MMC MICROMACHINE

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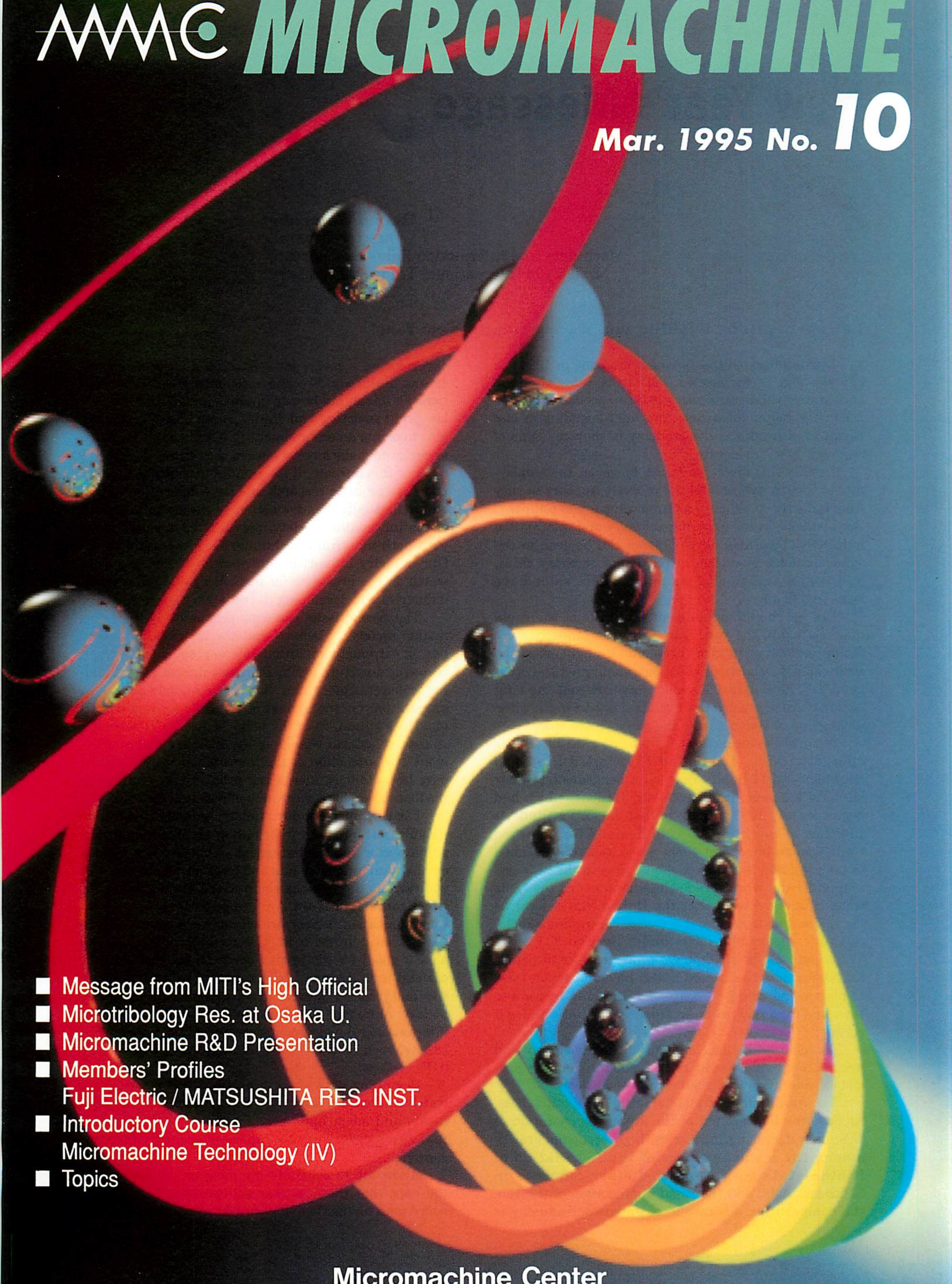

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Micromachine Center

New Year's Message

Osamu Watanabe
Director-General,
Machinery and Information Industries Bureau,
Ministry of International Trade and Industry

Let me begin by wishing you a very Happy New Year!

Looking back on the Japanese economy in 1994, we can say that in the second half of the year, after the government's five consecutive and comprehensive packages of economic measures, consumer spending at last began to pick up and the economy is showing signs of recovery, albeit moderate.

Despite this favorable trend, however, the employment remains severe, and the recovery appears to vary from industry to industry as from company to company. For instance, in the area of machinery and information industries, favorable developments can be seen in the semiconductor business, in particular memory chips, and in the automobile industry, where sales have recovered firmly.

But on the other hand, in the wake of the rapid appreciation of the yen, manufacturing industries are facing serious structural problems brought about by their rapid development of overseas activities and other factors. These industries now must confront the vital issue of how to ensure their competitive strength while paying due consideration to the employment side.

Meanwhile, in the area of trade, as a result of their energetic talks, Japan and the United States in September 1994 finally reached a settlement to their bilateral economic framework negotiations, which had begun in July 1993. I believe that Japan's attitude at the time of rejecting the U.S. demand for managed trade was an important event when Japan is assumed to take the role that Japan should play in the new system under the World Trade Organization. At the same time, it is regrettable that the United States went as far as deciding to carry out a survey concerning supplementary automobile parts under Section 301 of its Trade Act. As far as Japan is concerned, we recognize that Japan and the United States have important roles to play in the world economy and intend to respond to the issue from now on in accordance with international rules.

As regards the development of the machinery and information industries in 1995, I would like to pay special consideration to the following two issues.

The first issue concerns industrial competitiveness. Against the background of the strong regeneration of U.S. manufacturing industries, high economic growth among the member states of the Association of Southeast Asian Nations and other countries in Southeast Asia, and the rapid appreciation of the yen, the comparative advantage of Japanese industry is experiencing a severe jolt. At such a time, as a front runner in the world economy, the most important questions for Japan are how to improve its fateful high-cost, low-profit structure and, in this harsh business climate, how to create an environment that will enable industrial circles to make a move toward the future.

