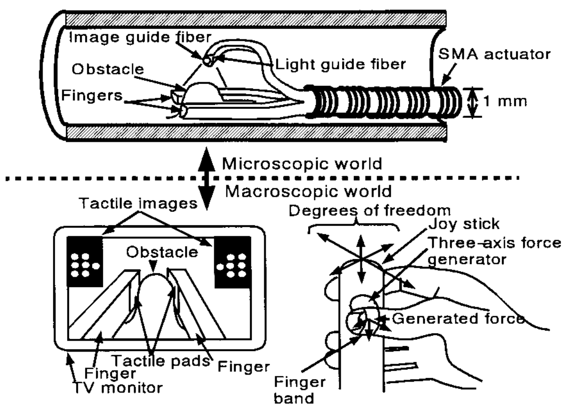


Fig. 1 Tactile Microsensor/Tactile Information Display System

3. Tactile Microsensors

This tactile sensor utilizes a phenomenon in which diffused reflection is caused at a part of the contact between a light guide and a rubber sheet. When a small conical projected array is formed at a part of the contact between a rubber sheet and a light guide, the area of contact of the conical projection increases in proportion to contact pressure. This enables the distribution of contact pressure to be obtained by measuring the distribution of luminance after the conical projection contact part has been photographed with a CCD camera as shown in Fig. 2. The distribution of shearing stress can also be obtained by measuring a travel distance since the conical projection moves horizontally in proportion to the degree of shearing stress.

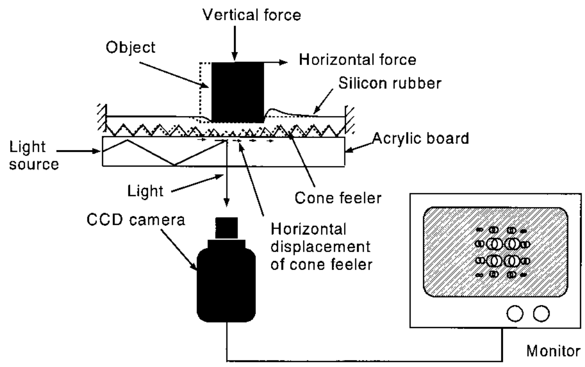


Fig. 2 Principle of Tactile Microsensor

An experimental system was structured as shown in Fig. 3 to confirm the above principle. This system is composed of a tactile sensor, a bore scope, an electronic balance, a parallel-plates typed force sensor, and two dynamic strain gauges. The electronic balance was used for calibrating vertical force while the parallel-plates typed force sensor and dynamic strain gauges were used for calibrating load in the horizontal direction.

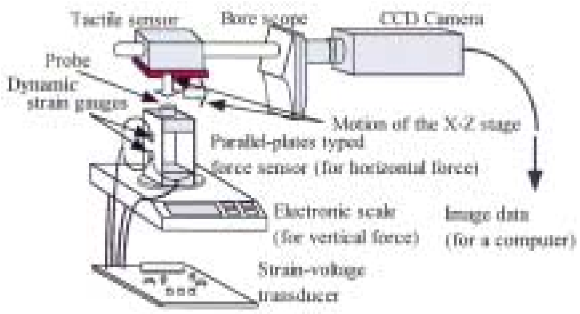


Fig. 3 Prototype of Tactile Microsensor System

Fig. 4 shows vertical force detection characteristics. As the figure clearly indicates, load and luminance values exhibit high linearity. Horizontal force detection characteristics are given in Fig. 5, which reveals that the relationship between horizontal force and horizontal travel distance also shows linearity.

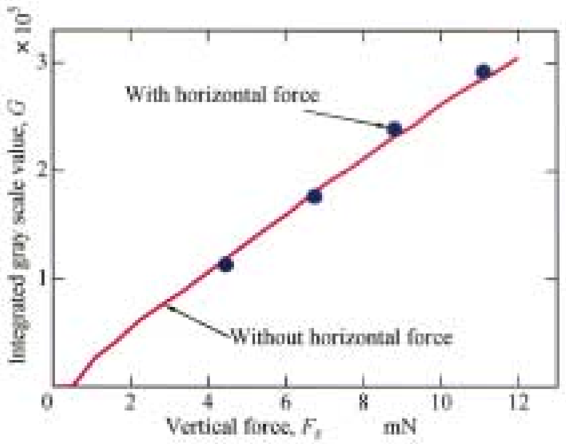


Fig. 4 Vertical Force Detection Characteristics

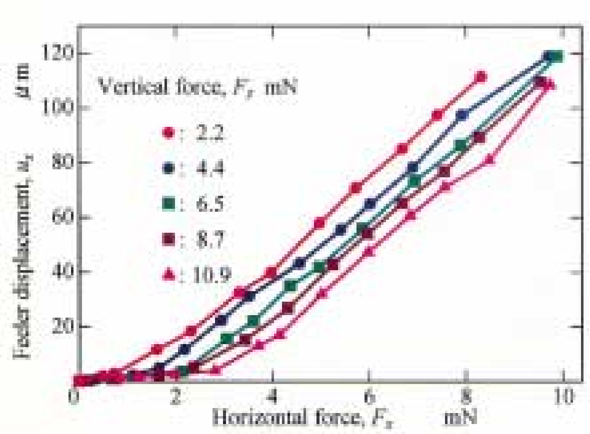


Fig. 5 Horizontal Force Detection Characteristics

4. Tactile Information Display System

This tactile microsensor, with an ability to measure three-axis force distribution, must also be able to display the three-axis force for a system that displays the tactile information measured by this sensor. The tactile information display system on which this laboratory is carrying out research is also expected to be developed in a manner that will be able to display ultimately three-axis force distribution. Introduced here is a tactile information display system manufactured on a trial basis to display pressure distribution.

Fig. 6 gives an experimental unit consisting of an X-Y table with an air bearing, an encoder, a DC motor, and a tactile information display unit. On the upper surface of the tactile information display unit are arrayed 2×2 projections that transmit pressure to the finger. The operator can freely move this display part in the two-dimensional plane with his finger pressed on the array of this display point. Since this movement is measured by the encoder, a slave robot can be moved according to the value measured. A system, similar to the one shown in the beginning in Fig. 1, can be realized by mounting the tactile sensor, shown in the foregoing Fig. 3, on the end effector of the slave robot. Now under study are the enlargement of an array scale of the tactile information display part and a method of displaying shearing stress.

5. Conclusion

At this stage, we are far behind our future scheme as described in the beginning, and therefore must study further as well. As a tactile sensor becomes smaller, a higher technology is required for machining parts with the tactile sensor. We also feel strongly the necessity for a cleaner, vibration-less experimental environment.

In view of the foregoing, we are not only trying to put the experimental environment in order, but also looking for a way out while studying another principle. For example, we are also planning an experiment in which the results detected by using the AFM (Interatomic Force Microscope) as a tactile sensor can be displayed on the tactile information display unit introduced herein. It is quite likely that we will be able to touch and feel a nanometer world in the near future.

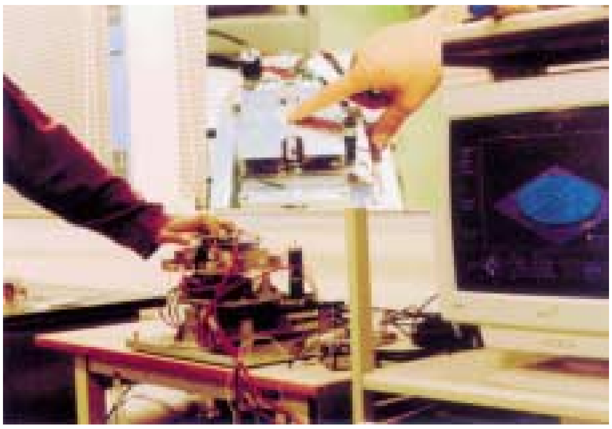


Fig. 6 Prototype of Tactile Information Display Unit

Overview of MMC's Activities in Fiscal 2000

In F.Y. 1999 the Micromachine Center (MMC) will implement the following five programs with the aim of establishing the basic technologies for micromachines and increasing utilization of micromachines.

① Investigations and research on micromachines,
② Collection and provision of micromachine information,
③ Exchange and cooperation with worldwide organizations involved with micromachines,
④ Promotion of standardization of micromachines,
⑤ Dissemination and education about micromachines.

I. Investigations and Research on Micromachines

The Industrial Science and Technology Frontier Program of MITI's Agency of Industrial Science and Technology (AIST) has entered the final year of its second phase. To achieve the goal of the basic plan for the R&D (Phase II), the R&D system will be further improved and research delegated to MMC will be actively promoted. Also MMC will exchange technical information with researchers in various countries and provide results of investigations and research for those concerned in and outside of Japan.

1. The AIST's Industrial Science and Technology Frontier Program "Micromachine Technology" (This project has been delegated to MMC by the New Energy and Industrial Technology Development Organization (NEDO).)

