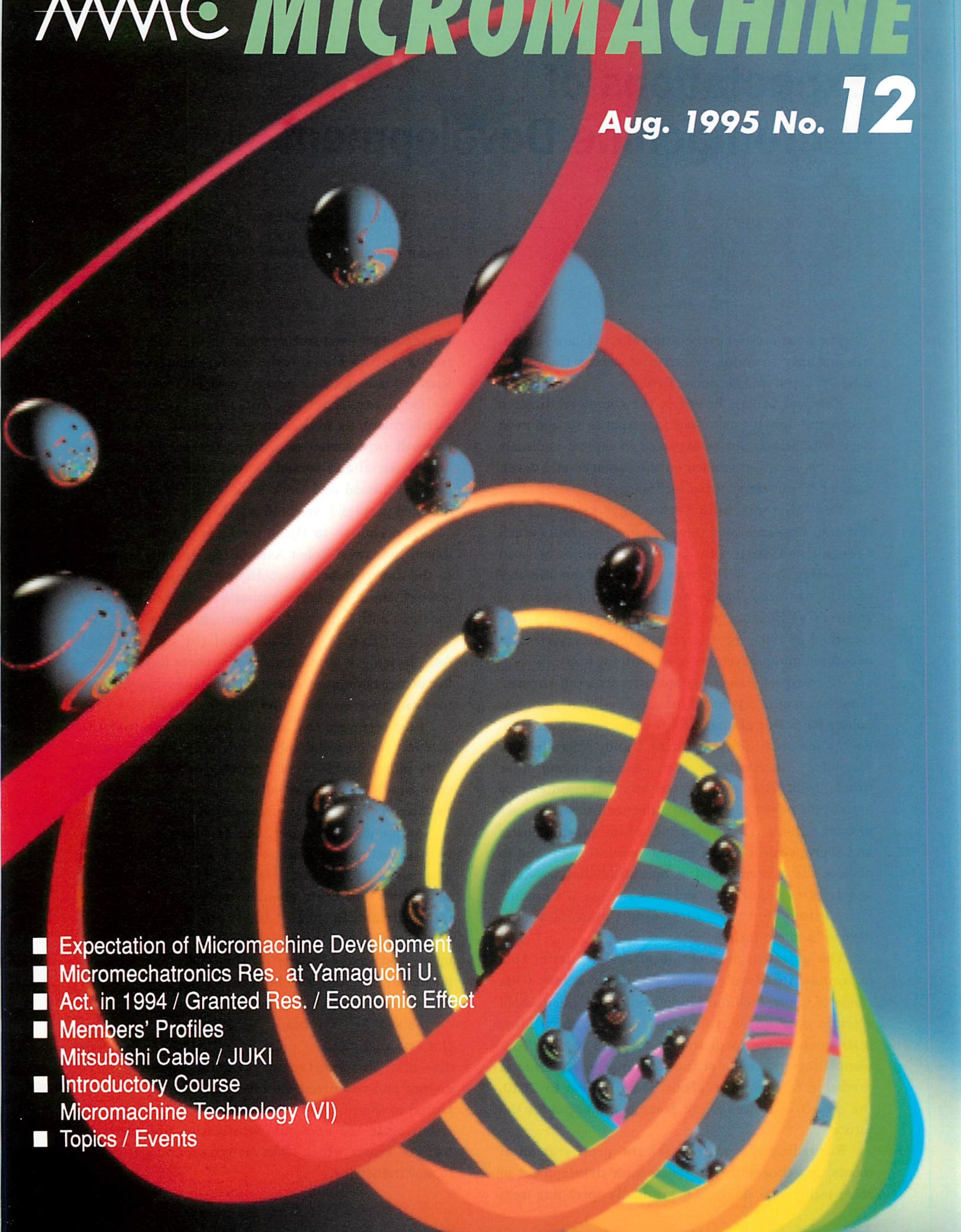
MMC MICROMACHINE

Aug. 1995 No. 12



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Micromachine Center

Expectations of Micromachine Development

Yoichi Morishita
Chairman
Japan Robot Association

The need for and expectation of robots are spreading not only in industry but also across the entire range of social and economic fields.

Needless to say, however, the commercialization and promotion of businesses in response to this need for robots, which can be expected to expand endlessly from now on, are premised on the research and development of innovative robot technology.

The "Micromachine Technology" project of the National Research and Development Program (which reorganized into the Industrial Science and Technology Frontier Program in 1993) of the Ministry of International Trade and Industry's Agency of Industrial Science and Technology, which was launched in 1991, aims to pursue the miniaturization of equipment and systems to the utmost limit.

The project has three specific research themes: "Development of advanced function maintenance technology for power plants," "R&D of micromachine technology for medical applications," and "Micro-factory technology." Accordingly, it is seeking, among other things, to develop an advanced function maintenance system for power plants and other facilities that uses micromachines, to develop intra-luminal diagnostic and therapeutic systems for the medical field, and to develop the microprocessing, operating, and assembly technologies required for the construction of a production system that uses ultra-small manufacturing devices (a micro-factory).

The practical application of the results of this micromachine development will cover a very wide range of areas, including industrial plants, household electric appliances, information communications, instrumentation, medicine, space, and the environment. Since the scale of the micromachine market is predicted to expand to about ¥3.20 trillion by 2010, the project embraces many dreams and hopes for the future.

Regarding the outlook for the proliferation of robots, together with the spectacular development of robot technology, demand is gradually spreading from the manufacturing sector, which initiated the need for robots, to the nonmanufacturing sector, including such fields as nuclear energy, medical treatment and welfare, construction, and ocean development. Furthermore, as well as these industrial areas, there is much expectation concerning the use of robots in nonindustrial and personal areas, such as social welfare (livelihood and work assistance for elderly and disabled people), household activities, and leisure.

In response to these background factors, the Japan Industrial Robot Association changed its name to the Japan Robot Association in June 1994 and is strengthening the organization to promote the use of robots in both industrial and nonindustrial fields.

According to predictions of the Japan Robot Association, the total demand for robots in the manufacturing, nonmanufacturing, and nonindustrial sectors will reach an estimated ¥2 trillion in 2005.

Furthermore, the association predicts that the demand for personal robots will reach an estimated ¥200 billion in 2005, ¥1.7 trillion in 2010, and will grow to a level on a par with the automobile industry by the end of the twenty-first century.

As mentioned earlier, the development of these robots technologies depends a great deal on the progress of R&D in the field of micromachine technology, which will bring about tremendous advances in miniaturization and in functions, precision, and speed, which are the main themes of robot development, and vastly expand its range of application. In particular, the micromachine technology holds the key to the development of personal robots.

As well as stimulating the development of robots, the establishment of micromachine technology will also play an important role in the conservation of energy and resources. So much expectation is being placed in the results of the project as a means of contributing to the economic vitalization and development of Japan, which lacks resources, and giving rise to new industries.

Study of Micromechatronics

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This laboratory focuses on micromechatronics in educational research. Our specialty is the micromachine with micro actuator made of shape-memory alloy. Three teams are engaged in research and development of millimeter-scale micromachines, micron-scale micromachines, and Si type micromachining devices. The activities of these three teams are reported below.

1. Research of millimeter-scale micromachines

Noting that shape-memory alloys (SMA) have high force-to-weight ratio and that micromachines made of this material shows faster response because of higher surface area-to-volume ratio, the team built millimeter-scale micromachines using SMA thin wires and SMA thin plates (thickness about 50 μm) on a test basis. They tested the machines to find problems and to search for the solutions. Fig. 1 shows a micro manipulator having a spiral actuator made of SMA thin plate (50 μm thick) that rotates the arm joint axis. When the spiral actuator is heated by electrical current going through the actuator, it recovers its original (memorized) flat shape. This reforming torque rotates the axis. An inverse spiral actuator made of SMA thin plate is installed on the back side of the axis. The axis is rotated in the reverse direction by heating the backside spiral SMA actuator.

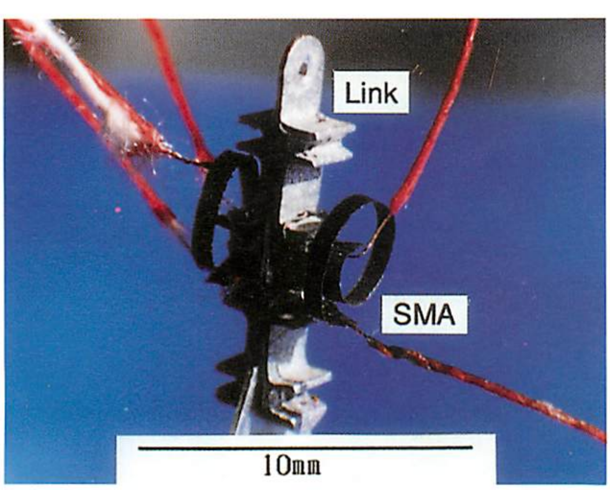

Fig. 1 SMA spiral 1-axis manipulator

A conduit guided wire system transfers great force as far as the wire tensile strength or conduit buckling strength, and therefore many researches are being made on its applications such as for medical catheters. Fig. 2 shows a gripper that was test manufactured as basic research for an endoscopic surgical manipulator. The gripper has four degrees of freedom and it can manage not only to pick up things but to roll things with its fingertip as well. Pinching force is detected by the micro tactile sensor placed near the gripper and is fed back to the master hand bilaterally as braking force. This means that it can detect whether the picked thing is soft or hard. On the other hand, because the conduit guided wire system has the high friction between conduit and wire, we are trying to reduce the friction by applying vibration.