For this purpose, it is essential to continue positive efforts to promote research and development, strengthen intellectually creative activities through the growth of the information society, provide new creative fields with both material and human resources, and so on. Our ministry intends to contribute by keeping a close watch on the prospects for machinery and information industries and developing the necessary policies.

The second issue concerns promotion of the information society. I believe that the information society has an extremely important role to play in realizing an economic structure led by domestic demand and building a more affluent and vigorous economic society in preparation for the arrival of a full-fledged aged society. In addition, from the point of view of achieving a smooth structural change of the industry and employment, the promotion of the information society will be very important in increasing productivity and laying the foundation for the creation of new industries.

For this purpose, our ministry intends to continue its efforts to promote information technologies in the public sector and the industrial sector and to strengthen the foundations of new information businesses. In addition, as the vice-chairman of the Headquarters for the Promotion of an Advanced Information and Communication Society, which has been established in the cabinet, I intend to make active efforts to formulate a basic policy for the promotion of the information society and to undertake such promotion in a comprehensive and planned manner in accordance with this basic policy. Moreover, I will make an active response to international developments regarding the information society, such as the Global Information Infrastructure (GII) concept.

Beginning with these issues, we will keep a close watch on domestic and international economic developments and adopt appropriate and active measures so that the recovery of the Japanese economy becomes genuine.

Allow me to conclude my message by expressing the hope that the new year will prove to be a springboard for a further leap forward for everyone.

Micromachines and Mircrotribology

Nobuo Ohmae
Department of Precision Engineering,
Faculty of Engineering, Osaka University

Tribology — no doubt an unfamiliar term to many people — refers to the study of the friction, wear, and lubrication involved or required when two moving surfaces are in contact. The field of tribology has progressed from "Just add oil and it'll be all right" to considerations of how to design and create surfaces to prevent or control surface damage. With micromachines, where "bare atoms" come into contact with one another, *microtribology* is a key technology, ensuring high levels of precision and reliability.

Microtribology

When hard-disc drives were being developed, one problem remained until the last stages: how to overcome the mutual interaction between the surface of the head and that of the media. More crucial than even disc capacity, this issue was one on which microtribology had to be brought to bear. The two surfaces would have to contain mutually noninteractive atoms, to prevent adhesion, and would have to be extremely stable chemically. Such advanced analytical processes as scanning probe microscopy and X-ray photoelectron spectroscopy were used to come up with the ultimate solution: coating the magnetic media surface with a lubricant only several molecules thick. (With the acceleration of research in tribology on the micro level during the past several years, my colleagues and I have been able to conduct tribological research on the atomic scale, using field ion microscopy.) The hard-disc drive example reflects two primary focuses of microtribology — how to characterize surfaces on the atomic level and how to modify them appropriately.

Water Molecule Adsorption onto Micromachine Surfaces

Water molecule adsorption onto micromachine surfaces is the most troublesome impediment to proper functioning when micromachines are operated in the atmosphere. About four or five layers of water molecules are thought to adsorb onto such surfaces in conditions of 50% relative humidity. The small menisci thus formed causes stiction, which could theoretically result in enough resistance to stop a micromachine from functioning.

Consequently, my colleagues and I have been researching the nickel film used in the lithographie-galvanoformung-abformung (LIGA) process as a means of analyzing water adsorption and its influence on the tribology of micromachine surfaces. We electrodeposited a nickel film on a quartz crystal microbalance set up a method of analyzing water adsorption onto this surface, from a single layer of water molecule to multiple layers, and measured the interaction between the nickel tip and the water-covered surface for each adsorption thickness. We discovered that adsorbed water molecules behave like solids when they are in the vicinity of a solid surface and that they are highly viscous. The adsorption model seen in Fig. 1 indicates that near the surface of a solid the water molecules are in a contiguous arrangement and possess a long-range order, while the water molecules situated at a greater distance from the surface, in a region of disorder, have a bulk water arrangement with short-range order. The increase in frictional resistance due to stiction depends in large part upon this arrangement of water molecules.

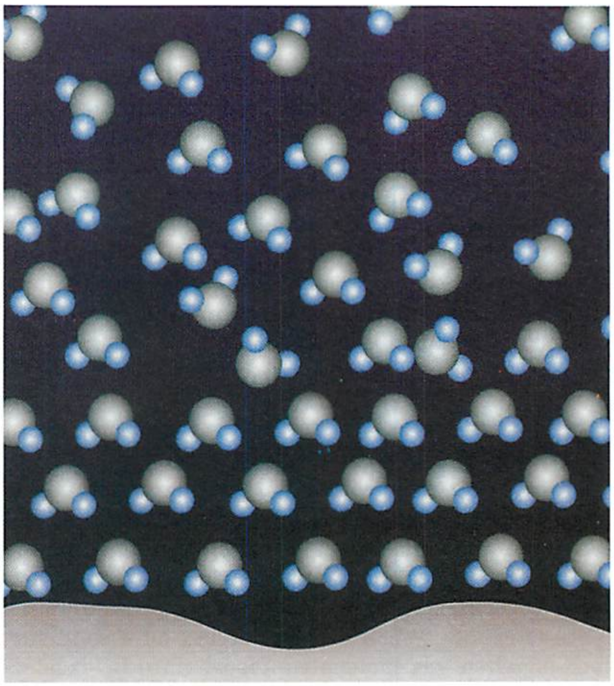


Fig. 1 Water adsorption model

The situation in micromachines is considerably more severe than that of the thin-water layer (ten or so molecules thick) model of our experiments. The inside of pipelines in nuclear power plants, for example, or body fluids are problematic environments. Basic research in water adsorption and tribology should provide valuable information for the development of micromachines.

C_{60}

C_{60}, also known as the Buckminsterfullerene, is considered a promising lubricant for micromachine surfaces because of its soccer ball shape (7 Angstroms in diameter), which would theoretically allow the molecule to act like a miniature ball bearing (Fig. 2; the white points are carbon atoms). However, whether this structure exists under normal atmosphere conditions has not been verified. A process for putting fluorine or silicon atoms on the surface of the C_{60} molecule needs to be developed.