Based on the R&D results on fundamental device technology in the first phase, the ultimate purpose of this project is to establish technologies applicable to the realization of micromachine systems. These systems are mechanical systems composed of small functional elements that locomote within very narrow spaces in complicated facilities for a power plant and inside of the human body. They can also perform intricate work autonomously, and produce small industrial products as a microfactory. Following research will be conducted in F.Y. 2000.

(1) Development of advanced maintenance technologies for power plants

① R&D of systematization technology (Experimental wireless micromachine for inspection on inner surface of tubes)

R&D of systematization technology will be conducted through production of an experimental system for a wireless micromachine. Inside a metal tube with a curved section, this micromachine will be able to move forward, backward, horizontally and vertically, stop optionally, and recognize its surroundings as well as detect defects of tubes. R&D topics promoted are realization of an experimental wireless micromachine for inspection on inner surface of tubes through developing a locomotive device and a microwave energy-supply/communication device as the main technology, and systematization of a microvisual device and an optical energy transmission device.

② R&D of systematization technology (Experimental chain-type micromachine for inspection on outer surface of tubes)

Systematization technology will be developed through production of an experimental micromachine system composed of a group of single machines capable of combining or separating according to the form of the object to be inspected. R&D will promote the following topics: creation of an experimental chain-type micromachine for inspection on outer surface of tubes through developing a driving device to propel the machine, and systematization of speed reduction and traveling devices and a microconnector.

③ R&D of systematization technology (Experimental catheter-type micromachine for repair in narrow complex areas)

R&D on systematization technology will be conducted by producing an experimental micromachine system capable of entering the equipment of various structures and performing measurements or repairs of minute flaws. R&D topics promoted are: creation of an experimental catheter-type micromachine for repair in narrow complex areas through developing multi-degrees of freedom flexible pipe structure; and systematization of a position detection device and a monitoring device.

④ R&D of functional device technologies

R&D will be conducted to promote micronization, high performance, and multi-functionalization of functional devices that form the components necessary to realize future micromachine systems and highly advanced micromachine technology. R&D will focus on creating the following: an artificial muscle, microjoint, low-friction suspension device such as magnetic bearing, micro-battery, optically driven free joint device, etc.

⑤ R&D of common basic technologies

R&D will be conducted on common basic technologies such as technologies for control, measurement, design, and evaluation necessary for realizing micromachine systems. R&D will center on achieving pattern forming technology for a group of distributed micromachines, hierarchical group control technology, measuring technology for micromachines, etc.

⑥ Comprehensive investigation and research

Comprehensive investigation and research on micromachine technology will be promoted including investigation and research to conduct the conceptual design of maintenance micromachines necessary for maintaining future power plants, and leading investigations and research on micromachine systems expected to be used for maintenance.

(2) Development of microfactory technology

① R&D of systematization technology (Experimental processing and assembly system)

R&D will be conducted on systematization technology by producing an experimental system for processing and assembling capable of manufacturing models of small parts by integrating processing, assembly, conveyance, and inspection machines in a limited narrow space. R&D topics promoted include: micro processing technology, micro assembling technology, micro fluid technology, micro optical driving technology, micro electric driving technology, micro conveyance technology, and micro inspection technology.

② Comprehensive investigation and research

Comprehensive investigation and research on micromachine technology will be promoted. This will include the influence of microfactories caused by such problems as electromagnetic interference generated when various devices are integrated or concentrated in a small space, and advanced research on micromachine systems to be used in production. In addition, we will conduct research on enhancing the performance of micro-electron guns for beam processing jointly with AIST's Electrotechnical Laboratory.

(3) Research and development of micromachine technology

① Research on micromachine systems

In the medical field, R&D on miniaturization and multi-functionality of micro-laser catheters and micro-tactile sensor catheters will be conducted. These catheters are the major functional components of a micro-catheter for diagnosis and treatment of cerebral blood vessels, an intraluminal diagnostic, and therapeutic system. In addition, R&D on a scanning-type imaging tube unit for medical micromachines will be conducted.

② Comprehensive investigation and research

Comprehensive investigation and research on micromachine technology will be carried out on the future applications of micromachine system to the medical field. In conjunction with AIST's Mechanical Engineering Laboratory, MMC will also conduct research on micromachine basic design and manufacturing technologies.

2. Research and Development on the Application and Extension of Micromachine-based Systems to Industry (activities to help promote the machine industry)

Forecast of the future application and extension of micromachine-based systems to industry will be conducted, and the route to practical use of micromachine technology will be revealed. Thereby, aiming to promote the introduction of new technologies to various industrial fields, ① investigations on current states and roadmap surveys on key-technologies in various fields, and ② roadmap surveys on the application and extension of micromachine-based systems in various fields, and surveys on their application and extension in other fields and in new uses, will be conducted.

3. Research and Development of the Applicability of Emerging Technology in Other Fields to Micromachine Technology (activities to help promote the machine industry)

Pursue joint efforts among government, academia and industry to search out emerging technology in other necessary fields in order to promote the diversification and practical use of micromachine technology, and to verify its applicability and fusion. In this fiscal year, we will search out emerging technology in the bioscience, chemical, physical science and medical fields.

4. R&D of Micromachine Materials

Jointly with the Mechanical Engineering Laboratory of AIST, MMC will conduct ① research on the operating environments for micro functional elements, ② research on micromachine materials, and ③ feasibility studies on micromachine materials.

5. Investigation on R&D Trends of Micromachine Technology in Japan and Abroad

MMC will analyze the current state of research and development on rapidly progressing micromachine technology in Japan and abroad, and develop a body of information on the basic technologies for developing micromachine technologies.

II. Collection and Provision of Micromachine Information

Information and documents on micromachines in universities, industry, and public organizations in Japan and overseas will be collected, combined with survey results and documents produced by MMC, and made freely available in the MMC library and through MMC's internet web site.

III. Exchange and Cooperation with Worldwide Organizations Involved with Micromachines

To promote affiliation, exchange, and cooperation with related organizations in and outside Japan, MMC will implement the following. ① Hold the 6th Micromachine Summit in Hiroshima. ② Hold the 6th International Micromachine Symposium. ③ Provide research grants to research activities at universities for R&D on micromachine technology as part of its promotion of joint research with government, industry and academia. ④ Invite authorities from overseas, and dispatch authorities from Japan, to promote overseas exchanges. ⑤ Dispatch research missions overseas. ⑥ Hold joint seminars and workshops overseas.

IV. Standardization of Micromachines

1. Development of the International Standardization for supporting new industries "Standardization of the evaluation methods of material properties for micromachines" (This project has been delegated to MMC by the New Energy and Industrial Technology Development Organization (NEDO).)

MMC will develop a standard tensile test method that can evaluate mechanical properties of various kinds of thin films of about 10µm thick and under 100µm width, and will make it as an international standard. Concretely, we will clarify measuring methods of the stress and strain, loading methods of specimens, and their sizes and shapes, aiming to make drafts of international specifications through improving and synthesizing the various kinds of test methods which have been proposed now, and defining their applicable ranges. In this fiscal year, we will conduct round robin tests which evaluate the same specimens with using different test methods.

2. Investigation and Research on Micromachine Standardization

Based on progress in standardization as planned in F.Y. 1998, MMC will implement the following. ① Promote the Micromachine International Standardization Forum established in F.Y. 1998. ② Based on "Technical Terms in Micromachine Technology" issued in 1998, cause micromachine glossary to reflect the results of the Forum, while at the same time expanding content from the standpoint of international standardization. ③ With regard to measurement evaluation methods, study collation of past research results into a comprehensive technical report, pursue research into specific standardization topics deemed necessary, and move to standardize their technical issues.

V. Dissemination of and Education about Micromachines

In order to achieve wider utilization of micromachines, MMC will implement the following. ① Issue public information publications. ② Hold the 6th Micromachine Drawing Contest, seminars on micromachines, briefing session on research results, and preparation of videos. ③ Hold the 11th Micromachine Exhibition. ④ Serve as the Federation of Micromachine Technology Secretariat.

The Research Subjects for the 7th Micromachine Technology Research Grant

The research subjects for the 7th Micromachine Technology Research Grants (for F.Y. 1999) were selected at the Board of Directors meeting held in March 2000. As a result of a rigorous screening and examination process, seven new research subjects and six ongoing research subjects (2nd year) were selected from a large number of applications, as shown in the appended table.

A total of ¥20.3 million in financial assistance grants will be presented. This research grant program was started in F.Y. 1993 as an independent activity of the Micromachine Center, and provides financial assistance to researchers engaged in basic research on various aspects of micromachine technologies. It is aimed at providing support for further progress of micromachine technologies, and at promoting exchange and cooperation between industry and academia.

On March 27, 2000, a ceremony to award the research grants was held at the Tokai University Alumni Hall in the Kasumigaseki Building. Dr. Tsuneo Ishimaru, Chairman of the Micromachine Center, gave the sponsor's greeting. Mr. Masahiro Fujita, Director, Industrial Machinery Division of MITI, gave his guest speech, and Prof. Yoji Umetani, Chairman of the Industry-Academia Joint Research Committee of the Micromachine Center, reported on the results of the screening. Following this, financial assistance awards were presented to the thirteen researchers who were selected. Prof. Takehiko Kitamori of The University of Tokyo spoke on behalf of the grant recipients. Later, each of the seven researchers on the new research subjects that were selected gave overview of his research, followed by an informal discussion.