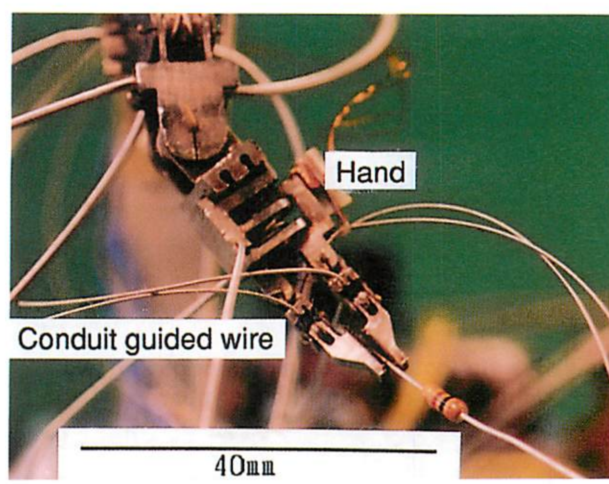

Fig. 2 Millimeter-scale hand with conduit guided wire (100 μm dia.)

2. Research on micron-scale micromachines

If much smaller micromachines made of SMA than the above size are to be developed, they will require SMA thin films of several microns thickness, which cannot be manufactured in the same way as one makes materials for millimeter-scale micromachines. Our laboratory took the lead in manufacturing SMA thin films of about 5 μm thickness by the sputtering method. These films are the main material of our micron-scale micromachines. Fig. 3 shows a macro type machine made of the SMA thin films, as an example of the test product. This machine is a reversible SMA thin film actuator, and its memorized shape is an arc. When heated and cooled, the arc changes from (a) to (b) to (c). Reversible SMA is a promising material for micromachine actuators since bias spring and other complex structures are not necessary and only a few volts are sufficient to drive the actuator.

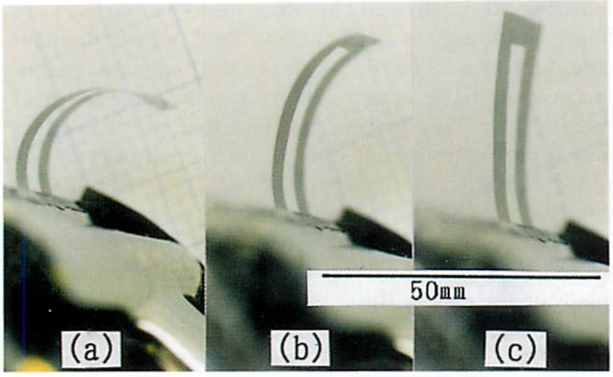

Fig. 3 Reversible SMA thin film

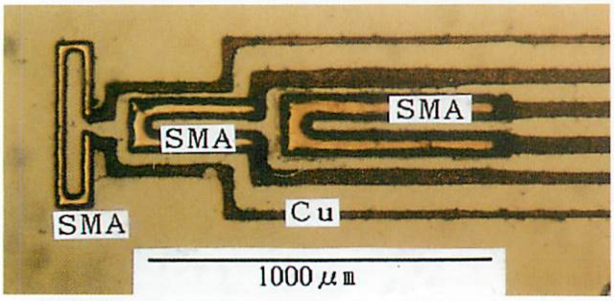

Fig. 4 Si wafer pattern of manipulator having two degrees of freedom with a gripper

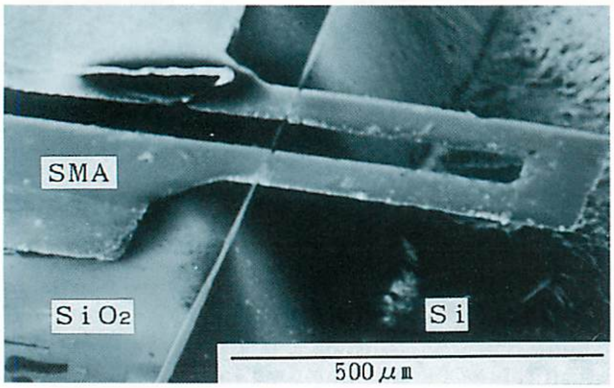

Fig. 5 SMA thin-film cantilever on Si wafer

The next research subject is connection with the Si process, etc. Fig. 4 shows wet etching of SMA and Cu films on a Si wafer in the process of manufacturing a manipulator with a gripper having two degrees of freedom. Fig. 5 shows an SMA cantilever produced on a Si wafer, as a first step in making a three-dimensional structure.

3. Research of RIE for micromachine development

We found that the anisotropic etching process can be speeded by lowering the Si substrate temperature of the reactive ion etching (RIE), and have built a low-temperature RIE apparatus to study its characteristics. Fig. 6 shows an example of results we obtained in researching the characteristics. The results were rather favorable. Apart from RIE, we also researched and developed apparatuses such as chemical vapor deposition (CVD) systems and sputtering machines specialized for micromachines. Our laboratory is inviting both doctoral and research students.

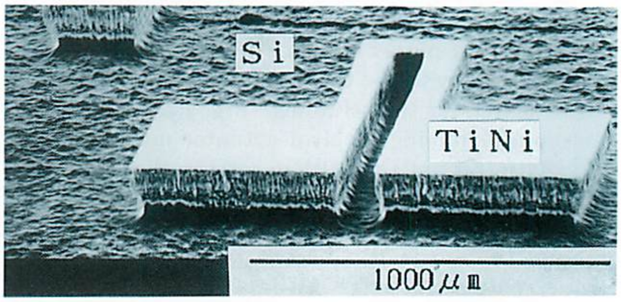

Fig. 6 Example of Si etching by RIE (mask: TiNi)

Activities of the Micromachine Center in Fiscal 1994

Micromachines are composed of functional elements only a few millimeters in size and are capable of performing complex microscopic tasks. During fiscal 1994, the Micromachine Center (MMC) conducted the following activities to establish basic micromachine technologies and disseminate micromachines in society, thus contributing both to the development of domestic industry and the international community through investigating and research, collecting and providing information on micromachines, fostering exchanges and cooperation with related organizations in Japan and in other parts of the world. In particular, the Center is devoted to improving its management system and expanding international exchange activities.

1. Investigation and Research on Micromachines

(1) Industrial Science and Technology Frontier Program "Micromachine Technology" of MITI's Agency of Industrial Science and Technology (AIST) *(Entrusted to MMC by the New Energy and Industrial Technology Development Organization)*

The ultimate purpose of this project is to establish technologies applicable to the realization of micromachine systems. These systems are composed of small functional elements, locomote in very narrow spaces in complex equipment such as a power plant and in a living organism, and can perform intricate work autonomously, or manufacture small parts.

In the fourth year of this project, "Micro-factory technology" started in addition to ongoing research from previous years. While the project as a whole successfully proceeded as scheduled, part of it must be carried over to the next fiscal year because of the Kobe earthquake in January 1995.

[Development of advanced maintenance technology for power plants]

Research and development on the element technology for microcapsules, mother ships, cableless and cabled inspection modules, of which this advanced maintenance system consists, were carried out, including trial manufacture, experiment, and evaluation.

[Micro-factory technology]

R&D on the element technology for micro operation and driving mechanisms was conducted, including trial manufacture, experiment, and evaluation. Also, the measurement of energy-saving effects and problems caused by electromagnetic wave noise and static electricity between equipment in conjunction with microsizing were investigated.

[Medical application technology]

To develop the element technology for micro catheters for cerebral blood vessels, which is a typical intra-luminal diagnostic and therapeutic system, R&D was conducted on piezoelectric tactile sensors, optical contact force sensors, pressure sensation transmission mechanisms, laser-applied diagnostic and therapeutic micro laser catheters, and blood pressure and flow sensors, including trial manufacture, experiment, and evaluation.

(2) Research on basic design and manufacturing technologies *(Joint research with the Mechanical Engineering Laboratory of AIST)*

Joint research was carried out with the Mechanical Engineering Laboratory of AIST to establish basic design and manufacturing technologies for micromachines.

(3) R&D on micromachine materials *(Joint research with the Mechanical Engineering Laboratory of AIST)*

Because material technology is important as a basic technology for micromachines, "research on micromachine materials" was carried out jointly with the Mechanical Engineering Laboratory of AIST.

(4) Investigations on basic micromachine technology *(Financially supported by the Japan Motorcycle Racing Organization: Promotion of industry and academia joint research)*

Joint research between industries and universities on 11 themes related to micro science and engineering and design engineering for the realization of diversified micromachines were carried out to explore technical "seeds."

(5) Investigations of the economic effects (technical prediction) of micromachine technology *(Commissioned by the Japan Machinery Federation)*

(a) Prediction of the development of micromachine technology
(b) Evaluation of the economic effects expected from micromachine systems in various industries

As the target area, in addition to the five areas of information communications equipment, precision equipment, medical application, instrumentation, and automobiles covered in fiscal 1993, nanotechnology, micro-factory, maintenance, environment, aerospace, and leisure were added in fiscal 1994. The scale of these markets in the year 2010 will be an estimated 3.2 trillion yen.