Predicting Breakdowns with Exoelectrons

Detecting the breakdown of micromachines is another major issue in the field. Simply sending in a new micromachine to replace a broken-down one is one tactic, although monitoring conditions and detecting a possible breakdown before it happens would be more efficient. When a defect occurs on a solid surface or when gas molecules adsorb onto it, exoelectrons are emitted. In our research, my colleagues and I have detected exoelectrons emitted from micropoint at tip surfaces and have analyzed the emission site on the atomic scale. We expect that this phenomenon will eventually be put to use in predicting micromachine breakdown.

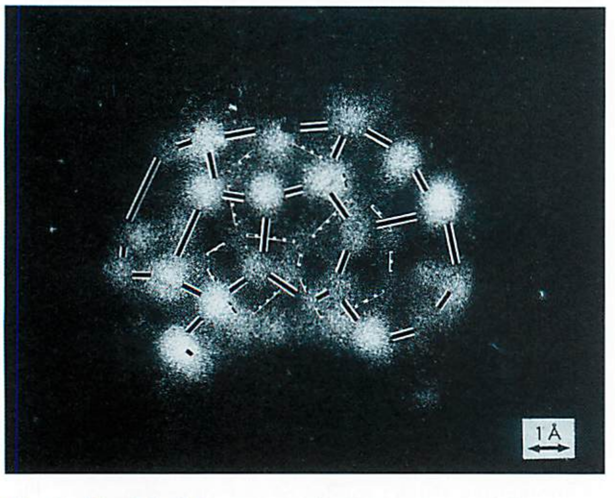


Fig. 2 Model of the soccer ball structure of C_{60}, observed by field ion microscopy
(This photo depicts the top half of the molecule.)

Space Station Micromachines

Researchers are currently developing conceptualizations for the use of micromachines in space, especially in space stations. Although water adsorption will not be a problem in space stations in a low earth orbit, cosmic rays, the heat cycle, and atomic oxygen will be. Because oxidation due to atomic oxygen is far more severe than oxidation by molecular oxygen, the danger that micromachine surface will decompose is substantial. My colleagues and I have created two atomic-oxygen generators and are currently researching the reaction process when the surface of a material is exposed to atomic oxygen, as well as the space tribology of exposure to atomic-oxygen radiation. We hope to apply our results to space micromachines in the near future.

A Mechanical Renaissance

Takayuki Hirano, the executive director of the Micromachine Center, has said that "micromachines are a sign of the approaching mechanical renaissance." If so, then tribology's father is Leonardo da Vinci, the giant of the Renaissance. Micromachines, microtribology, and the Renaissance are phenomena whose connections cannot be explained by mere chance.

R&D Presentation on Micromachine Technology in Fiscal 1994

On November 16 (Wed.), 1994, the R&D Presentation on Micromachine Technology in Fiscal 1994 was held at the Science Museum, Kitanomaru Park, Chiyoda-ku, Tokyo. The presentation was sponsored by the Micromachine Center (MMC) and Japan Industrial Technology Association, with the support of the Agency of Industrial Science and Technology (AIST) of MITI and the New Energy and Industrial Technology Development Organization (NEDO).

Seiuemon Inaba, Chairman of the MMC, gave an opening address, followed by two guest addresses by Hidefusa Miyama, Deputy Director-General for Technological Affairs of the Agency of Industrial Science and Technology of MITI, and Tamotsu Mukai, Executive Director of NEDO. Then Professor Hirofumi Miura of the Faculty of Engineering at The University of Tokyo delivered a keynote speech titled "History of Machinery and Micromachines."

Hiroshi Kasai, the Director of Machinery and Aerospace R&D, AIST, gave a speech on "Current Status of the Micromachine Technology R&D Project," and the results of research at the Mechanical Engineering Laboratory, Electrotechnical Laboratory, and National Research Laboratory of Metrology were presented. Then Hideharu Tanaka, Chairman of MMC's Research and Development Sub-Committee, and Tatsuaki Ataka, Chairman of the Microfactory Group, made speeches. In the afternoon, the results of four R&D themes, actuator technology, sensor technology, energy supply technology, and system and control technology, which are being carried out at the MMC, were presented.

Opening greetings by Seiuemon Inaba, Chairman, MMC

During the meeting, the results of studies of MMC's Research Supporting Members were displayed on panels, where visitors and display attendants were seen enthusiastically discussing the topics.

It has been almost four years since the Industrial Science and Technology Frontier Program started, and the results of research were both visible and substantial. We had more visitors than we expected; nearly 400 people including 345 general admission visitors learned the results of the project. According to the on-site survey conducted about the speeches and panel displays, more than 80% of the visitors were very interested in the presentation.

Oral presentation

Poster session

Research Results of 8 Research Supporting Members

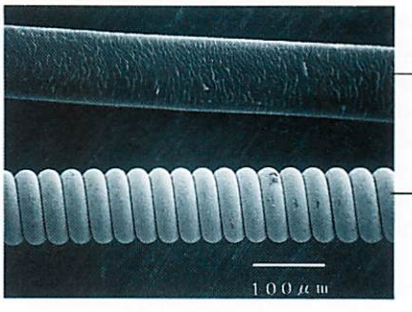
Shape Memory Alloy Micro-Coil Actuators

Keisuke Yamamoto
Mitsubishi Cable Industries, Ltd.

Because shape memory alloy (SMA) is a material that is a high output actuator and thermal sensor in nature, it is suitable for making a simply structured actuator. Research and development of SMA in various shapes including wire, plate, film, and coil has been continuing. However, where greater displacement and better controllability is required, such as in tip-articulation mechanism for endoscopes and catheters, the best shape is the coil spring. We conducted research and development on fabrication and evaluation technologies of SMA spring coils, intending to pursue the limits of miniaturization while retaining the advantages, and to establish an elemental technology of micromachine technology.