Applications for the F.Y. 2000 research grant program will be solicited and accepted from July to October of this year.

The new research subjects that were selected for the 7th Research Grant are summarized in the following pages.

Subjects for the 7th Micromachine Technology Research Grant

New Research Projects Granted for Fiscal 1999

Leader & Co-Worker	Affiliations	Subjects	Period
Dr. Masayuki Yamato	Research Assistant Professor, Institute of Biomedical Engineering, Tokyo Women's Medical University	Development of noninvasive single cell manipulator utilizing temperature-responsive polymer	2 Years
Prof. Yoshihiro Ito, Dr. Eng.	Department of Biological Science and Technology, Faculty of Engineering, The University of Tokushima	Construction of micro-lens array by micro-fabrication of stimuli-responsive gel	2 Years
Assoc. Prof. Kazuhiko Ishihara, Dr. Eng.	Department of Materials Science, Graduate School of Engineering, The University of Tokyo	Study of novel polymer micro-actuator powered by enzymatic reactions of biomolecules	2 Years
Dr. Yoichi Haga	Research Associate, Department of Engineering Research, Tohoku University Graduate School	Catheter tip position sensing system using MI sensor	2 Years
Assoc. Prof. Gen Hashiguchi, Dr. Eng. Prof. Hiroyuki Fujita, Dr. Eng. Dr. Manabu Ataka	Faculty of Engineering, Kagawa University Institute of Industrial Science, The University of Tokyo Research Associate, Institute of Industrial Science, The University of Tokyo	Electrical, thermal and mechanical properties of nano mechanical structures	2 Years
Assoc. Prof. Takaaki Oiwa, Dr. Eng.	Faculty of Engineering, Shizuoka University	Coordinate measuring machine using parallel mechanism for micromachine parts	1 Year
Prof. Takehiko Kitamori, Dr. Eng. Dr. Hideaki Hisamoto	Department of Applied Chemistry, Graduate School of Engineering, The University of Tokyo Lecturer, Department of Applied Chemistry, Graduate School of Engineering, The University of Tokyo	Integration of chemical systems toward artificial organ	2 Years

Carried-Over Projects Granted for Fiscal 1998

Leader & Co-Worker	Affiliations	Subjects	Period
Prof. Masao Washizu, Dr. Eng.	Department of Mechanical Engineering, Kyoto University	Molecular surgery of DNA based on microsystems	2nd Year
Prof. Kazunori Kataoka, Dr. Eng. Dr. Atsushi Harada	Department of Materials Science, Graduate School of Engineering, The University of Tokyo Research Associate, Department of Materials Science, Graduate School of Engineering, The University of Tokyo	Structural design of "chemical nano-machine" based on the self-organization of polymers and its application to targeting therapy	2nd Year
Dr. Tooru Ooya	Research Assistant Prof., School of Materials Science, Japan Advanced Institute of Science and Technology, Hokuriku	Study on biomedical micromachine using biodegradable supramolecular assembly	2nd Year
Dr. Hiroshi Toshiyoshi Prof. Hiroyuki Fujita, Dr. Eng.	Lecturer, 3rd Division, Institute of Industrial Science, The University of Tokyo 3rd Division, Institute of Industrial Science, The University of Tokyo	Micromachine system for micro-optical smart pixel application	2nd Year
Prof. Shigefumi Nishio, Dr. Eng. Dr. Kiyoshi Takano	2nd Division, Institute of Industrial Science, The University of Tokyo Research Associate, 2nd Division, Institute of Industrial Science, The University of Tokyo	Experimental study on fluid flow and heat transfer inside micro-channel utilizing micro-machining technology	2nd Year
Assoc. Prof. T. H. Barnes	Physics Department, University of Auckland	Low-noise feedback interferometry for micromachine servo actuators	2nd Year

Mr. Fujita, Director of Industrial Machinery Division, MITI, gives his greeting.

Researchers who received research grants for F.Y. 1999

Outline of the New Subjects for the 7th Micromachine Technology Research Grant

Development of Noninvasive Single Cell Manipulator Utilizing Temperature-Responsive Polymer

Masayuki Yamato
Tokyo Women's Medical University

Recently, there has been an increased need for research into the next generation of artificial organs. This had led to the necessity for better understanding of cell-cell interactions in tissues and organs which are composites of various cell types. Therefore, there is an urgent need to develop a technique for the three-dimensional arrangement of the different cell types. Single cell manipulators having the necessary technology for effective cell attachment and detachment of selected cells in a noninvasive manner will be a very useful and important tool. Such manipulators could also be used for gene introduction, nuclear replacement and so on. Here we propose to develop a single cell manipulator which enables selective switching between cell attachment and detachment using a temperature-responsive polymer and a Peltier device for temperature control.

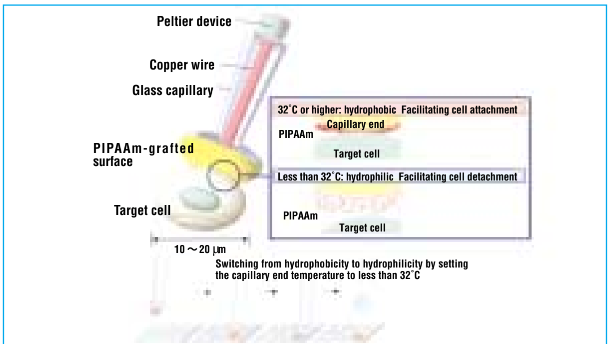
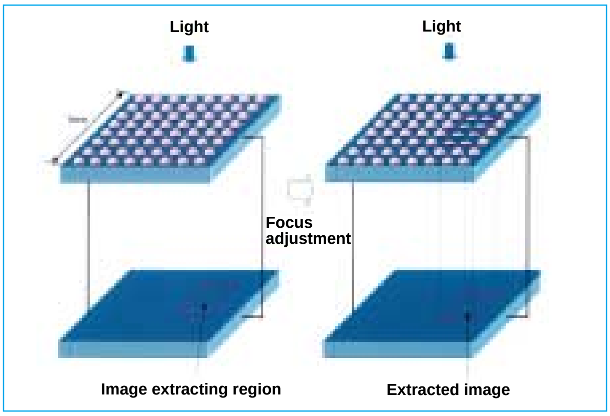


Image Diagram of Cell Manipulator Use

Construction of Micro-Lens Array by Micro-Fabrication of Stimuli-Responsive Gel

Yoshihiro Ito
The University of Tokushima

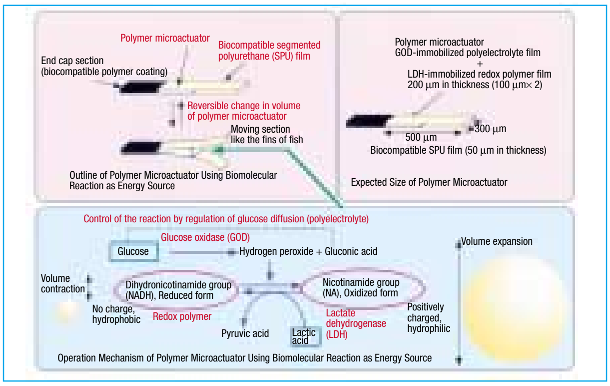
In this research, we will create a micro lens array with variable focal length by micromachining a gel which expands and contracts in response to electrical stimulation. By using this array, we will create a device which can improve image processing efficiency by adjusting the lens focal length only in the region corresponding to the particular image to be sharpened among the images already captured on the light-receiving surface. Moreover, we intend to create a lens array on a curved surface in order to apply it to a new compound-eye system. Stimulation-responsive intelligent gel micromachining as described here is expected to become an important basic technique for micromachine engineering in the future.



Study of Novel Polymer Microactuator Powered by Enzymatic Reactions of Bio-molecules

Kazuhiko Ishihara
Graduate School of Engineering,
The University of Tokyo

In order to operate a micromachine in a living body, it is vital for the machine to generate energy in the body, rather than obtain energy externally. Therefore, in this research, it will be created an actuator combining an polyelectrolyte and redox polymer, the structure of which change in response to the chemical information distinctly translated from the glucose and lactic acid present in the body by using enzymatic reactions. In addition, it will be developed basic techniques for creating a device which allows the actuator to actuate medical elastomer films with improved biocompatibility and make them move like the fins of fish.