(6) Investigations on R&D trends of micromachine technology in Japan and in other countries *(Commissioned by the Japan Machinery Federation)*

(a) Review of the technical development of micromachines
(b) Analysis of the technical trends of micromachines

Both the review and analysis were carried out through surveys of researchers, research subjects, research contents, research results, and research organizations selected from universities, research institutions, and private businesses in Japan, the United States, and Europe, using questionnaires and publications.

2. Collection and Provision of Micromachine Information

(1) Collection of micromachine information

Periodical publications, books, and other materials containing information and data on micromachines were collected from universities, industry, and public organizations within and outside Japan. These materials were catalogued and kept with MMC's research data at the Center's documentation room.

(2) Provision of micromachine information

These collected materials were made available to interested people concerned at MMC's documentation room.

(3) Investigations on the construction of micromachine technology information database

Investigations were carried out on the following to determine a desirable database for the Center.

1) Kinds of information to be collected in the database
2) Forms of information expected from users
3) System configurations meeting the above requirements

3. Exchange and Cooperation with Worldwide Organizations Involved with Micromachines

To promote affiliation, exchange, and cooperation with related organizations with common interests, MMC made research grants as part of joint projects with government, industry, and academia, and invited researchers and scholars to a micromachine summit and seminars.

(1) Research grants for micromachine technology

To make research grants to university professors devoted to the basic research on micromachines and to promote exchange between industry and academia, MMC solicited applications for research grants in fiscal 1994 for the second time. After strict screening of many applications, MMC awarded research grants to 11 projects, including those continuing from the previous fiscal year.

(2) International exchange on micromachines

1) First Micromachine Summit

The First Micromachine Summit was held March 13-15, 1995, at the Miyako Hotel in Kyoto and brought together leaders from micromachine-related universities, research institutions, and industries (28 representatives from 10 countries; a total of 120 participants). They freely exchanged opinions on extensive subjects ranging from R&D to commercialization. The summit was also intended to increase awareness of micromachines inside and outside Japan through broad publicity. The next Summit will be held in 1996 in Switzerland.

2) Micromachine technology seminars

To promote international exchange, technology exchange seminars were held in three European countries:

(a) Crans Montana, Switzerland, June 28-29 (4 participants)
(b) London, UK, June 21 (30 participants)
(c) Brussels, Belgium, June 24 (25 participants)

3) Acceptance of missions, etc.

Visitors from eight countries including China, the United States, and Switzerland were received and opinions were exchanged on the "Micromachine Technology" under the AIST's Industrial Science and Technology Frontier Program and the MMC's activities.

4) Dispatch of missions

(a) '94 Spring Micromachine Study Mission to Europ (16 members, June 21 to July 3, 1994)

During their participation in the Switzerland-Japan Technology Exchange Seminar, the mission members visited universities and research institutions in France and Switzerland and exchanged opinions on the trends of micromachine technology research.

(b) '94 2nd Micromachine Study Mission to Europe (16 members, January 28 to February 8, 1995)

During their participation in the MEMS '95 held in Amsterdam, the Netherlands, the members in three groups visited micromachine technology-related research institutions in European countries, exchanged opinions, and investigated the trends of R&D.

5) Sponsorship of and participation in symposia on micromachine technology

(a) The 5th International Symposium on Micro Machine and Human Science was held October 2-4, 1994, in Nagoya under the cosponsorship of Nagoya City, the Chubu Industrial Advancement Center, the Federation of Micromachine Technology, MMC, and others (400 participants from 8 countries).

(b) MMC participated in the Symposium MUST '94 held at Veldhoven, the Netherlands. The members visited universities, research institutions, etc., in the Netherlands, Switzerland, and Germany (September 19-20, 1994).

(c) MMC participated in the MEMS '95 held January 29 to February 2, 1995, in Amsterdam, the Netherlands. MMC-related presentations were four oral presentations and five items in the poster session (224 participants).

4. Promotion of Micromachine Standardization

Commissioned by the Japan Machinery Federation, MMC carried out classification (including hierarchical structure) of 183 terms, which are integral to micromachine technology, and explored the meaning of 103 terms that were not explored in fiscal 1993. Also, MMC carried out a more in-depth study on the results of the questionnaire survey conducted last fiscal year on the basic instrumentation/evaluation research items for micromachine technology. MMC simultaneously collected technical data for the items deemed important, and analyzed measurement methods, specific measuring requirements, and any technical problems that might emerge in future.

5. Dissemination and Enlightenment of Micromachines

(1) Publication and distribution of public relations magazine

During fiscal 1994, the Japanese edition (Nos.7-10) and English edition (Nos.7-10) of MICROMACHINE were issued.

(2) '94 Micromachine Technology R&D Presentation

The meeting for presenting the progress and results of the "Micromachine Technology" project delegated to MMC by NEDO was cosponsored by the Japan Industrial Technology Association on November 16, 1994, at the Science Museum in Kitanomaru, Tokyo. Eleven lectures and 30 exhibits were presented to about 400 participants.

(3) 6th Micromachine Symposium

This symposium was held May 11-12, 1994, at the Science Museum at Kitanomaru, Tokyo. Twenty-three lectures were presented to about 400 participants.

(4) 5th Industrial Micromachine Exhibition

During the 6th Micromachine Symposium, this exhibition with "Micromachine, a Dream Fostering Technology" as its theme was held May 11-13, 1994, at the Science Museum in Kitanomaru, Tokyo. Fifty-seven exhibitors participated and about 3,700 people visited.

(5) 1st Micromachine Drawing Contest

To have children understand and be familiar with micromachines, as one of the dissemination and enlightenment projects of micromachines, MMC held a micromachines drawing contest for primary and junior high school boys and girls. MMC received excellent entries. This was the first contest and with the cooperation of MMC's supporting members was conducted among five primary and junior high schools in Ina, Nagano Prefecture, and Shizukuishi, Iwate Prefecture. Twenty-four drawings were selected from a total of 1,001. The awards ceremony was held on March 27, 1995, at the Tokai University Alumni Association Hall.

(6) Evening Seminars

Evening seminars were held as the place for the dissemination and exchange of research results, etc., of micromachine technology (on the 3rd Wednesday of each month; a total of 8 times during fiscal 1994).

(7) Publication of the "Industrial Graph" on Micromachine

To enlighten children about micromachines, in cooperation with The Japan Economic Education Center Foundation, MMC published "Micromachine and its Technology" as the 174th issue of the "Industrial Graph." The publication is a supplementary teaching aid for civics courses in primary, junior high, and high schools (50,000 copies).

6. Participation in the Federation of Micromachine Technology

The Federation of Micromachine Technology was established to fully employ the characteristics and functions of various organizations, which differ in each area of science, and to simultaneously promote the exchange of and cooperation in research on micromachine-related topics. Acting as its secretariat, MMC held meetings of the Operation Council.

Main Results of Research Supported by the First Micromachine Technology Research Grant

The research grant system was commenced in 1993 as an independent activity of Micromachine Center with the aim of advancing micromachine technology and promoting intercourse between industrial and academic societies through giving support to researchers in universities engaged in basic research related to micromachines.

This report is the summary of the five one-year research projects granted with the aid in the first term (fiscal 1993), which have recently been completed.

The results of the research projects will be reported on September 22, 1995 at the meeting room of Micromachine Center. We will accept applications for the grant in 1995 until October 31st. For details, contact Micromachine Center.

Winners of the grant at the presentation ceremony (May, '94)

1993 Research Grant Recipients

Leader and Co-leader	Subjects	Period	Remarks
Kimiyuki Mitsui	Basic research on a method for evaluating the geometrical accuracy of micro parts	1 year	Page 9
Shinichi Yokota, Kazuhiro Yoshida	Development of micro control valve using functional fluid	1 year	Page 10
Hiroaki Misawa	Development of ultra-precision handling technique using a laser manipulation method	1 year	Page 11
Nobuhiko Yui	Basic studies on blood compatible and biodegradable polymers as materials for medical micromachines	1 year	Page 12
Yoji Yamada	Development of a tactile array sensor with 3-axis force and slip vibration sensing functions using PVDF film	1 year	Page 13
Shuichi Miyazaki	Basic research on the development of shape-memory alloy thin film for microactuators	2 years	—
E. M. Yeatman* R. A. Syms*	Research on micromolding and microactuation using surface tension	2 years	—
Kunihiko Mabuchi Iwao Fujimasa	Basic research on application of micromachine technology in the development of remote-controlled microscopic surgery systems	2 years	—

* University of London

(Note) The period of grant support for this research is as follows:
For one year R&D: March 1994 to March 31, 1995
For two year R&D: March 1994 to March 31, 1996

Basic Research on a Method for Evaluating the Geometrical Accuracy of Micro Parts

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To manufacture a micromachine, it is necessary to accurately evaluate the dimensional and geometrical accuracy of the component parts. At present, however, it is even difficult to measure precisely the inner diameter and depth of fine hole with a 0.5 mm or smaller diameter. Virtually no attempt has been made to prepare other dimensional accuracy measures we use for general parts processing, such as straightness, roundness, and squareness, into the micro-processing field. In the future, however, development of the micromachine technology and advances in fine processing technology will give rise to keen demand for technology to evaluate the dimensional and geometrical accuracy of micro parts.