We used a coiling machine that winds SMA wire at a regular pitch around a high-strength core with an outer diameter of 30 μm. Through fine control of the core strength, coiling conditions such as winding tension of Ti-Ni SMA wire and winding pitch, and heat treatment conditions for shape memory, we successfully fabricated an SMA micro-coil with a Ti-Ni SMA wire of a diameter of 30 μm, coil outer diameter of 92 μm, spring index of 2, shape recovery force of 35 mN (at a shearing strain of 3% in the wire). The scale effect characteristic of miniaturization, or improvement in response speed (cooling speed) by miniaturization was proved by measuring response speeds to direct resistance heating and laser heating with specimens of varying dimensions.

Our next aims are the fabrication technology of SMA micro-coils of a wire diameter of 25 μm and coil outer diameter of 75 μm, assembly technology for catheters, and optical drive and control technology.



New Actuator Applying Rectification of Mechanical Vibration

Satoshi Sugiura
Fuji Electric Corporate Research & Development Ltd.

Intending to develop micro actuators for driving the mechanism of a micromachine system, such as the steering mechanism for a piping inspection micro capsule, we studied an electrostatic linear actuator that outputs axial force.

Since mechanical vibrations can be relatively easily achieved with a micro actuator, we tried to design a method to convert the vibrations into long-stroke linear motions without frictional losses.

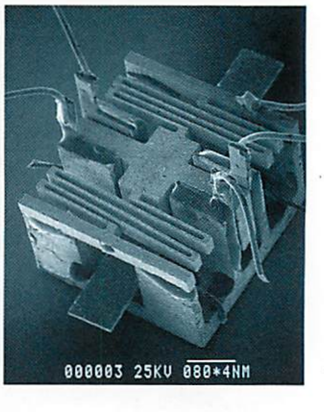
Comprising three major components; carrier, base, and movement, the electrostatic linear actuator applying rectification of mechanical vibration consists of two blocks, one for generating mechanical vibration and the other for rectifying the vibration. Each block is driven electrostatically and no slide friction is involved.

Operation simulation results guaranteed that the driving force can be controlled to adjust to the varying load.

Operation of the actuator was demonstrated using a 4-mm square model. The result showed that the speed of the movement increases as the driving signal frequency rises up to the 170 Hz, thereafter the speed decreases. This is considered to be the operation limit of the 4-mm model.

The actuator can be placed in vertical position, if the movement is controlled to move vertically. The possibility of locking and unlocking the movement was also examined in the experiments.

A video of the experiments was shown.



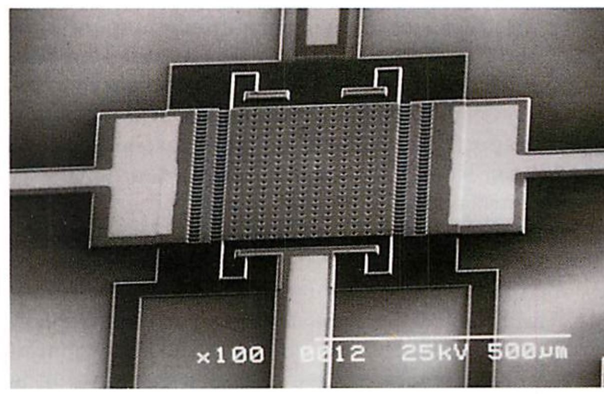
A Vibrating Micro-Gyroscope

Katsuhiko Tanaka
Murata Manufacturing Co., Ltd.

For a micro capsule or a micro robot that moves in a confined space like a pipe, a micro-gyroscope is essential to measure and control the position and attitude of the device. We applied silicon surface micromachining technology to fabricate experimentally a vibrating micro-gyroscope with a vibrator measuring about 400 µm (W) X 800 µm (L) X 5 µm (T).

The electron micrograph of the device shows four beams supporting the vibrator afloat on the substrate. When alternate voltage is applied to the comb-actuators on both sides of the vibrator, it vibrates in a direction parallel to the substrate surface (drive mode), to detect micro vibration displacement in the direction vertical to the substrate that occurs under influence of rotational angular speed (detection mode) by the variation in capacitance between the vibrator and the substrate. The device was designed based on vibration analysis by finite element method simulation. The most crucial technologies in the device fabrication process are: vertical beam processing by reactive ion etching, sacrificial layer etching, and drying after etching.

Affected by air damping, the mechanical quality factor (Q) of the vibrator largely depends on the degree of the vacuum of the operating environment. In a high vacuum environment of 0.1 Pa or lower, Q-factor in drive mode and detection mode were 2800 and 16000, respectively, and both were saturated. The angular speed-output voltage characteristic of the micro-gyroscope was measured in a vacuum of 1 Pa: Driven by sine wave peak-to-peak voltage of 10 VAC (5 VDC biased), an angular speed resolution of 7 degrees per second (conversion from noise level) was achieved.



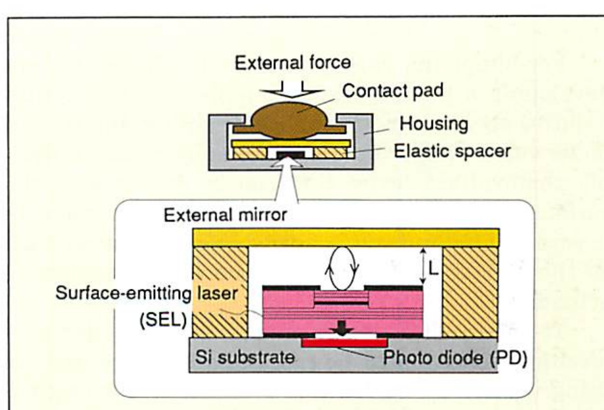
Optical Tactile Sensor for Medical Application

Eiji Yamamoto
Olympus Optical Co., Ltd.

An experimental optical tactile sensor consisting of a surface-emitting laser (SEL), a mirror supported by an elastic spacer, and a photo diode (PD) integrated to Si substrate was fabricated and its basic operations were demonstrated. When external force is applied, deformation of the elastic spacer displaces the mirror, causing intense modulation of the laser light at the half period of its wavelength. This modulation is detected by the variation in the PD output. Making use of the interference of the lights, this sensor is highly sensitive and less affected by electromagnetic interference.