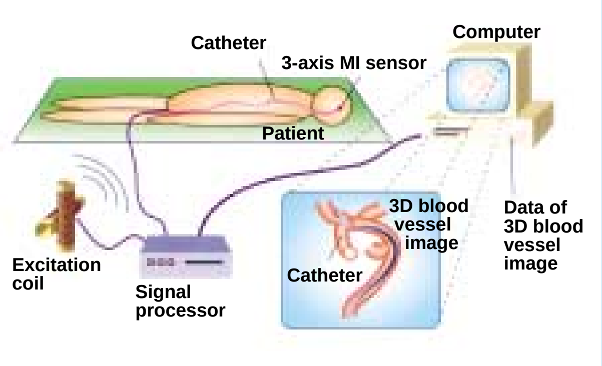


Catheter Tip Position Sensing System Using MI Sensor

Yoichi Haga
Tohoku University

We will develop a system which detects the three-dimensional position and attitude (direction and torsion) of the tip of a medical catheter by equipping the catheter with micro magnetic vector sensors, which detect the magnetic field created by an external coil.

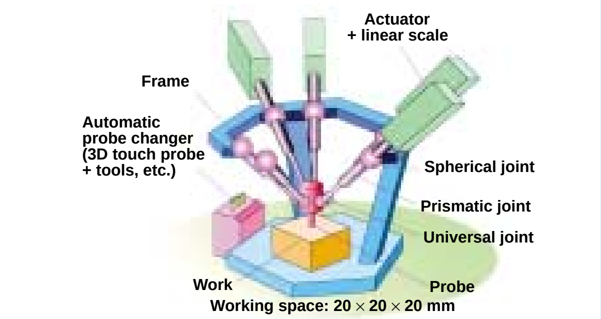
If this sensor system is compared to a car navigation system, the catheter tip corresponds to the car, and the blood vessels to roads. Before operation, three-dimensional blood vessel images are obtained and storaged in a computer by using contrast medium CT or MRI, and the three-dimensional position and attitude of the catheter tip is detected and superimposed onto the blood vessel images on the screen. This system is also expected to be applied to an endoscope.



Coordinate Measuring Machine Using Parallel Mechanism for Micromachine Parts

Takaaki Oiwa
Shizuoka University

While the machining of precision micro parts with three-dimensional, complex shapes is being realized, their geometrical deviation measurements need to be performed on a three-dimensional basis. In this research, we will investigate a small three-dimensional coordinate measuring machine (CMM) for high-precision three-dimensional measurement of the geometrical deviation of a $20 \times 20 \times 20$ mm micro part. Thus we will use a parallel mechanism, which contributes to high stiffness, precision, and speed, rather than a slide mechanism, such as the conventional rectangular coordinate type. Moreover, we propose a micro CMM that employs elastic hinges, and is free from the effects of friction and wear, as revolutionary pairs (joints).

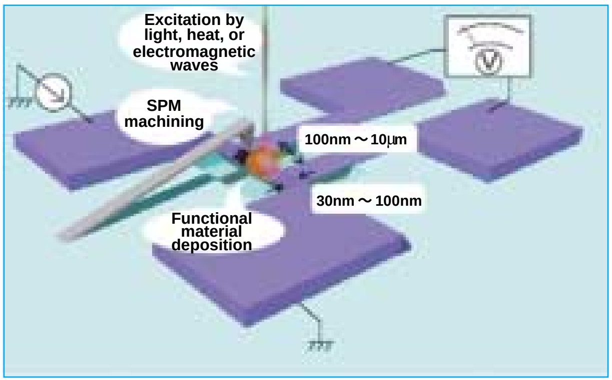


Conception of Parallel Mechanism Type Nano-CMM for Micromachine Parts

Electrical, Thermal and Mechanical Properties of Nano Mechanical Structures

Gen Hashiguchi
Kagawa University
Hiroyuki Fujita and **Manabu Ataka**
The University of Tokyo

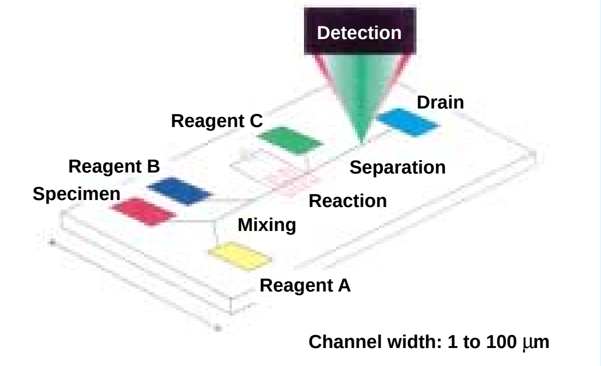
There have recently been growing expectations for the development of new functional devices using mechanical structures in the order of nanometers. However, little is known about the physical properties of nano-structures. This research is intended to reveal their properties by performing precise measurement of their physical-to-electrical-quantity conversion properties by means of a four-terminal nano-device. The line width and thickness of the four-terminal nano-device to be created will be 30 to 100 nm. The results of this research will raise expectations for realization of super-high performance sensors and devices using nano-structures.



Integration of Chemical Systems toward Artificial Organ

Takehiko Kitamori and **Hideaki Hisamoto**
Graduate School of Engineering, The University of Tokyo

We will integrate chemical reaction, separation and detection systems for liquid-phase chemical processing system by micromachining a micro channel network within a glass microchip. In this research, we will determine the size effects on molecular behavior and chemical reactions in liquid-phase micro space, and develop methods concerning highly efficient chemical reactions and their control. Among other things, we will demonstrate that the boundaries between liquids – liquid-liquid interfaces – in liquid-phase micro space are similar to those of living cells, and so construct a chemical system similar to the living organ. Also we will realize artificial micro biochemical systems such as diagnostic devices and detox devices incorporating immunoreactions or enzymatic reactions.



Oita Micromachine Seminar

Oita Micromachine Seminar was held in the afternoon of February 10, 2000 at Oita Industrial Research Institute in Oita City. It was organized by the Micromachine Center and Oita Industrial Research Institute, and officially supported by the Oita Industrial Creation Organization, Oita Industrial Technology Research Society, and Oita Machine Technology Research Society.

At the seminar, in addition to presenting recent developments in micromachine technology, an overview of Micromachine Technology Research and Development, an Industrial Science and Technology Frontier Program project currently being carried out under MMC's leadership, and four concrete results were presented.

In addition, during breaks, Mr. Takashi Kawano and Mr. Tsuneji Yada, General Manager of the Information Department gave demonstrations of "Laser Powered Micropump" (made by AISIN COSMOS R&D CO., LTD.) and "In-Pipe Micro Inspection Machine" (made by DENSO CORPORATION), both of which were exhibited on site. The exhibits and presentations provided a good opportunity for the attendants to learn about micromachine technology.

The master of ceremonies for the seminar was Mr. Yoshiomi Goto, Manager of the Mechanical and Electronics Technology Division of Oita Industrial Research Institute, while the chairman for the seminar was performed by Mr. Tatsuo Sato, Chief Researcher for the Institute.

The program opened with a welcome by Mr. Hideo Tsukune, Director-General of the Oita Industrial Research Institute, after which a series of presentations ensued. Mr. Hajime Arai, Director at MMC, spoke about "MMC's Activities"; Dr. Tokio Kitahara, Professor at Shonan Institute of Technology, spoke about "Features of Micromachines"; and Mr. Tsuneji Yada, General Manager of the Information Department at MMC, spoke about "An Outline of the Second Phase of the Micromachine Project".

The seminar also included the following presentations on results of the Industrial Science Technology Frontier Project.

"Development of Microconnector"
Mr. Tsuyoshi Haga (SUMITOMO ELECTRIC INDUSTRIES, LTD.)
"Development of Microgyroscope"
Mr. Hiroshi Kawai
(MURATA MAUFACTURING CO., LTD.)
"Micropump"
Mr. Takashi Kawano
(AISIN COSMOS R&D CO., LTD.)
"Micro Servo Actuator"
Mr. Hiroshi Nakamura
(YASKAWA ELECTRIC CORPORATION)

The seminar was brought to a close in a great success with the closing address by Tatsuo Sato, Chief Researcher at the Oita Industrial Research Institute.

A high degree of interest was expressed in this seminar, with 43 participants from 30 companies in Oita Prefecture and Kumamoto Prefecture related to precision machinery, displays, laser processing industry and semiconductor processing, together with 17 participants from universities, research institutes and public organizations, giving a total of 60 participants. Lively question and answer sessions took place about the content of the addresses, making it a highly meaningful seminar.

A scene from the Oita Micromachine Seminar

A scene showing portable exhibit of micromachine technology

Sixth Micromachine Drawing Contest Award Ceremony Held

The Micromachine Drawing Contest sponsored by the Micromachine Center (MMC) for elementary and junior high school students was held this year for the sixth time. Pupils from 23 elementary and 12 junior high schools in Amagasaki and Itami (Hyogo), Hirakata (Osaka), Kariya (Aichi), Ina (Nagano), Nakai and Kawasaki (Kanagawa), Narashino (Chiba), Tsukuba (Ibaraki), and Shizukuishi (Iwate) entered this year's contest. The contest was conducted with the cooperation of MMC's supporting members SANYO Electric Co., Ltd., Matsushita Research Institute Tokyo, Inc. and MITSUBISHI ELECTRIC CORP., as well as the Science Museum in Tokyo.