This study attempted to develop a non-contact geometry measurement instrument that applies voltage between a probe and a conducting sample and utilizes the tunnel effect by approaching the probe and the sample at a distance of about 1 nm.

Fig. 1 shows the conceptual diagram of the instrument. The object of measurement is placed on the *XY* stage. A piezoelectric transducer on the *Z* axis stage holds a probe, a 0.25 mm tungsten wire that has been polished electrolytically. Fine movement stages are controlled in the *X*, *Y* and *Z* directions by a personal computer via the GP-IB interface. Stage coordinates can be determined from the built-in encoder. An analog circuit for applying bias voltage, detecting tunnel current and actuating the piezoelectric transducer is connected to the personal computer via an A/D converter.

With the piezoelectric transducer with probe extended, that is, with voltage applied to the transducer, the stages move toward the measurement point. At the moment the probe reaches the proximity to the object that allows tunnel current to flow, the probe is quickly retracted to avoid contact with the object, the motion of the stages is stopped and the position is read.

Because it is difficult with micro parts to move the probe to the measurement point by eye, we used an optical microscope system providing extended images with long depth of focus by image processing, which was developed by the authors. This enabled us to check the image of the object on the monitor display while commanding the measurement point and the direction of entry of the probe.

Fig. 2 shows the measured result of the inner diameter of a hole in a metal plate bored with a 1 mm diameter drill. As seen from Fig. 1, the probe retractor is placed on the turntable so that the probe can be retracted in any direction in the horizontal plane.

Fig. 3 shows an example of measuring the shape of a screw conforming to the M2 standard. In this case, the probe is mounted on the piezoelectric transducer that extends and contracts in *Z* direction, and the *Z* axis stage is moved while the height is measured. The results are measurements of the height performed at intervals of 30 μm in *X* direction and 50 μm in *Y* direction.

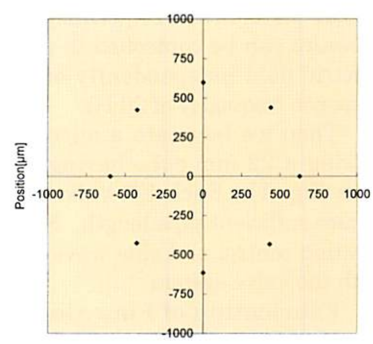

Fig. 2 Results of measurement of hole inner diameter

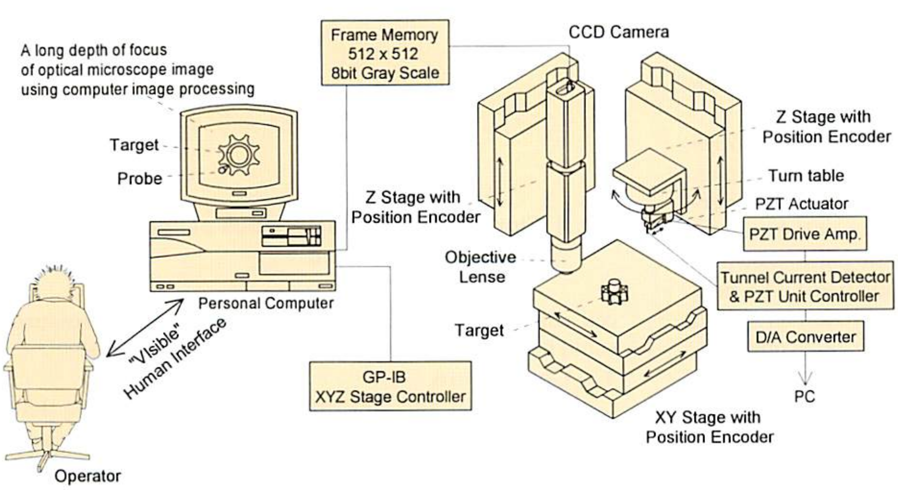

Fig. 1 Configuration of dimensional and geometrical measurement instrument for micro parts

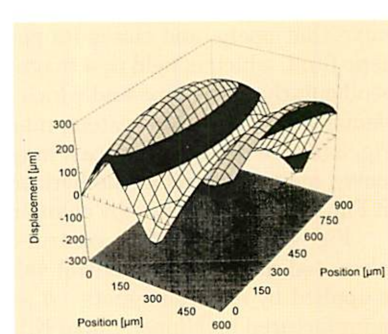

Fig. 3 Results of measurement of M2 screw geometry

Development of Micro Control Valve Using Functional Fluid

Shinichi Yokota, Professor and **Kazuhiro Yoshida,** Research Associate
Precision and Intelligence Laboratory, Tokyo Institute of Technology

1. Introduction

The authors are studying micromachines that use fluid power of high output power density to implement utility micromachines such as inspection robots for nuclear reactor small-diameter tubes. For this research we need high performance micro control valves. This paper reports our planning, fabrication, and basic examination of a micro control valve using electrorheological (ER) fluid and magnetic fluid. The valve is leakless since it has no sliding surface for processing errors to affect.

2. Fabrication of Micro Control Valve using ER Fluid

An ER fluid is one in which rheological properties are changed when an electric field is applied. Recent developments have produced ER fluids with excellent properties.

In this study, a suspension of organic-inorganic complex particles in silicone oil, an ER fluid manufactured by Fujikura Kasei Co., Ltd., is used as the working fluid. Our goal is to fabricate a valve that uses voltage changes to control ER fluid flow passing between planer electrodes placed in parallel to each other. (This valve is called the ER valve below.) First, we manufacture a macro model having twelve stacks of planer electrodes. Experiments prove that hydraulic pressure can be controlled in proportion to the applied electric field independently of flow rate and with the response frequency of 30 Hz.

Then we fabricate a micro ER valve system comprising a 22 mm cube having four ER valves bridged (See Fig. 1). Each ER valve has comb electrodes to secure sufficient pipe length. Fig. 2 shows the results of position control and sine wave drive of a small cylinder with the valve system.

3. Fabrication of Flow Control Valve using Magnetic Fluid

Magnetic fluid is a functional fluid that is attracted by magnetic force. Magnetic fluid may be used for such applications an air-tight sealing material.

In this study we suggest the probability of a control valve that opens and closes its gate by means of magnetic fluid, which is held in a magnetic field applied perpendicularly to the pipe and which serves as the valving element. In the actual system, magnetic poles shown in Fig. 3 (a) are used to produce a magnetic field. The field moves magnetic fluid in the horizontal section as shown in Fig. 3 (b) and (c), thereby changing the valve opening.

Fig. 4 shows the flow control characteristics of the fabricated macro model control valve. A magnetic field is applied by electromagnets. A sealing magnetic fluid manufactured by Nippon Seiko K.K. is used as the magnetic fluid. The working fluid is water. Though there is hysteresis, flow rate is proved to be controllable by the coil current. It is also confirmed that control pressure could be improved by the use of multistage valves.

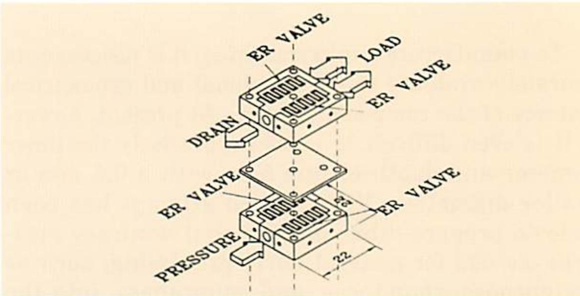

Fig. 1 Trial manufactured Micro ER valve system

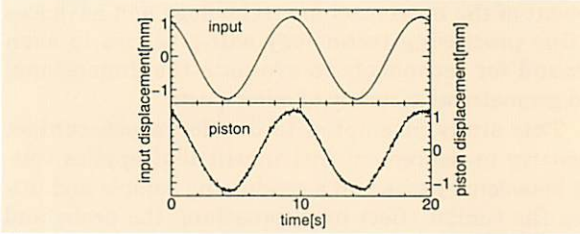

Fig. 2 Example of sine wave drive of small cylinder by ER valve system

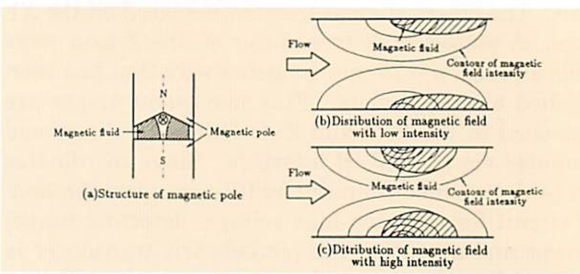

Fig. 3 Principle of flow control valve using magnetic fluid

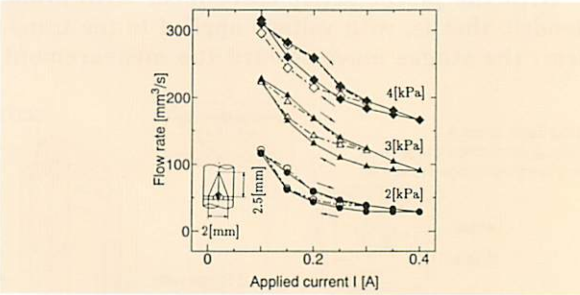

Fig. 4 Flow control characteristics of control valve using magnetic fluid

4. Conclusion

We suggest and fabricate a micro control valve that utilizes electrorheological fluid and magnetic fluid, and we test its basic characteristics. We will study the characteristics further in efforts to apply the device to micromachines moving inside tubes.