The oscillation wavelength of the SEL fluctuated slightly by the return of reflected light, and has a narrow range in the spectrum. The sensor module using SEL needs no optical parts such as lenses and thus can be readily microminiaturized. The tolerance of relative position error of the laser emitting surface and the reflection mirror is several hundred times greater than the conventional stripe type sensor. The laser device we fabricated oscillated at room temperature at a threshold current of 16 mA and a wavelength of 0.98 µm. The experimental device measured 5 mm X 5 mm X 1 mm and achieved a high sensitivity of 0.022 gf/pp by counting the output pulses.

In the future, we will try to fabricate a sensor that can operate a catheter while sensing contact pressure against the inner wall of a blood-vessel.



Configuration of optical tactile sensor
(The elastic spacer is a urethane rubber ring with an outer diameter of 4.5 mm, width of 1 mm, and thickness of 1 mm.)

Micro-Generator

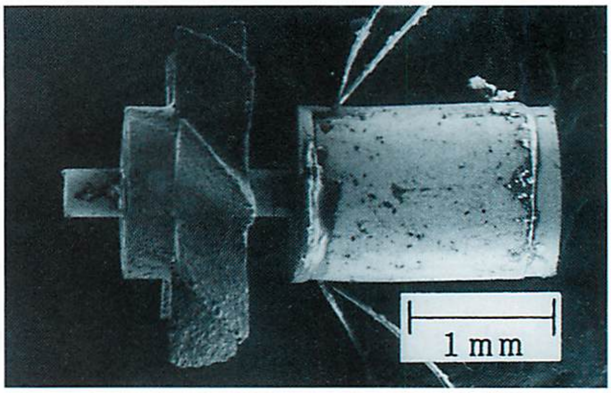
Ken Morinushi
Mitsubishi Electric Corporation

In order to fabricate a radial gap micro-generator of about a 1-mm diameter, many elemental technologies are required. For instance, high-energy product cylindrical permanent magnet thin film rotors for increasing flux density, cylindrical high-density winding stators for increasing the number of turns and improving efficiency, and high-speed micro bearings for low-loss, high-speed driving. We are pursuing the R&D to achieve these technologies. Major results are as follows.

(1) As basic research of technology for the high-energy product cylindrical permanent magnet thin film rotor, Nd-Fe-B permanent magnet thin film was formed on a flat substrate by ternary simultaneous sputtering. Optimization of composition and sputtering conditions and partial replacement of Nd by Tb were examined. Consequently, we succeeded in producing a high-performance permanent magnet thin film 2 µm thick that has a maximum energy product of 210 kJ/m^3.

(2) As the technology for a high-density winding cylindrical stator, semiconductor process technology was applied and extended to the stator manufacturing process where high-density winding is formed and set in a stator-core mold and undergoes permalloy electroplating to complete the stator. Stators with an outer diameter of 1 mm, axial length of 0.5 mm were fabricated. The winding was made as follows: The insulation layer of a width of 2 µm was prepared by polyimide to form the conductor mold. Ten turns of the conductor coil with a cross section of 7 µm X 15 µm was formed by copper electroplating, in two layers, for a total of 20 turns. The volume factor was about 70%.

(3) Using the high-density winding stator with an outer diameter of 1 mm described above, the experimental micro-generator with an outer diameter of 1.2 mm shown in the photo was fabricated. The magnet and bearing of the rotor were the processed conventional bulk magnet and conventional slide bearing, which have poor performance and durability. However, we verified that output can be obtained from this micro-generator connected to a turbine which was revolved at up to 100,000 rpm by a high-speed air flow.



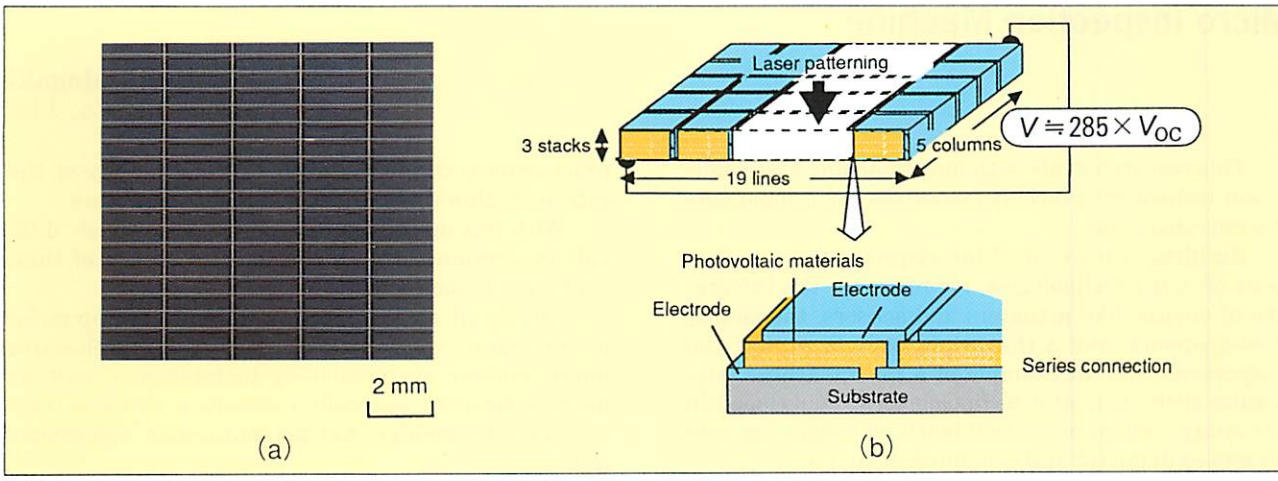
Micro Photovoltaic Devices

Seiichi Kiyama
Sanyo Electric Co., Ltd.

For supplying energy to micromachines, we are developing a photon energy supply technology that requires no wires and is applicable both in the air and underwater. Major development subjects are a flexible photovoltaic device that can be mounted on the surface of a micromachine and supply high voltage up to several hundred volts to drive micro actuators such as the electrostatic actuator and the piezoelectric actuator.