This year's contest garnered an all-time record of 3,215 entries, 1,511 in the elementary school category and 1,704 in the junior high school category. The participating schools were as follows.

The participating schools

Elementary Schools:

Sonoda-kita Municipal Elementary School (Hyogo Prefecture)
Sonoda Municipal Elementary School* (Hyogo Prefecture)
Sonoda-higashi Municipal Elementary School (Hyogo Prefecture)
Kamisakabe Municipal Elementary School (Hyogo Prefecture)
Sonowa Municipal Elementary School (Hyogo Prefecture)
Ozono Municipal Elementary School (Hyogo Prefecture)
Koyanosato Municipal Elementary School (Hyogo Prefecture)
Nakamiya-kita Municipal Elementary School (Osaka)
Iura Municipal Elementary School (Aichi Prefecture)
Fujimatsu-minami Municipal Elementary School (Aichi Prefecture)
Futaba Municipal Elementary School (Aichi Prefecture)
Sumiyoshi Municipal Elementary School (Aichi Prefecture)
Kotakahara Municipal Elementary School (Aichi Prefecture)
Fujimatsu-higashi Municipal Elementary School (Aichi Prefecture)
Ina Municipal Elementary School (Nagano Prefecture)
Inokuchi Municipal Elementary School (Kanagawa Prefecture)
Nakamura Municipal Elementary School (Kanagawa Prefecture)
Mita Municipal Elementary School (Kanagawa Prefecture)
Okubo-higashi Municipal Elementary School (Chiba Prefecture)
Namiki Municipal Elementary School (Ibaraki Prefecture)
Shizukuishi Municipal Elementary School (Iwate Prefecture)
Science Hall Received (Two)

Junior High Schools:

Sonoda-higashi Municipal Junior High School (Hyogo Prefecture)
Sonoda Municipal Junior High School (Hyogo Prefecture)
Karigane Municipal Junior High School* (Aichi Prefecture)
Kariya-minami Municipal Junior High School* (Aichi Prefecture)
Kariya-higashi Municipal Junior High School (Aichi Prefecture)
Isami Municipal Junior High School (Aichi Prefecture)
Asahi Municipal Junior High School (Aichi Prefecture)
Fujimatsu Municipal Junior High School (Aichi Prefecture)
Nishiminowa Municipal Junior High School (Nagano Prefecture)
Nakai Municipal Junior High School (Kanagawa Prefecture)
Minamiikuta Municipal Junior High School (Kanagawa Prefecture)
Takezono-higashi Municipal Junior High School (Ibaraki Prefecture)

* School prize awarded.

A jury listed below selected 15 artworks from the elementary school category and 15 from the junior high school category. The selected artworks are shown on the following pages.

Jury

Dr. Hirofumi Miura (Chief), Professor, Kogakuin University
Dr. Naotake Ooyama, Director-General, Mechanical Engineering Laboratory, Agency of Industrial Science and Technology, MITI
Dr. Keiko Nakamura, Deputy Director General, Biohistory Research Hall
Dr. Ryoze Yamashita, Associate Professor, Tokyo National University of Fine Arts and Music
Mr. Takayuki Hirano, Executive Director, Micromachine Center

The award ceremony was held on March 28 at the KASUMIGASEKI TOKYO KAIKAN on the 35th floor of the Kasumigaseki Building in Tokyo. It was attended by some 50 persons, including the best entry prize and the first prize winning pupils, school members, guests, and the juries.

At the award ceremony, Mr. Yoshikazu Yamaguchi, Director for Machining and Aerospace R&D, AIST, MITI made a speech to the children after explaining easily why the research and development of micromachines is needed. "It will take more and more times for practical application of such technology, so I hope this contest proves to be a springboard for at least one or two of you to someday enter the fields of science, technology, or research and development not only in micromachines."

Professor Miura, the Chief of the jury, reported on the judging process and commented on the work submitted. He said, "In this contest, incidentally, both of two Best Entry Prizes have themes of environmental problems in society, and both of two First Prizes are drawings of IT (Information Technology)-related applications. I have been impressed that the children have got well the need change in the era. I have pleasantly judged as well as I have been made consider them."

Following the introduction of the selected drawings, testimonials and prizes were awarded to Kaori Matsui (6th grader of Futaba Municipal Elementary School in Aichi Prefecture) in the elementary school category and Takashi Suzuki (3rd grader of Kariya-minami Municipal Junior High School in Aichi Prefecture) in the junior high school category. In addition, the elementary and junior high schools that submitted the most submissions received school awards.

After receiving the award, Mr. Suzuki expressed his will for the future: "Now, through this contest, I've been impressed by the great possibility of micromachines, and at the same time realized it depends completely on human's creative ideas whether utilizing the possibility or not. I will also make my efforts to get much creative ideas since now."

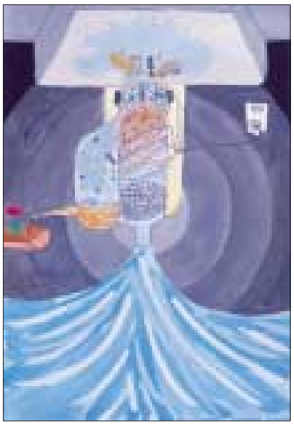
After the ceremony, six portable micromachine technology exhibits were displayed at the hall. The children and their parents and teachers alike crowded around the exhibits, their eyes gleaming in wonder at the first actual micromachines they had ever seen.

Commemorative photograph of award winners

Winners of the Sixth Micro

Elementary School Category:

Best Entry Prize
Water cleaner for home use, With compost maker



Kaori Matsui
Futaba Municipal Elementary School (6th grade)

First Prize
Ring-type cellular phone

Yuki Terada
Nakamiya-kita Municipal Elementary School (6th grade)

Second Prize
Little MM nurses, Pichi and Minya

Asuka Nakamura
Ina Municipal Elementary School (4th grade)

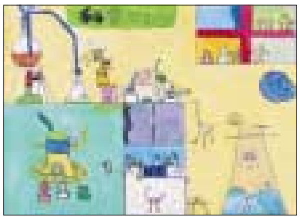
Second Prize
Threader

Daiki Furuya
Inokuchi Municipal Elementary School (4th grade)

Third Prize
Mr. Drain-pipe Cleaner

Aya Katsurasako
Sonoda Municipal Elementary School (6th grade)

Third Prize
Science machine

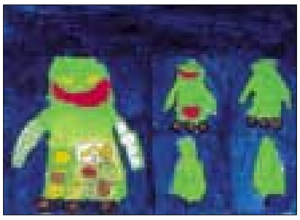


Rei Itoh
Nakamiya-kita Municipal Elementary School (6th grade)

Third Prize
MM Cleaner

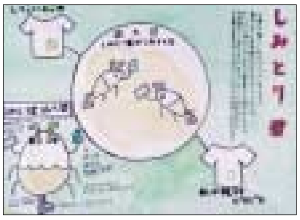
Hiromasa Tsukamoto
Fujimatsu-minami Municipal Elementary School (4th grade)

Honorable Mention
Rescue machine 181



Takahiro Kodama
Nakamiya-kita Municipal Elementary School (6th grade)

Honorable Mention
Mr. Stain Remover

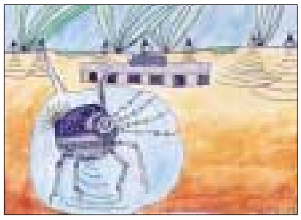


Mihoko Ushiroda
Fujimatsu-higashi Municipal Elementary School (6th grade)

Honorable Mention
Cleaner snail

Saki Hazama
Nakamiya-kita Municipal Elementary School (6th grade)

Good Idea Mention
Landmine detector



Yoshitaka Ohta
Sonoda-higashi Municipal Elementary School (4th grade)

Good Idea Mention
Responding machine to contact lens

Kana Kobayashi
Sonoda Municipal Elementary School (5th grade)

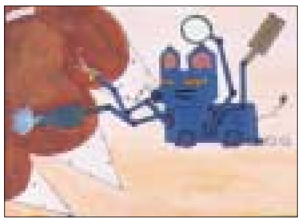
Good Idea Mention
Do-anything machine

Ken Itoh
Ina Municipal Elementary School (4th grade)

Effort Mention
Communicator machine

Yoshiaki Ohsawa
Fujimatsu-higashi Municipal Elementary School (5th grade)

Effort Mention
Beauty saloon for pets

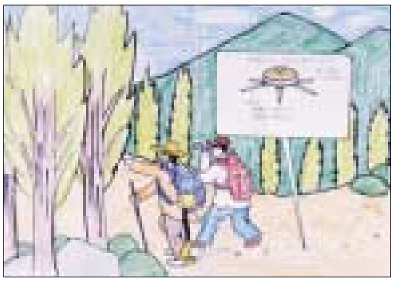


Sakurako Hirahara
Nakamiya-kita Municipal Elementary School (6th grade)

machine Drawing Contest

Junior High School Category:

Best Entry Prize
Rescue machine for mountaineering accidents

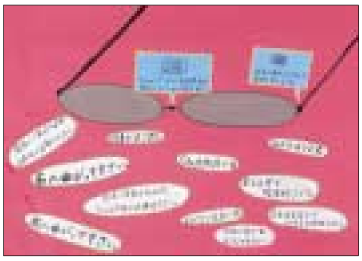


Takafumi Suzuki
Kariya-minami Municipal Junior High School (3rd grade)

First Prize
Any language is OK, Mini Japanese translator

Nozomi Mimura
Sonoda Municipal Junior High School (3rd grade)

Second Prize
Safety eye

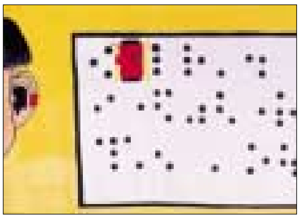


Syoko Ohno
Kariya-minami Municipal Junior High School (3rd grade)

Second Prize
Stimulating cap for anti-forget-fulness

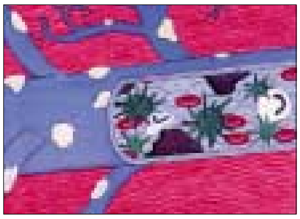
Yukari Tomikawa
Karigane Municipal Junior High School (3rd grade)

Third Prize
Dot character reading machine



Izumi Kaneko
Nakai Municipal Junior High School (3rd grade)

Third Prize
Anti-arteriosclerosis machine



Masahiro Hara
Nakai Municipal Junior High School (3rd grade)

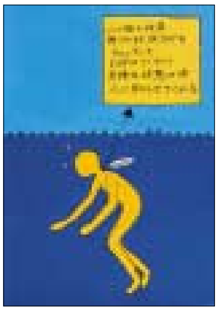
Third Prize
Human detector after disasters

Tae Suzuki
Nakai Municipal Junior High School (3rd grade)

Honorable Prize
MM ladybug

Katsuhiro Ogawa
Karigane Municipal Junior High School (3rd grade)

Honorable Prize
Emergency notifier

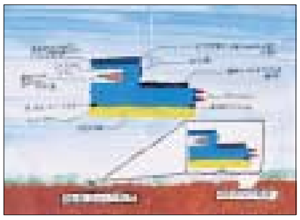


Kayoko Sugiura
Kariya-minami Municipal Junior High School (3rd grade)

Honorable Mention
Vacuum-and-burn type anti-virus MM

Akane Ohsera
Sonoda-higashi Municipal Junior High School (3rd grade)

Good Idea Mention
Seeking and fixing machine for landmines



Atsushi Tsuchiya
Karigane Municipal Junior High School (3rd grade)

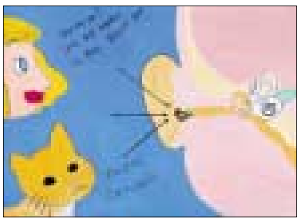
Good Idea Mention
Rocket repairing machine

Keigo Bove
Nakai Municipal Junior High School (3rd grade)

Good Idea Mention
Mini-mini barber

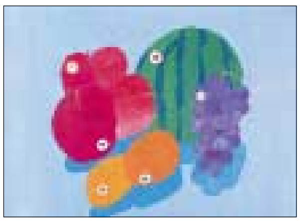
Mizuho Koshimizu
Nakai Municipal Junior High School (3rd grade)

Effort Mention
Instantaneous translating earring



Yuki Kondoh
Kariya-minami Municipal Junior High School (3rd grade)

Effort Mention
Ready detector



Arisa Ohashi
Sonoda Municipal Junior High School (3rd grade)

AISIN COSMOS R&D CO., LTD.


President Masami Inada

1. The challenge of Micromachine Technology

With micromachines being considered a basic technology highly likely to revolutionize automobile parts and life-related equipment in the field of business of AISIN SEIKI CO., LTD. the company is emphasizing the research and development of this technology. For the past five years, the company, aiming at accumulating micromachine-related basic techniques, has focused its research on miniaturizing elemental functional parts. In the process of this research and development, the advantages of the micromachine technology, along with its commercialization, have been unveiled. This has convinced the company research and development toward the commercialization of this technology on the basis of the techniques accumulated so far is essential in the future. It is therefore necessary to deal with the miniaturization, improvement of reliability and durability, and cost reduction of the equipment in question. The company intends to promote its research and development activities so that it can put its products on the market at an early date.

2. Development of Micromachine Technology

The company has been accumulating basic maicromachine techniques through the research and development of miniaturizing micropumps that move in a worm-like manner with laser light energy. This peristaltic micropump, mounted on the tip of a micromanipulator, is used for ejecting trace amounts of adhesive when assembling microparts in the microfactory system. Within this research and development are incorporated many technical development factors that constitute the subject of miniaturizing elemental functional parts for controlling viscosity and for supplying heat and energy (See Fig. 1). This research and development is expected to deepen the understanding of micromachine technology. This has prompted the company to develop a large displacement diaphragm, a light actuator utilizing liquid phase changes, light actuator arraying, and a light waveguide with the added function of radiating laser light outside the plane. The company is now in the stage of verifying the functioning of a laser-driven micropump prototype (Fig. 2) and carrying out the research on how to advance the technology to a higher degree. Particularly worthy of note is that the micropump has been miniaturized with the peristaltic mechanism employed and that it has enabled the feeding of liquid continuously and bi-directionally and the discharging of a trace amount of adhesive with the loss of pressure in the liquid path properly controlled. At present, the pump part of the light-driven coating device, 3.5×1.8 mm in section and 14.5 mm in length, has been confirmed to be able to coat adhesives to a level of some 10 nl.

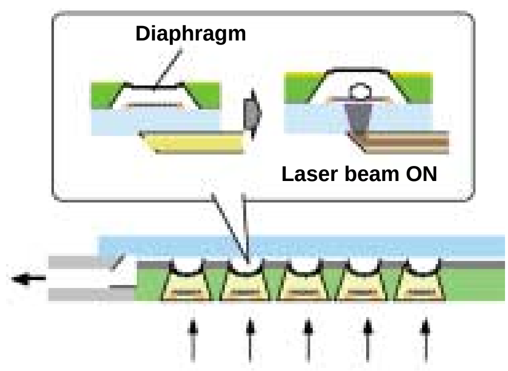


Fig. 1 Principle of Peristaltic Micropump

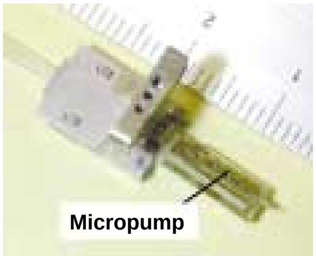


Fig. 2 Light-driven Coating Device

Fig. 3 How Trace Amounts of Adhesive are Discharged

3. Future Stance

In recent years, micromachine technology has emerged from the initial field of microsensors to a larger field of fluid-related applications. However, the company intends to further perfect the techniques it has accumulated so far, including micropump techniques and those directly related to market-needs-oriented products.

OMRON Corporation

Managing officer Tsukasa Yamashita

1. The challenge of "Micromachined Sensing"

As society becomes increasingly diversified and individualized, control components such as sensors and relays are required to be not only smaller in size but also to have capacities that satisfy various needs. Omron's micromachined sensing is aimed at pursuing the potential of semiconductors as sensors and relays, and forming micro mechanisms in the order of microns, which may be called "intelligent structures," onto chips. This technology should satisfy the need for device downsizing, and also be of considerable value to every aspect of industry, society, and daily life. Omron has already developed MEMS (Micro Electro Mechanical Systems) products such as electrostatic acceleration sensors, pressure sensors, and micro lens arrays using micromachining techniques based on IC fabrication process technology. They have been incorporated into products such as sphygmomanometers.

2. Development of Micromachine Technology

As part of the research and development of advanced technology, the Industrial Science and Technology Frontier Program called "Research and Development of Micromachine Technology" is dealing with the research and development of optical technology, a fusion of MEMS technology and optics. We have the objective of realizing a micro optical scanning type image sensor for measuring the size of small cracks in generator turbine blades, etc. in this project. To date, we have developed a two-dimensional micro optical scanner using a 2-degree-of-freedom vibrator, and a high-performance piezoelectric thin-film actuator to drive the scanner. Moreover, in order to miniaturize a recognition sensor (image sensor) with an optical scanner, we have designed a multi-layer stacked device structure in which different functional elements composing the sensor (the light source, micro optical elements, photo detector, and two-dimensional micro optical scanner) are placed on their respective substrates, which are then stacked into one piece. This has resulted in the realization of a micro optical scanning sensor with external dimensions of 2 mm × 4 mm × 3 mm (the size of a grain of rice). This sensor also has a distance-measuring function which, despite its very small size, enables object size measurement with a resolution of 0.5 mm or better in a measurement range of 50 mm ± 10 mm by using information on the image of the detected object and the distance to the object.

3. Future Stance

In the Industrial Science and Technology Frontier Program, we have been able to obtain basic technology for the two-dimensional micro optical scanner, a key device in the micro optical scanning sensor. Our future challenges include packaging technology and process development for mass production. We aim to put the sensor to practical use and apply it to other uses.