Development of Ultra-Precision Handling Technique Using a Laser Manipulation Method

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1. Introduction

Being closely related to the handling, driving and control of micromachines, the technology of accurate remote control of small objects is an important theme. Recently, laser manipulation is attracting attention as a handling method for such small objects. This method utilizes radiation pressure produced when a laser beam is reflected or diffracted by materials to remotely operate fine particles of micrometer dimensions. This technique is easy to use and has excellent space control characteristics. We succeeded in holding fine structure objects consisting of fine particles by the laser scanning manipulation method using a single laser beam, and examined the characteristics of the acquisition.

2. Experiment

Fig. 1 shows a block diagram of a laser system used in this study. The continuous wave Nd:YAG laser beam (1064 nm) for trapping objects was split into two by a beam splitter, and each split beam scanned in two axis directions using a pair of galvanomirrors. These beams were made coaxial again and focused into spots of about 1 μm through the objective lens of an optical microscope (×100, numerical aperture 1.30). *Q*-switched Nd:YAG laser (532 nm, pulse width 30 ps) for ablation was introduced coaxially to the trapping beam. The structure of the minute objects and their swinging behavior were recorded using a CCD camera and video recorder.

The minute objects were produced by the following process: Polystyrene particles (diameter 3.0 μm) were dispersed in ethylene glycol. Two particles were brought into contact using the trapping laser beam. The interface of contact was irradiated by pulse laser so that the particles were bonded together by ablation. This process was repeated to produce rod structures consisting of two, three, or four particles in length (See Fig. 2) .

3. Results and Discussion

Minute structures consisting of two, three, and four particles were called A, B, and C, respectively. The trapping laser scanned the structures in the rod length direction and the holding characteristics were examined. L_s was the scan distance. L_0 was the distance between the centers of the end particles of structures A, B, and C (A: 3.0 μm, B: 6.0 μm, C: 9.0 μm). With all structures, A, B, and C, holding was successful only when $L_0 + 0.2\ \mu m < L_s < L_0 + 2.0\ \mu m$. Swinging motion of the structure was heavily dependent on the scanning speed (V_s) of the laser beam and the laser power (P). The swinging width was proportional to L_s, and reduced as V_s increased. The present method appears promising as a technique for precise drive and control of minute structures by selecting appropriate P, L_s, and V_s for a given L_0. In the case of $L_0 = L_s$, a swinging width of about 100 nm was observed with all the structures, A, B, and C, independent of P and V_s. We further studied this phenomenon through measurement of spot position of holing laser beams in a dye solution, and observed position fluctuations of about 100 nm. Therefore, if $L_0 = L_s$, swinging width of a structure is determined by the accuracy of the galvanomirrors.

In the future, we will study the holding by laser scanning manipulation of objects of more complex shape.

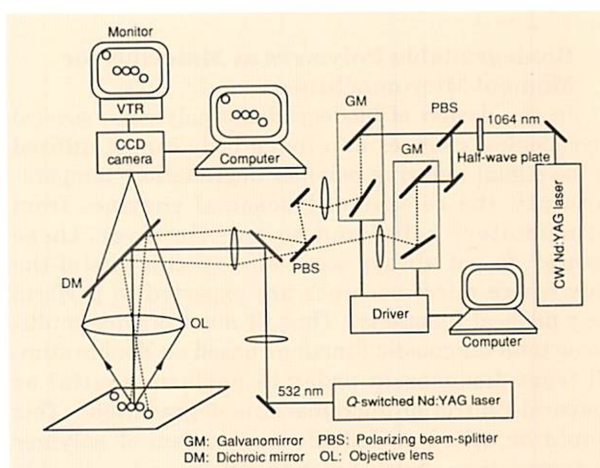


Fig. 1 Laser scanning manipulation system

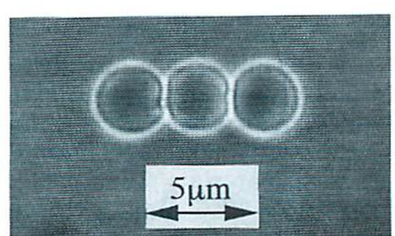


Fig. 2 Minute structure consisting of three polystyrene particles

Basic Studies on Blood Compatible and Biodegradable Polymers as Materials for Medical Micromachines

Nobuhiko Yui, Associate Professor
School of Materials Science, Japan Advanced Institute of Science and Technology

1. Introduction

The progress of micromachines for medical use will require the design of materials which have excellent biocompatibility and functions suitable for micromachines. Their required biocompatibility to enable medical functions in living bodies depends on the environments such as circulatory organs or digestion ones, and an appropriate methodology for the recovery of micromachines from living body after their use has to be considered. One promising answer to this issue will be in the design of materials which degrade in living body after completing the role of micromachines because their retrieval from living bodies can be avoided. Furthermore, the hydrophilic surfaces of these micromachines must be important in the point of getting blood compatibility. Thus, it is suggested that biodegradable hydrogels will be promising materials as medical micromachines.

2. Biodegradable Polymers as Materials for Medical Micromachines

In the design of biodegradable polymers, several physiological changes in a living body can be utilized as the signal inducing polymer degradation: temperature, pH. the release of lysosomal enzymes from inflammatory cells, and so on. However, these changes do not always occur at a specific site of the body where micromachines are expected to perform their medical functions. Thus, it must provide multiple or total diagnostic functions based on double stimuli from diseases in order to perform spatial or temporal control of micromachine degradation. This should be called as failsafe mechanism of polymer biodegradation. Such function will be indispensable to prevent the disorder of micromachine degradation, especially when complicated diseases are being suffered because much more physiological changes will occur spontaneously at the same time.

3. Design of Hydrogels which Degrade in Response to Double Stimuli

In this study, biodegradable hydrogels consisting of oligopeptideterminated poly (ethylene glycol) (oligopeptide-PEG) and dextran (Dex) with interpenetrating polymer network (IPN) structure were designed as novel materials for medical micromachines: oligopeptide-PEG and Dex networks are crosslinked independently to form IPN structure. IPN-structured hydrogels were synthesized by sequential crosslinking reactions of *N*-methacryloylglycilglycilglycil-terminated PEG and Dex. *In vitro* degradation of the IPNstructured hydrogels was examined using papain and dextranase as model enzymes of hydrolyzing oligopeptide and Dex. Specific degradation in the presence of papain and dextranase was observed in the IPN-structured hydrogel with a particular composition of oligopeptide-PEG and Dex whereas this hydrogel was not degraded by one of the two enzymes. Such specific degradation is considered due to the chain entanglement of two polymer networks in IPN-structure which can determine the size and distribution of two polymer domains. In the presence of either enzyme which can hydrolyze one of the two polymer networks, one of the polymer network at the surface may be degraded, however, further degradation can be restrained because of steric hindrance to enzymatic reaction due to another polymer network in IPN structure. In contrast, in the presence of both enzymes, the two polymer networks are hydrolyzed sequentially, leading to total degradation of IPNstructured hydrogel[1,2]. This proposed mechanism in an IPN-structured hydrogel is schematically illustrated in Figure 1. Therefore, it is concluded that double stimuli-responsive degradation was achieved by the design of IPNstructured hydrogels composed of two chemically different biodegradable hydrophilic polymers. Such characteristic of double stimuli-responsive degradation in IPN-structured hydrogels can be useful as materials for medical micromachines with fail-safe mechanism of biodegradation in living bodies.

4. References

1) M. Kurisawa, N. Yui, *Polym. Prepn. Jpn.*, **44**, 453 (1995)
2) M. Kurisawa, M. Terano, N. Yui, *Macromol. Rapid Commun.*, **16**, in press (1995)

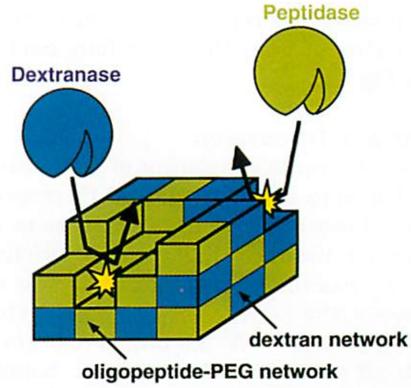


Figure 1. Double stimuli-responsive degradable hydrogel with IPN structure.

Development of a Tactile Array Sensor with 3-Axis Force and Slip Vibration Sensing Functions Using PVDF Film

Yoji Yamada, Associate Professor
Department of Control and Information Engineering, Toyota Technological Institute

Although a large number of studies have been made on tactile sensors of the pressure array sensing type (consisting of an array of pressure sensor elements), they have been unsuccessful in answering the simple question: "On what data does a person adjust grasping force when picking up an object with fingers?" The answer to the question is the ability to vibratory sense inherent in human fingers. Detection of the coefficient of static friction in the contact system of the sensor and the object is necessary, along with careful observation of incipient slip vibrations in the early stage of dropping of the object.