To satisfy these requirements, finely divided photovoltaic devices must be connected in series without using wires. We solved this problem by our original development of a high-precision, high-selectivity laser micro-processing technology. As a result, device formation technology on a flexible substrate was established. The device was mounted on a bug-like actuator of about 1 cm square and proved capable of receiving light and supplying electric energy.

We proceeded to develop a high voltage micro photovoltaic device that measures 1 cm square and generates 200 V or higher voltage. To connect many photovoltaic elements in series in a minute area, connections both in the thickness and width were made simultaneously. Three-dimensional connection of 285 elements exposed to sunlight (AM1.5, 100 mW/cm^2) achieved a maximum voltage (open-circuit voltage: V_{OC}) of 207 V, a maximum current (short-circuit current: I_{SC}) of 36.6 µA, a fill factor (F.F.) of 0.615, and a maximum output power (P_{max}) of 4.65 mW. The maximum voltage is a world record for a 1 cm^2 device. It is also unprecedented that this kind of device was demonstrated to be capable of driving a piezoelectric actuator.



View (a) and structure (b) of a high-voltage micro photovoltaic device

Behavior Control Approach for Autonomous Control of Micromachines

Rajiv S. Desai
IS Robotics Inc.

We are conducting R&D on the behavior control of several micromachines to construct a control system of micromachines.

In micromachines, limited space and power require low power consumption in the control circuit and a simple communication method in a very low bandwidth. Behavior control enables autonomous control with very little computation resources. We developed a robot consisting of a microprocessor with up to 10 kbytes of memory and simple sensors, which is capable of complex autonomous operations and manipulation. Conventionally, each control circuit is assigned to a function. In the behavior control approach, each control circuit is assigned to a task. Therefore, individual tasks are performed by simple control circuits. The autonomous behavior control system we developed consists of 100 or fewer gates, capable of mounting on a micromachine, and advantageous for miniaturization.

To demonstrate the performance of behavior control, we fabricated the experimental robot shown in the photo, which is called KAA and performs pipe inspection tasks. This robot has 12 degrees of freedom and is controlled by three 8-bit microprocessors and a program memory of 64 kbytes or smaller. KAA can hold an object without being explicitly programmed with the shape.

Research and development of prototype robots proved that behavior control enables realtime control of complex operations with a minimal number of circuits, hence making its use optimum for micromachines.

Micro Inspection Machine

Kohji Idogaki
Nippondenso Co., Ltd.

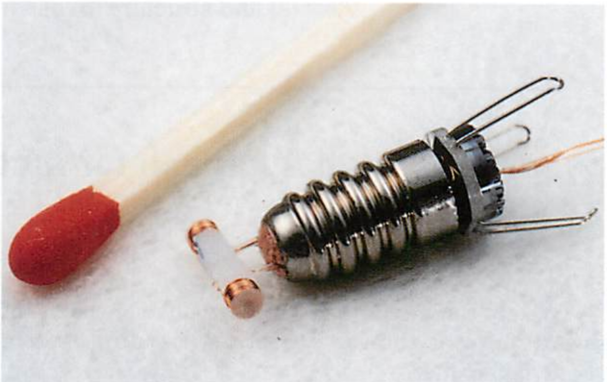
This research deals with micromachine systematization technology which systematizes the components of a micromachine.

Building a micromachine requires the development of many technologies, for instance, the integration of devices like actuators and sensors, the joining of components, and a thin, rigid body to protect the components. As an example of a micromachine integrating such elemental technologies, we developed in this study a micro inspection machine measuring only 5.5 mm in diameter and weighing about 1 g.

This micromachine supports an eddy current sensor of a diameter of 2 mm and a piezoelectric actuator that measures 2 mm X 3 mm X 9 mm. This piezoelectric element (lead zirconate titanate: PZT) was joined using dissimilar material direct bonding technology onto an aluminum base on which the inspection machine legs were mounted. Considering the heat dissipation and electronic circuit mounting required for systematization of the micromachine, micro heat dissipater fins were also joined to the aluminum base by the dissimilar material direct bonding technology. For packaging, one of the important micromachine systematization technologies, we also developed the processing technology to fabricate the body of the extremely thin three-dimensional shell structure.

With this inspection machine, the previously difficult inspection through the narrow curves of thin, long pipes becomes easy.

Aiming at an advanced maintenance system for power plants, we will try to develop comprehensive micromachine systematizing technologies, such as micro component assembly technology, wireless energy supply technology, and communication and control technology.



Posters Presented by 26 Research Supporting Members at the Poster Session

Title	Institution	Abstract of Presentation
Micro-Generator	Mitsubishi Electric Corp.	Structure of a high-performance micro-generator and technical problems in the improvement of performance were explained. Prototype generators measuring 7 mm, 3.2 mm, and 1.2 mm in diameter were displayed. Output characteristics of the first two and the structure and voltage characteristic of the last one were shown.
Micro-Ultrasonic Transducer	Sumitomo Electric Ind., Ltd.	Miniaturization of a transducer was attempted by the use of composite piezoelectric material which consisted of an array of fine, high-aspect ratio PZT columns embedded in resin. LIGA process for fabrication of an array of PZT columns (diameter: 20 μm and height: 100 μm) were reported as well as the transducer characteristics.
Micro Actuator	Fuji Electric Corporate R&D, Ltd.	Electromagnetic and electrostatic micro actuators were explained. Size reduction and establishing mass production technology by batch process were the development goals.
Electrostatic Wobble Motor	Matsushita Res. Inst. Tokyo, Inc.	An electrostatic wobble motor that required no assembly thanks to the film formation process technology on cylindrical surface was displayed, together with a video of the operations of the motor.
Micro-Gyroscope	Murata Manufacturing Co., Ltd.	A micro-gyroscope applied to position detection devices was fabricated by micromachining technology. To exploit the advantages of manufacturing by surface micromachining for size reduction, suitable device structures were examined. Basic characteristics of the micro-gyroscope were evaluated. Technical problems in the application to actual devices were examined.