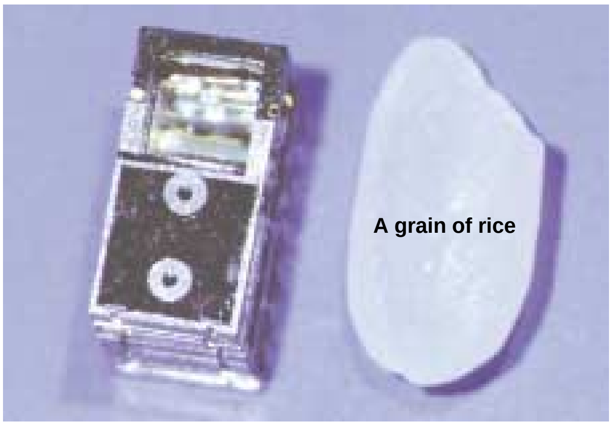


Fig. 1 Micro Optical Scanning Sensor

Fig. 2 Example of the Size Measurement

MEMS 2000 Report

The 13th MEMS international convention, hosted by the IEEE Robotics and Automation Society and supported by the Micromachine Center, was held at the Miyazaki Seagaia Convention Hall for five days from January 23 to 27, 2000.

Four of the five days were allotted for the convention, which had 141 presentations in total, with three invited lectures, 41 oral presentations, and 97 poster presentations.

The number of applications (abstract applications) was a record high at 319, which demonstrates severe screening with an adoption ratio of 43%.

The numbers of presentations by country (excluding invited lectures) were: 48 from Japan and 45 from the US, followed by 9 from Switzerland, 8 from South Korea, 8 from the Netherlands, 7 from China, 5 from Germany, 3 from France, 3 from Sweden, and 2 from Taiwan.

Of the 433 people registered in advance (registration list), their numbers by country were: 258 from Japan, 79 from the US, 25 from South Korea, 13 from Switzerland, 12 from the Netherlands, 9 from Taiwan, 9 from Germany, 8 from China, and others. The attendance from South Korea was noticeably high. The total attendance eventually reached 521. Many people from companies participating in the Industrial Science and Technology Frontier Program “Micromachine Technology” were also present and made six presentations as shown in Table 1.

According to the contents of the session program, there were 23 presentations related to electrostatic, piezoelectric, and other actuators, 21 presentations on sensor technology for pressure, acceleration, and gyroscopic sensors, 17 on micro-fluidics, 16 on opto-MEMS, 16 on novel technologies, and others on 3D structures, biotechnology, bonding and packaging, materials and measurement, modeling design, etc.

Of the 23 presentations on actuators, 9 were related to electrostatic actuators (5 of them dealing with switches, light, fluids, positioning stages and others developed for specific applications), 7 on piezoelectric actuators (2 of them for their application to μ fluidics), 3 on SMA actuators (1 of them for their application to catheters), 2 on pneumatic actuators, 3 on polymer actuators, 1 on electromagnetic actuators, and 1 on other topics. (The presentations falling under more than one field are counted more than once.)

Photo 1 Reception Party Scene

Of the 21 presentations on sensors, 6 were on acceleration/gyroscopic sensors, 4 on pressure sensors, 2 on flow sensors, 3 on heat sensors, etc.

There were 17 presentations on micro-fluidics, with 2 on micropumps, 2 on micropipettes, 2 on micro integrated fluid devices, and 1 on each of valves, thrustors, mixers, and diffusers, respectively.

The application session included presentations on AFM, spectrometers, acoustic devices (two presentations), microrelays (two presentations), and ink-jet printers. Researches in mechanical fields were also presented, ranging from micro flight mechanisms (two presentations), decelerators, catheters, and microrobots to displacement magnification mechanisms.

Moreover, at the lobby in front of the lecture hall, the Micromachine Center exhibited trial systems, and Denso, Sanyo Electric, Sumitomo Electric, Yokokawa Electric, Yasukawa Electric, and Mitsubishi Cable Industries each displayed panels to present their researches.

On the evening of the first day, a reception was held at the Seagaia Ocean Dome next to the hall (Photo 1). It was a buffet-style party in a restau-


Photo 2 Banquet Scene

rant facing a beach washed by artificial waves. Participants were requested to wear bathing suits, in principle, and they enjoyed swimming in the sea, a dance show with a tropical flavor, and a demonstration by surfers. During the party, college professors, executives of participating companies and many other participants deepened relationships with one another, and this arrangement of the party really helped to make their personal relationships closer. The party ended with a laser show using fountain water as projection screen and broke up as participants left.

On the night of the third day, a grand banquet was held in a rearranged lecture hall (Photo 2). There were attractions such as *Yamatodaiko* drumming and rice cake making, and an introduction to Interlaken in Switzerland, the next venue.

The next convention will be held from January 21 to 25, 2001, and the deadline for abstract applications will be August 15, 2000.

Table 1 Research results from the Industrial Science and Technology Frontier Program "Micromachine Technology" presented in MEMS2000

(1) "Ultrasonic Micromixer for Microfluidic Systems" (POSTER SESSION)
Z. Yang, H. Goto, M. Matsumoto, and R. Maeda / Mechanical Engineering and OMRON Corp.

(2) "Optimization of Mechanical Interface for a Practical Micro-Reducer" (POSTER SESSION)
H. Takeuchi, K. Nakamura, N. Shimizu, and N. Shibaike / Matsushita Research Institute Tokyo, Inc.

(3) "Profile Measurement of High Aspect Ratio Micro Structures Using a Tungsten Carbide Micro Cantilever Coated with PZT Thin Films" (POSTER SESSION)
M. Yamamoto*, I. Kanno**, and S. Aoki* / *Matsushita Research Institute Tokyo, Inc., **Matsushita Electric Industrial Co., Ltd.

(4) "Torque Measurement Method Using Air Turbine for Micro Device" (POSTER SESSION)
H. Ota, T. Ohara, L. Luming, M. Takeda, H. Narumiya, and K. Namura / MITSUBISHI ELECTRIC CORPORATION

(5) "A New Smart Vision System Using Quick Response Dynamic Focusing Lens" (POSTER SESSION)
T. Kaneko, N. Mitsumoto, and N. Kawahara / DENSO CORPORATION

(6) "Development of Chain-Type Micromachine for Inspection of Outer Tube Surfaces (Basic Performance of First Prototype)" (ORAL SESSION)
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Latest Micromachining Technology — Part 1

Shaping by Etching — Bulk Micromachining

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In this four-lecture series beginning with this issue, we will outline the latest machining process technology aimed at micromachining. The entire series, including this lecture, is comprised as follows:

(1) Shaping by etching – bulk micromachining
(2) Forming 3-D structures of thin films – surface micromachining
(3) Pursuing finer machining – precision machining technology
(4) Mass production by transferring shape – fine-molding technology

Micromachines have already come into use in the form of devices that are familiar to us, such as ink-jet printer heads and video projector devices. These devices have been realized by micromachining technologies. The above (1), (2), and (4) technologies have achieved great success in industrial use because of their features of integrated manufacturing processes, such as precise arrangement of numerous micro-mechanical elements and mass production of products of uniform quality. The subject of this lecture: "bulk micromachining" is a technology to be contrasted with the next subject "surface micromachining." This is a process technology for creating structures on work material substrates (bulks) by etching.

1. Classification of Etching Methods

Etching is a process in which an etching mask is placed on the surface of the substrate to be machined, and a minute opening pattern is formed in given regions of the mask by photolithography to selectively remove substrate materials according to the pattern. Table 1 shows specifically what agents are used to remove substrate materials.

Table 1 Etching Methods and Classification of Agents

Wet etching	Acid:	(example) hydrofluoric acid, nitric acid
	Alkali:	(example) KOH, ammoniac agents
Dry etching	Gas:	(example) XeF_2, BrF_3
	Radical:	(example) F
	Ion:	(example) Ga, Ar, Cl, fluoro-carbon
	Atom:	(example) Ar

Among wet etching and dry etching agents, highly reactive gases, radicals, and ions react chemically with substrate materials to remove them. On the other hand, low reactive ions and atom beams physically remove materials by hitting the surface of the substrate after the particles are accelerated. Thus, etching has various mechanisms to remove materials, so that etching characteristics are also varied as described below.

2. Utilization of Etching Characteristics

There are isotropic and anisotropic etching characteristics, which result in major differences in machined cross sections. In general, when etching is begun at a mask opening, machining proceeds in the direction normal to the surface and affects the lower part of the mask. This is called side etching or undercutting. If the supply of etching agents (etchants) and the discharge of reaction products are performed smoothly, and work materials are homogeneous and isotropic, the amount of side etching approximately equals the etching depth. This kind of system is known as isotropic etching. A typical cross section resulting from such etching is shown in Fig. 1. In isotropic etching, deep machining will cause mask pattern information to be lost. Therefore there are limitations to its application to the machining of such structures as micromachines, but it is useful for limited purposes. For example, isotropic etching proceeds in all directions at the same rate, which allows minute concave surfaces to be machined when the etching is performed from a mask with dot-shaped openings (see the left of Fig. 1). An example of the utilization of this characteristic is ultrasonic microscopic concave lenses formed on single-crystal silicon. On the other hand, sharp points can be created if etching is begun on the periphery of a disk-shaped etching mask and is stopped when the undercut has reached the center of the disk. An example of the utilization of this characteristic is electron emitting cathodes.