The authors developed the titled sensor with the ability to detect at each contact point: when an object is in contact with the sensor at multiple locations, (1) three-axis vector components of the contact force, and (2) vibration of sensor elements generated by relative displacement from slipping. With this sensor, the contact motion of the object and the contact status changes can be estimated microscopically, as well as, of course, the items that conventional pressure array sensors can detect, such as the degree of contact with the object and the geometry and hardness of the object.

Fig. 1 shows the structure of the sensor element. The element consists of the base and the sensor head. The base is a glass epoxy substrate having a concave, negative triangular pyramid, with the walls of the concave covered with polyvinylidene fluoride (PVDF) film. The sensor head is a steel ball (2 mm dia.) covered with silicone rubber and connected to a signal wire via conducting silicone rubber. The base and the head were produced separately and then the ball was embedded in the pyramidal groove with its top not buried.

Pressure from the contacting object is transferred to the steel ball and distributed to the pyramidal groove walls. The intensity of the signals from the PVDF film transducers on the three walls change as the magnitude and direction of the force vector applied to the ball vary. Stick-slip vibration produced by a slipping object is converted into voltage changes and output as a signal by the highly sensitive mechanical switch, which consists of the groove walls acting as electrodes and the steel ball functioning together to switch on and off repeatedly.

PVDF film, which plays an important role in this research, has a piezoelectricity and is highly sensitive to pressure in the thickness direction. In addition, being flexible and easy to form into a fine electrode pattern, the film is advantageous for implementation of high density tactile sensor elements and integration of the detector circuit. However, PVDF transducers show dynamic characteristics (Proportional-plus-derivative characteristics) when combined with the force-voltage conversion circuit used in the next stage. To cope with this, we designed a detector circuit so as to obtain frequency characteristics and step response suited to the sampling requirements.

Fig. 2 is an example of an output image from the tactile sensor fabricated in the research. The image is one scene in a sequence where a rectangular parallelopiped objective slides from the upper right to the lower left of the figure while being pressed against the sensor. In the figure, the force vector from the object acting on each contacting point is represented by the length and direction of the line, and partial slip is shown ahead of the object.

In the above I have briefly reported the tactile sensor we developed. This research was financially supported by the first Micromachine Technology Research Grant, and we wish to express our thanks for their generosity.

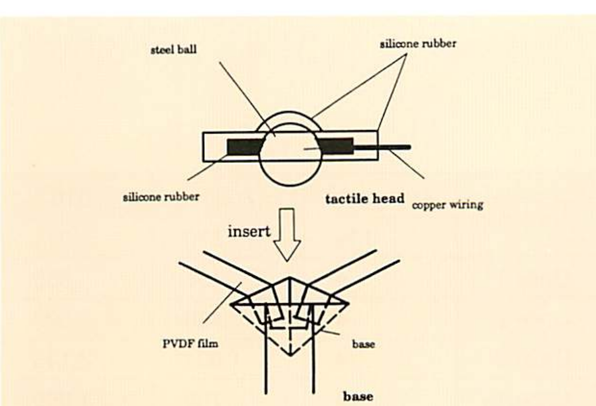


Fig. 1 The structure of the sensor element.

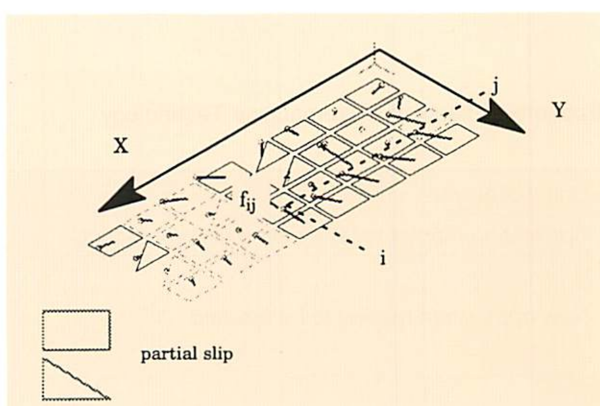


Fig. 2 Example of an output image from the tactile sensor fabricated in the research.

Summary of Reports on "Investigation of the Economic Effects (Technical Predictions) of Micromachine Technology"

Continuing from fiscal 1993, the Micromachine Center implemented "Investigations of the economic effect (technical predictions) of micromachine technology". The investigation was conducted by the committee of which chairman was Prof. Kiyoshi Itao of Chuo University and the report of the investigation was presented at the end of March 1994.

This research is a long-term prediction what effects will be brought by introducing micromachine technology into various industrial fields. The committee predicted the market scale in 2005 and 2010, examined the probability of future introduction and application of the technology, prepared an algorithm for predicting economic effect, and made an estimation.

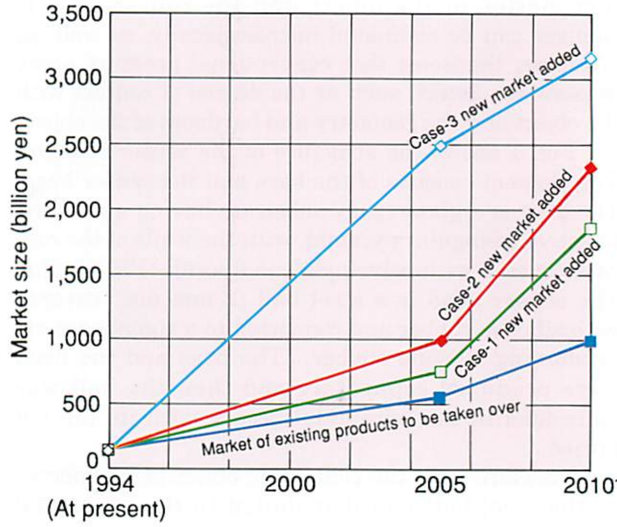
In fiscal 1993, prediction were presented of the effects in five industrial fields: information and communication facilities, precision equipment, medical applications, measuring equipment, and automobiles. In fiscal 1994, supplements were issued in these fields, and new predictions have been made in the fields of nanotechnology, microfactory, maintenance, environment, aviation and space technology, and hobbies.

The two years of investigation have covered all the fields in which micromachine technology is expected to be introduced.

The market for micromachine technology applications that will replace existing products was estimated to grow to about ¥570 billion in 2005 and ¥1 trillion in 2010.

Added to this, there will be a totally new application market that micromachine technology is expected to create. This market was estimated using three growth curves of other relatively new products. Adopting case 3, in which the growth curve of the personal computer market is applied, the total application market of micromachine technology is predicted to be about ¥2.5 trillion in 2005 and ¥3.2 trillion in 2010. (See the figure and table below.)

F.Y. 1993 prediction was ¥1.9 trillion in 2010 for the same case. The difference of ¥1.3 trillion has been supplemented in F.Y. 1994.



Economic Effects of Micromachine Technology

Unit: billion yen		At present	2005	2010
Application market to take over existing products		139	570	1,014
New application market to be created	Case 1	4	197	855
	Case 2	4	430	1,320
	Case 3	4	1,934	2,145
Total micromachine market	Case 1	143	768	1,869
	Case 2	143	1,000	2,334
	Case 3	143	2,504	3,159

Mitsubishi Cable Industries, Ltd.

1. Outline of the company

Mitsubishi Cable Industries, Ltd. was established in 1907 as an industrial cable manufacturer. Today its business covers the microscopic to aerospace worlds, including telecommunications, aerospace, electronics, medical, and energy utilizations.

We recently visited its Itami Works, where a broad range of products are manufactured. Located between Osaka and Kobe, its operation began in 1962 as the main plant for telecommunication cables. Itami Works has supplied optics-related products worldwide, such as high quality optical fiber cables for advanced technology in today's optical telecommunications, and the world's first long-image scopes using pure silica glass, as well as high-frequency coaxial cable products that are vital for radio telecommunications. All of these have earned a strong reputation.

The research and development of micromachines are carried out at the Fundamental Research Department in the Central Research Laboratory, which were established in 1989 to seek technologies for the future.

2. Characteristics of technological development

About 350 researchers are devoted to research under a company policy that recognizes corporate development as being dependent on R&D.

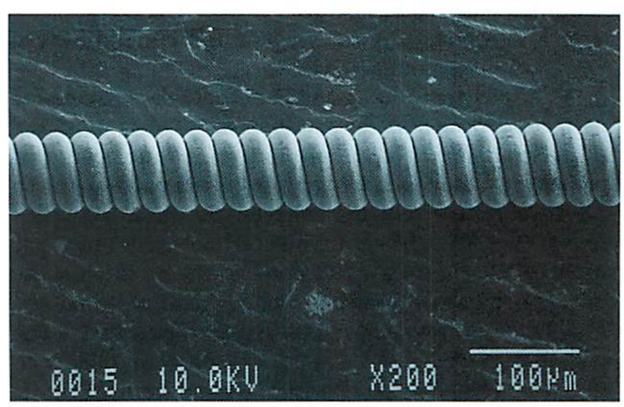
Each Division of the company has its own research department, which provides technology for business and is responsible for supporting current needs. They are also devoted to research for new business, to meet the needs of tomorrow. This covers automotive optical electronics, energy utilization technology, and electronics parts. The emphasis of the basic policy for product development is market needs.

Technological development to "create the future" is the responsibility of the Central Research Laboratory, which stress basic research for micromachines, optoelectronic semiconductors, high-temperature superconducting materials, and highly functional materials. Of these R&D themes, high hopes both within and outside the company are being placed on micromachines, which are expected to play a major role in the 21st century. Mitsubishi Cable Industries is clearly devoted to a broad range of areas and subjects.