Title	Institution	Abstract of Presentation
Micromachining of Silicon	Royal Melbourne Inst. of Technology	Micro-processing method using anisotropic etching of silicon with KOH solution and formation of copper pattern on silicon substrate was studied. Inductance of the copper spiral coil was calculated.
Driving Mechanism (Electrostatic Actuator)	Yaskawa Electric Corp.	Examples of experimental electrostatic actuators were shown. Structure and dimensions of the actuators with rotor diameters of 5 mm and 3 mm were compared in figures and explained. Features and characteristics of a mother ship moving model and an integrated actuator with a planetary reducer were also noted.
Integrated Multi-Dimentional Optical Scanner	Omron Corp.	An experimental optical element-integrated micro mechanical device having both an optical scanning mechanism (vibrator) and a photodetecting element mounted on a silicon substrate was fabricated. The manufacturing method and characteristics of the device integrated using silicon fine process technology were reported.
Piezoelectrically Driven Active Joint Having Three Degrees of Freedom	Kawasaki Heavy Ind., Ltd.	Good piezoelectric monolayer film, the driving element of an actuator, was fabricated and displacement characteristics of the piezoelectric thin film were reported. A friction-driven, small rotary actuator with three degrees of freedom and the high-speed controller of the actuator were displayed.
Piezoelectric Linear Actuator	Fanuc Ltd.	Two types of experimental actuators were fabricated and their operations were verified. One was a progress wave type linear actuator with a piezoelectric element that generated progressive waves. The other was a grip type linear actuator in which the driver mechanism accumulated and transferred small displacement of piezoelectric element.
Holonic Mechanism and Form Change Control	Mitsubishi Heavy Ind., Ltd.	Examples of holonic mechanism configurations currently being developed were shown. Examples considering the evaluation function setting for optimal form changes during movement of this mechanism by controlling only necessary joints were also displayed.
Micro Battery Electrodes	Mitsubishi Materials Corp.	Micro batteries using a hydrogen-storage alloy for a small, high-capacity secondary battery were under study as a source of energy for micromachines. Characteristics of micro battery electrodes fabricated by micro die forming and plasma ion vapor deposition were reported.
Behavior Control	IS Robotics, Inc.	A micromachine autonomous control system consisting of small control circuits and sensors was developed. Despite its simplicity, the system was guaranteed to perform complex autonomous operations and manipulations.
Electrostrictive Polymers Artificial Muscle	SRI International	Achievement of good distortion factor and driving pressure of electrostrictive polymers, which are crucial in the fabrication of a high-performance micro actuator, were reported. (Distortion factor of 20% or greater and driving pressure of 1.9 MPa)
Micro Inspection Machine	Nippondenso Co., Ltd.	Elemental technologies that comprise a micro inspection machine and its systematization were described. Breakthroughs in elemental technologies such as dissimilar material direct bonding technology and extremely thin structure formation technology and the problems in the systematization of the technologies were explained. Operations were explained in a video.
CCD Micro Camera	Toshiba Corp.	Elemental technologies necessary for a small camera for inspecting narrow places were examined using a large-scale model. It was revealed that a lens of a diameter of 2 mm focuses from 10 mm to the infinite, that it could be used both for proximity inspection and moving direction checks.

Title	Institution	Abstract of Presentation
Control and Drive Technologies of Micromachine	Meitec Corp.	To effectively control a group of micro robots working in a narrow area, an experimental remote control system having functions to recognize the intention of the operator was fabricated as a man-machine interface. An experimental piezoelectrically operated model that can move quickly through pipes was also fabricated.
Wide Range Photo Detector	Yokogawa Electric Corp.	An experimental novel field-effect photo detector that detects light as electromagnetic waves was successfully fabricated. Using the device, microwaves and infrared laser waves were detected. Principle of the photo detector and measurements of its characteristics were reported. The photo detector was displayed.
Micro Photovoltaic Device	Sanyo Electric Co., Ltd.	For photon energy supply to a micromachine, a flexible photovoltaic device that had a small size of 1 cm^2 and yet generated a high voltage of 200 V or higher and was able to be mounted on a curved surface was developed by advanced laser micro-processing and device technology.
REGO Type Block Technology	Fujikura Ltd.	In the ongoing development of REGO type block technology, airtight, surface-backside metal through hole electrodes that enabled high-speed weak signal transmission were successfully developed. Measurements of electrical characteristics, gas leak characteristics, and pressure proof characteristics were announced and an example of application of the electrodes to an infrared sensor was shown.
Optical Tactile Sensor for Medical Use	Olympus Optical Co., Ltd.	An optical tactile sensor suitable for size reduction and detecting contact force in organisms was designed. The principle of the sensor based on a surface-emitting laser was verified. Contact pressures were successfully detected with high sensitivity. The structure and characteristics of the developed surface-emitting laser as well as its evaluation as a tactile sensor were disclosed.
Optically Driven Micropump	Aishin Cosmos R&D Co., Ltd.	A thermal expansion type optical actuator was developed. By arranging several of these actuators, a peristaltic type micropump was fabricated. Operation of the micropump was shown in a video. The optically driven micropump was also displayed.
Kinetic Mechanism of Locomotion	Seiko Instruments Inc.	As a micro structure fabricating technology indispensable to micromachines, three-dimensional wet processing technology based on electrochemical machining was studied and the formation of patterns measuring from several microns to several tens microns were successfully formed. New downsizing structures of piezoelectric rotary motors were studied and the operations of these motors were tested.
Photoelectric Device	Terumo Corp.	Simple explanations of the principle, structure, and process technology of photoelectric devices and actuator devices were provided. Operations of these devices were shown in a video. Prototype models of the devices were also displayed.
Operating Characteristics of Electrostatic Valve	Hitachi, Ltd.	An experimental electrostatic valve measuring 25 mm X 25 mm X 1.3 mm that enabled high stroke was fabricated. The valve operating pressure difference range determined by the driving voltage and the port opening area was reported. The valve was also displayed.
SMA Micro-Coil Actuator	Mitsubishi Cable Ind., Ltd.	Through in-depth study of micro-coil spring fabrication technology, experimental shape memory alloy micro-coil actuators with coil outer diameters of 100 μm or less with a shape recovery force of 50 mN or greater were successfully fabricated. The micro-coil actuators and a prototype of a tip-articulation mechanism for an endoscope in which the actuator was applied were displayed.