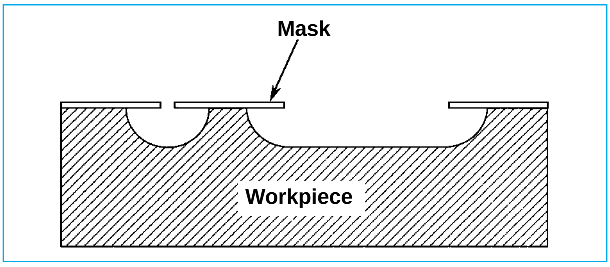


Fig. 1 Cross Section Resulting from Isotropic Etching

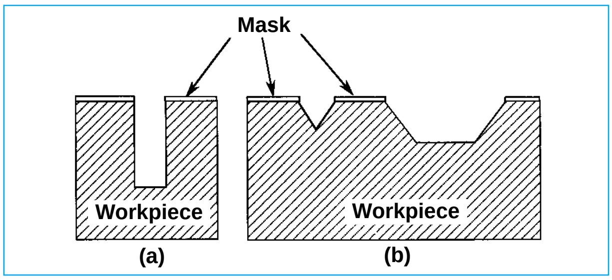
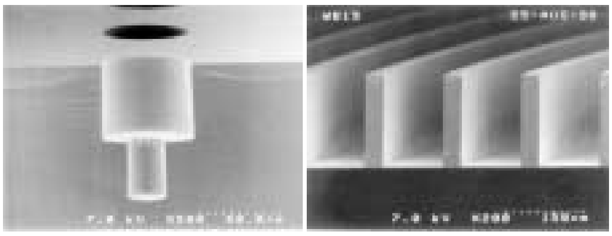


Fig. 2 Cross Section Resulting from Anisotropic Etching

In contrast to isotropic etching, the etching characteristics involving minimized side etching and deep machining from a narrow mask apertures are known as anisotropic etching. A typical cross section resulting from such etching is shown in Fig. 2. Since this etching enables deep machining according to mask pattern information, it is generally suitable for machining micromachine devices. Its realization requires special consideration to be given to the combination of work materials and etchants, and other machining conditions. Dry processes and wet processes have both contributed to major advances in characteristic anisotropic etching techniques over the past several years.

A typical method of anisotropic dry etching is reactive ion etching (RIE). Fluoric gases such as CF_4 and SF_6, for example, are introduced into a vacuum chamber, and a high-frequency voltage is applied between the electrodes to generate plasma, priority is then given to the execution of etching in the direction normal to the silicon substrate. In micromachine research applications, the use of high-density plasma by means of inductive coupling type equipment (ICP) has recently allowed machining with an etching depth of 300 to 500 µm at an aspect ratio of 15:1 to be performed at an etching rate of 5 µm/min. Fig. 3 (a) shows a cross-sectional photograph of the step hole of an ink-jet printer nozzle machined by this method. The smaller opening is 28 µm in diameter.



(a) (b)

Fig. 3 Examples of Machined Ink-Jet Printer Heads
(a) Nozzle Hole Machined by Dry Etching
(b) Ink Reservoir Machined by Wet Etching
(Both by courtesy of SEIKO EPSON CORPORATION)

Among the anisotropic wet etching methods, on the other hand, there is chemical anisotropic etching which uses the anisotropy of the work material itself. Since the equipment necessary for this machining is inexpensive, it is used with a far higher degree of frequency than dry etching for the production of practical devices. The silicon single crystal has a diamond crystal structure, and causes the etching rate to differ by as much as 100 times depending on its crystal orientation, showing strong anisotropy. This results in a unique three-dimensional etched shape reflecting its crystal structure; in other words, polyhedral structures as shown in Figs. 2 (a) and (b) can be readily obtained. KOH aqueous solutions, tetramethyl ammonium hydroxide (TMAH) aqueous solutions, etc. are known as its etchants. Fig. 3 (b) shows a cross-sectional photograph of a printer ink reservoir etched with a KOH aqueous solution. Each compartment is uniformly etched, leaving the 2.2 µm-thick diaphragm at the bottom for pumping operation. Moreover, etching performed from the top and bottom surfaces of the silicon substrate will result in a more complex three-dimensional structure. Fig. 4 is an example of curved surface machining performed at the base of a silicon beam used in an acceleration sensor. Chemical anisotropic etching, which has been thought to be performed only on polyhedrons, has allowed a smoothly curved three-dimensional surface to be realized. In order to machine complex three-dimensional structures such as the one shown in this example, a few etching processes using the same number of different mask patterns, rather than only one etching process, are required. The relation between the crystal orientation of the substrate and mask shape as well as the composition of the etching solution and the temperature determines the finished shape. Etching simulation systems and databases on the etching characteristics of silicon, which enable such process design, have recently been developed and put to practical use.

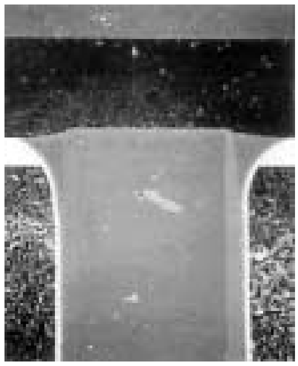


Fig. 4 Example of Curved Surface Machining by Chemical Anisotropic Etching

Crystal anisotropic etching can be performed not only on silicon single crystals, but also on other crystal materials such as quartz and GaAs.

3. Comparison of Wet and Dry Etching

The advantages and disadvantages of dry and wet etching are compared with respect to several items, which is shown in Table 2. The type of etching to be applied will depend on the machining characteristics required, and in industrial applications, returns on plant and equipment investments must be considered. In micromachine development, the selection of an etching method directly affects device design, so that the machining techniques you have determine the types of devices you can manufacture. In other words, micromachine device development requires a concurrent type of development system that integrates design with machining.

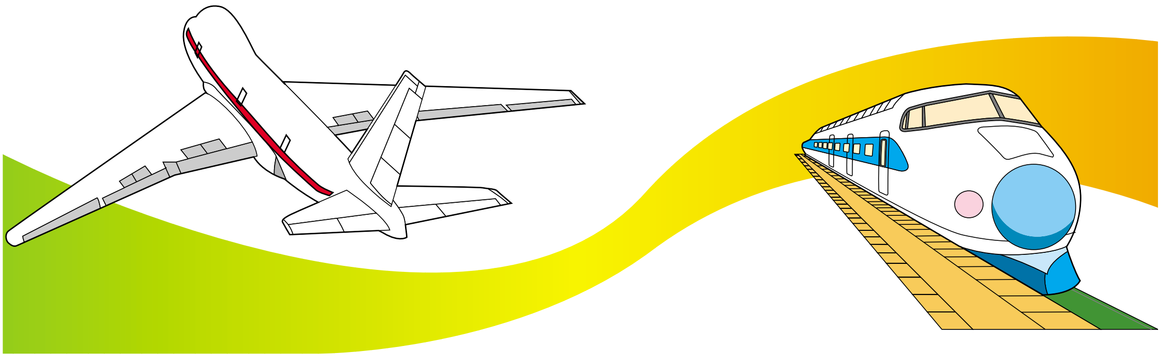
Table 2 Comparison of Dry and Wet Types of Anisotropic Etching (+: superior, –: inferior)

	Wet etching	Dry etching
Machining fineness	+	++
Cleanliness, ease of integration with electronic circuits	–	++
Etching with given two-dimensional patterns	– – –	+++
Etching depth controllability	++	+
Etching depth uniformity	++	–
Machining of special shapes	++	+
Equipment costs required for machining	+++	– –

Preliminary Announcement

The 6th International Micromachine Symposium

November 9 and 10, 2000
at Science Hall, Science Museum, Tokyo, JAPAN



Exhibition
MICROMACHINE2000

November 8 - 10, 2000
at Science Museum, Tokyo, JAPAN

The Detail will be announced later.

Pictures on the cover: ***Winning artworks in the Micromachine Drawing Contests***
Bee-type robot, Navigator for vision handicaps, 3-dimentional robot "Ant", and Take-it-all (from top to bottom)

MICROMACHINE No. 31

MICROMACHINE is published quarterly by Micromachine Center (MMC) to promote the international exchange of information related to micromachines, R&D and other technical topics, and is circulated free of charge. Please send your comments about **MICROMACHINE** to the publisher:
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Internet Home Page http://www.iijnet.or.jp/MMC/

Change of Address: Please send old address label and new address to the publisher.
Editorial and Production Management: Japan Technical Information Service (JATIS)
Date of Issue: May 29, 2000