3. Tackling micromachine technology

The previously invisible micro world will become visible. The intangible will become tangible. The previously unknown will be revealed and contribute to solving problems in various fields. The company hopes that the research and development of micromachines will realize these dreams. The world's thinnest (0.25 mm in diameter) medical endoscope developed by Mitsubishi Cable can enter organs that were previously inaccessible, such as the narrowest parts of brain, eye, ear, nose, lung, heart, and other organs for diagnosis and treatment. A micro actuator (approx. 80 μm in diameter) using a shape memory alloy is able to expand and contract by heating and cooling. This actuator applied to the end of a micro-mechanism in a cabled micromachine permits a freely bendable endoscope, allowing extremely minute observation and operation. Furthermore, the company is devoted to the research and development that employs its optics expertise in micro-actuators and micro-sensors. The company intends to further microsize and advance these elements to contribute to better micromachines — to make visible and tangible a world that has been invisible.

General view of the Itami works



SMA micro-coil actuator

JUKI CORPORATION

1. Introduction

This company was established in 1938 in the quiet, verdant environment of the western part of Tokyo. Shifting its business in 1945, the company started manufacturing sewing machines for home use, and then expanded it to those for industrial use. Nowadays JUKI conducts business globally in five areas.

Industrial sewing machines which have won trust in 160 countries of the world as an apparel total system supplier meeting all sewing areas. Surface mounting devices of electronic parts in the electronic industry supporting the ultra micro electronic society. Such electronic equipment as mail processing systems supporting database and marketing. Household sewing machines and interior equipment which produce warm and affluent life. In these five areas, the company is conducting a comprehensive quality management with united efforts made in all phases from planning to servicing, by creating new values and technology and grasping increasingly diversifying market needs.

2. Development of the research and development system

Until early in the 1980's, the research and development department had been placed within each division, while the technological research laboratory was principally responsible for apparel equipment. In 1983, to improve the company's R&D activities, the company integrated the technological development functions so far held by divisions and established a comprehensive technological research laboratory with the following objectives.

- Intensification of research and development under corporate and long-term viewpoints.
- Timely development of profitable products demanded by divisions
- Improvement in exchange in and management of technology and personnel
- Improvement in and utilization of departments of supporting staff for development

Rearrangement of problems through integration of technological management systems could make research and development more effective. In 1992, the tenth anniversary of the integration of technological functions, a comprehensive review was done on the progress of the restructuring so far made in technological research and development to revaluate impeding problems and define future basic policies.

Since 1993, the company has been "rebuilding its research and development systems" for the 21st century.

At this stage, in addition to the corporate comprehensive technological research laboratory, the company has built development bases capitalizing on specialty technologies at production bases, and decentralized its research capability.

Further, as one of important measures, the company strengthened its technological planning functions, clarified its technological strategy, and is rebuilding its research and development system based on the mid- and long-term aspects.

3. Characteristics of technological development

JUKI's strategy for the 21st century carries a harmony of "human beings," "environment," and "information" as the basic concept.

The company believes that based on this concept, it should tackle problems lest it should cause inconveniences to either "producers" or "consumers" due to technological development, coping with a global society which is able to meet diversifying environments.

Particularly in the area of apparel equipment as the leading product, the company has accumulated technologies of pre-sewing processing, sewing assembling, cloth handling, system management and control, and total systems in the research of element technology, participating in MITI's Large-scale Project, "Automated Sewing System."

Taking the initiative in the industry, the company has made concerted efforts to tackle not just single products to automated and labor-saving machines but apparel systems achieving the maximum overall efficiency. In the research and development area, too, based on concrete measures, the company is devoted to maintaining the leading position in the industry.

4. Tackling micromachine technology

While we also intend to differentiate our products from competitors, as generally demanded in each field, increasing reduction in weight, downsizing, non-adjustment, and sophisticated control are called for.

In view of future problems in each product field from micromachine technology and its application, JUKI considers that what is needed as the core in small functional element technology are:

- Actuator technology
- Sensor technology
- Function combining technology

and that those in the control technology of the systematization technology are:

- Kinetic control technology
- Autonomous decentralized control technology
- Human interface technology

Taking this opportunity of its enrollment as a supporting member of the Micromachine Center, the company will more positively devote itself to tackle application of micromachine technology, by gathering information of new technologies and technological cooperation from member companies.

Micromachine Technology (VI)

Microassembly Technology

1. Key to Micromachine Manufacturing Technology of the Future

Microassembly technology is a new and still undefined term. Probably the first use of the term was by Professor Tadatomo Suga at Research Center for Advanced Science and Technology of The University of Tokyo , as a name for a new study meeting in the Japan Society of Precision Engineering. The term may be used in different ways by researchers in different fields. In fact the meeting itself was interdisciplinary and chaotic, and it was difficult for the members to understand each other. One might be skeptical of discussing microassembly under such circumstances, but I hope the following report will provide material for discussion about the direction of research and development for the future.

Until now, we have been learning about semiconductor processing technologies, including the photolithography, LIGA (lithographie-galvanoformung-abformung) process, by using synchrotron radiation, beam processing, and ordinary machining methods. Most of these processing technologies are for manufacturing parts. Yes, photolithography is able not only to process parts but also to assemble them to some extent, although currently, a simple actuator or a sensor is the most. It is doubtful that all future micromachines will be of such monolithic one-chip type. I, therefore, offer here the definition that microassembly technology is a technology whereby micro parts may be transferred into ready-to-use micromachines, which can move, judge and do the task autonomously.

At present, brisk research and development is being conducted in the field of micro parts such as the actuator, sensor, and structure. Microassembly is an important future technology for the building of these parts into a module or system.

2. Batch Assembly and Sequential Assembly

In the assembly process, parts may be handled in a batch or sequentially. Batch assembly is very close to batch bonding in the sense that it composes the parts into a system. In other words, the wafer level parts such as actuator, sensor, structure, communication control circuit, and so on are integrated. The goal of research on this technology is to increase positioning accuracy of integration at lower temperature and under lower pressure. On the other hand, the main purpose of study on sequential assembly is to reduce size of the existing machining center and robot arm to work on a smaller scale. The end effector and its operation principle has made various manipulation and handling techniques possible.

The gripper and the manipulator are the means for holding small objects. The gripper holds the object directly in a mechanical sense. The manipulator was developed to manipulate two needles like chopsticks (See Fig. 1). In handling a minute object utilizing mechanical contact, releasing is a problem because of high stickiness. Other manipulation methods using electromagnetic or ultrasonic fields have also been proposed. Another promising handling method utilizes the light pressure of a laser. These alternatives, however, have restrictions on the type of object that can be handled.

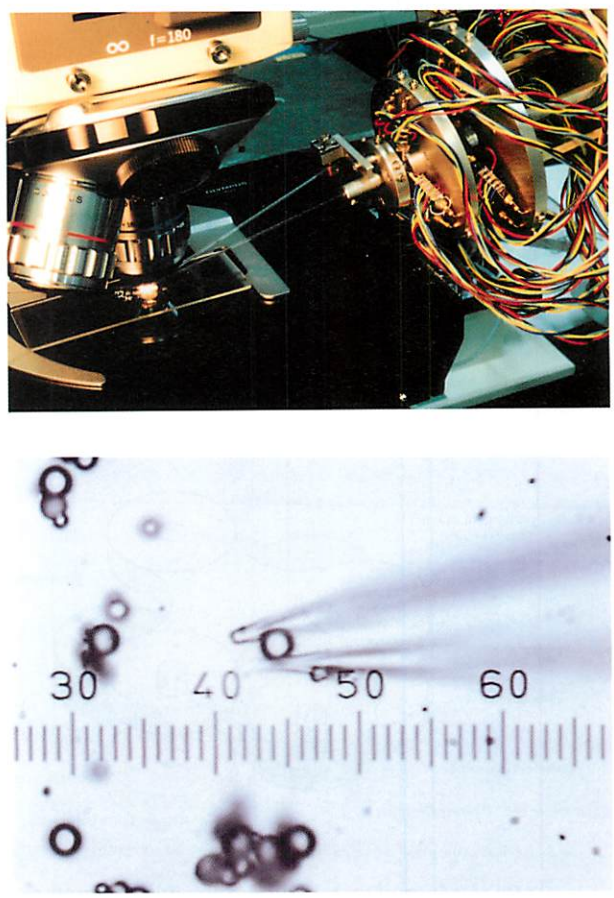
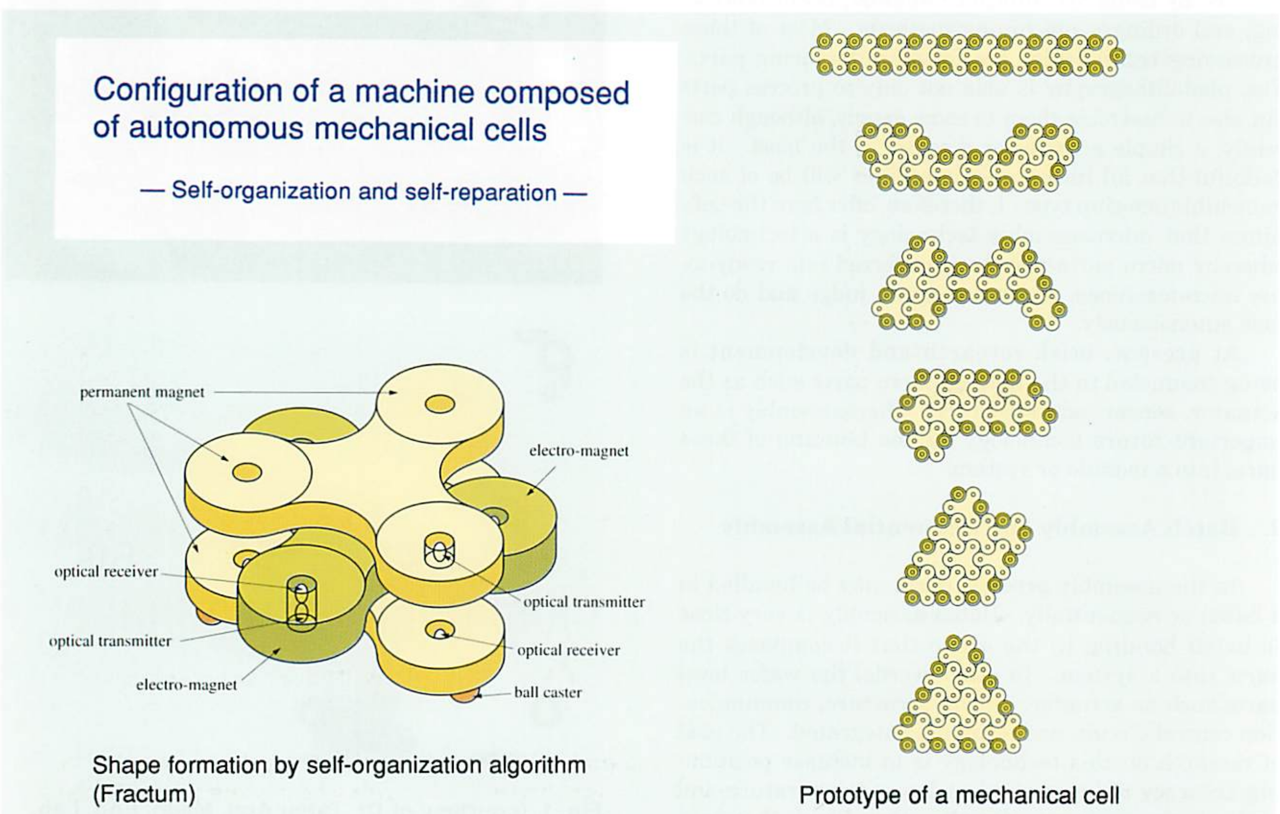


Fig. 1 (courtesy of Dr. Tatsu Arai, Mech. Eng. Lab., MITI)

Actual processing such as cutting, milling, and bonding are yet to be studied. Professors Yohtaroh Hatamura and Tomomasa Sato are vigorously working in this field. They are trying, briefly, to enclose a machining center into an electron microscope. Atom handling, in this sense, is a scanning tunnel microscope with machining functionality, which applies an intense electric field between a pointed needle and the workpiece, instead of using jigs. Similar operations can be performed by focused ion beam (FIB) device, the work tool of which is an ion gun using liquid metallic Ga as the ion source. These methods have their metallic Ga as the ion source. These methods have their merits in different fields. Fine processing in units of atoms improves accuracy but degrades processing efficiency. One future theme is improvement in both processing accuracy and work efficiency. Another is the choice of the best tool and best processing monitoring method for each respective operation.

3. Assembly Technology in the Natural World

All the assembly methods I have described perform assembly and processing forcibly and externally. However, apart from artificial structures, there are also creatures of nature. Self assembly is the technique of utilizing the natural mechanism of materials to form orderly structures. By this method, assembly is possible no matter how small the parts are. As an example, London University conducted manufacturing of minute boxes and plate folding by utilizing the surface tension of wax. In addition, the University of California at Berkeley has developed technology to lay trapezoid GaAs LEDs into trapezoidal holes in a Si substrate. Though the workpieces are not micro, a machine system utilizing the array of magnetic dipoles is under construction (See Fig. 2). Extensive research and development utilizing electric or magnetic fields is expected for manufacturing orderly structures.



Shape formation by self-organization algorithm (Fractum)

Prototype of a mechanical cell

Fig. 2 (courtesy of Dr. Satoshi Murata, Mech. Eng. Lab., MITI)

Report on Europe

A conference of the 2nd European Strategic Round Table on Microsystems and MEMS was held April 6, 1995 in Geneva, Switzerland. Mr. Takayuki Hirano, executive director of the MMC, was invited and gave a lecture.

The conference, sponsored by ESPRIT project's MUST, NEXUS, SEMI, and LETI, was held to provide a meeting place for users, manufacturers, and suppliers of Microsystem Technology (MST) and to disseminate and promote MST in Europe. At this conference, to strengthen its international commitment, a Japanese representative was asked to speak about the development of micromachine technology in Japan and the results of the First Micromachine Summit held in Kyoto in March 1995.

During the first part of the conference, lectures were given on the development of micromachine technology and its future prospects in various countries, including Japan and member nations of the EC. Mr. Hirano spoke about the subjects mentioned above. He mentioned that mechatronics-oriented development is being promoted in Japan, that approaches different from those in Europe and the U.S. are being taken, and that Japan is playing an important role, for example, by sponsoring the Micromachine Summit.

During the second part, the development of micromachine applications in European countries were presented. Applications are focused on sensors, and it seems that the applications are still concentrated on silicon-based techniques. No one presented the results of the development of "things that move" like actuators. Some of the representatives at the First Micromachine Summit participated in conducting this conference, which was a great success.

EVENTS

The 6th MICRO SYSTEM Technologies Japan (MST Japan '95)

Micromachines are expected to have extremely wide applications, such as in space, the ocean, medical treatments, welfare, and living-related fields, as well as in industrial facilities and plants. They will spread to various sectors of the economy and play important roles in the future. However, various technical developments and exchanges are still needed.

"Micromachine Technology," a project of the Industrial Science Technology Frontier Program promoted by the Agency of Industrial Science and Technology, Ministry of International Trade and Industry, started in 1991. It aims to establish the basic technology for micromachines. This project has sparked the interest of people concerned, and micromachine technology is expected to make rapid progress in the future.

The Micromachine Center has planned a micromachine exhibition in the hope of providing a place where engineers and researchers actively involved in basic research in various fields can present their findings, collect information on research in fields other than their own, gain clues to discovering new technological possibilities, or resolve problems in technical development. The major purpose of MST Japan '95 is to promote a better understanding of this project and exhibiting the results, since this is the final year of the first phase of the project. The exhibition will be held according to the following schedule and aims at establishing micromachine technology and contributing to international technology exchanges and to the future development of Japan's industries and economy.

Date: Oct. 31 (Tue.) through Nov. 2 (Thu), 1995
Place: Science Museum
2-1 Kitanomaru Koen, Chiyoda-ku, Tokyo
Sponsor: Micromachine Center,
Micromachine Society (Tokyo)
Supporter (Planned):
Ministry of International Trade and Industry
Application for exhibition or inquiries:
Secretariat of Micromachine Exhibition
c/o MESAGO Japan Corp.
YKB Sunny Bldg. 3F,
4-32-8, Yotsuya, Shinjuku-ku, Tokyo 106
Tel: +81-3-3359-0894
Fax: +81-3-3359-9328
Person in charge: Ms. Hiromi Nakoji

The First International Micromachine Symposium

The Micromachine Center will hold a two-day international symposium on micromachine technology to establish and disseminate the technology by presenting R&D results and the status quo of applications and measures to promote the technology worldwide. Detailed preparations are under way. This is the year for the interim evaluation of the Industrial Science and Technology Frontier Program "Micromachine Technology." Therefore, the Center plans to exchange opinions with people of learning and experience in Japan and abroad and use the results for the promotion of future projects.

To publicize the opening of the First International Micromachine Symposium in Japan and abroad, the theme "Micromachine Technology — Foundation of Industrial Technology in the 21st Century" has been selected, taking into account the possibilities to create the next industrial technology or next-generation technology.

In preparation, an organizing committee was formed, with Dr. Naomasa Nakajima, professor of the Faculty of Engineering, The University of Tokyo, as chairman. A program committee, international advisory board, and working group for operations were also formed. The program committee will draw up the detailed plan of the program and invite the lecturers. The international advisory board, consisting of nine overseas chief representatives who attended the first Micromachine Summit held last spring in Japan, will obtain advice based on international viewpoints. The working group for operations will handle practical matters necessary to conduct the symposium.

On the first day of this symposium, a keynote address and lectures will be given. Several lecturers will be invited from abroad. On the second day, the results of the Industrial Science and Technology Frontier Program "Micromachine Technology" will be presented, and as many presenters as possible are expected to participate.

Date: Nov. 1 (Wed.) through Nov. 2 (Thu.), 1995
Place: Science Museum
2-1, Kitanomaru Koen, Chiyoda-ku, Tokyo
Sponsor: Micromachine Center
Supporter (Planned):
Ministry of International Trade and Industry
Agency of Industrial Science and Technology
New Energy and Industrial Technology Development Organization

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