Fuji Electric Co., Ltd.

1. Introduction

Fuji Electric Co., Ltd. was established in 1923 to manufacture electrical machinery and apparatus such as generators and motors. The company has since made major changes in the line and scope of its operations and is now producing a broad range of electrical products, including energy-related and plant control equipment, semiconductors, information-related equipment, and vending machines.

We recently visited Fuji Electric Corporate Research & Development Ltd., the nerve center where these products begin. The research unit of Fuji Electric became independent in 1980 and is now a separate comprehensive R&D institute, integrating its strong technological capability synergistically with the basic research being done by the Central Research Laboratory. The headquarters of Fuji Electric Research & Development is situated on the shores of Sagami Bay in Yokosuka City of Kanagawa Prefecture, a warm and pleasant environment conducive to research from fundamental technology to final production.

2. Features in Technological Development

Fuji Electric's motto, *"Challenge to the Creativity,"* well expresses its goal of focusing on energy- and electronics-related technologies in particular, and on developing its own techniques for application in many systems, while maintaining strong basic technology to take it into the future.

In the energy area, the company is working hard to achieve clean energy systems, in addition to improving existing products, while its development of large-area modules in amorphous solar cells is recognized worldwide. Fuji Electric is also one of the earliest companies in Japan to begin developing fuel cells. They are now working on a phosphoric acid fuel cell which is close to being marketed, a solid polymer fuel cell operable at low temperature and easy to use and maintain, and a solid electrolyte fuel cell with high generation efficiency.

There are many aspects of electronics being pursued: power electronics, semiconductors, instrumentation and control, and information-related equipment. Power electronics further the effective use of power and is used in intelligent equipment. New technology examples are found in reactive power compensators with harmonics and unbalance compensation functions to secure power quality, general-purpose inverters which greatly improve the variable speed range of AC motors, and digital servo controllers with extremely precise speed controlling and positioning capabilities.

In semiconductors the company excels in power elements, and is now principally focusing on IGBT (insulated gate bipolar transistor) which has high speed, high voltage and large capacity. Custom ICs such as those for driving liquid crystal and those for controlling office automation equipment are being developed and refined. In instrumentation and control, studies are being done on control systems for iron and steel plants, chemical and food industries and control software employing AI and fuzzy theory. Various kinds of temperature, pressure and flow sensors, and instrumentation equipment using these sensors are also being developed. Information-related equipment includes photosensitive elements for copying machines, an uninterruptive power supply unit and magnetic disk media, all based on Fuji's unique technologies.

3. Tackling Micromachine Technology

"Downsizing" is a term commonly used in many areas, and equipment design must be increasingly compact, light in weight, and efficient. Micromachine technology is thus recognized as of key importance in radically improving products. At Fuji Electric, this technique has to date been used principally in the area of sensors: for example, in applications of micro fabrication technology for silicon, for acceleration sensors to activate automobile air bags, pressure sensors for plant instrumentation, and gas leakage sensors in which fine metal wire is coiled. Auto-focusing ICs, in which an optical lens and a photodetecting and signal processing IC are integrated with high dimensional precision, are used in many small cameras. These techniques are also based on micro fabrication technology and include electro-discharge machining and plasma etching, developed in the creation of a tactile sensor to be fitted to the fingertip of a robot in MITI's major project, "Research on Advanced Robots."

Current research on micromachines is directed toward improving sensors and the commercial use of actuators. A motor one millimeter in diameter using a thin film coil and an electrostatic linear actuator applying rectification of mechanical vibration providing long strokes have been successfully developed. In addition to commercialization of many sensors, new actuator applications are anticipated.

MATSUSHITA RESEARCH INSTITUTE TOKYO, INC.

1. Introduction

Crossing the Tama River on the Odakyu Line from Shinjuku, the train enters a hilly area. We had an opportunity to visit MATSUSHITA RESEARCH INSTITUTE TOKYO, INC. which is located on the top of a hill commanding a fine view of the river. This institute was established in 1963 as a wholly owned subsidiary of Matsushita Electric Industrial Co., Ltd. to conduct research on which the manufacturing industry is based, as advocated by the founder, Mr. Konosuke Matsushita. Its creative activities have made it the R&D base in the Tokyo area, and have been responsible for several new lines of business in the Matsushita Group, including ultrasonic diagnostic equipment, CO_2 lasers and automobile telephones.

The Institute in Tama is currently the Eastern Central Research Laboratory of the Group, and its research has now broadened further with four laboratories in this area: Advanced Materials, Image Processing, Human Interface and Opto-Electro Mechanics, and one in Boston, Mass., USA. There are 243 employees, 197 of whom are research staff, and the paid-up capital is 800 million yen. Business amounts to about 5 billion yen annually, principally research projects commissioned by the Group and the government.

2. Micromachine-related Research

Micromachine-related research is primarily undertaken by the Opto-Electro Mechanics Research Laboratory, and since the 1980s studies on and partial commercialization of the micro electro-discharge machine have been ongoing. Precision machining is another important focus. The micro electro-discharge machine allows the fabrication of a shaft with a diameter of 5 μm with which a hole of this small diameter can be bored. It is also effective in machining micro-gears and parts which are complex and precise in shape. The Opto-Electro Mechanics Research Laboratory is also researching micro fabrication using an excimer laser and silicon processing technology employing a semiconductor process.

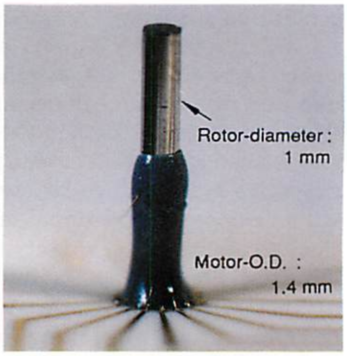
The Advanced Materials Research Laboratory is involved in investigations on scanning tunneling microscope (STM) and surface analysis using STM and its operations.

3. Commissioned Research Projects on Micromachines

The Micromachine Center has commissioned the Matsushita Research Institute Tokyo to study ultrasonic flaw detection, a theme taken up by the MMC's Micro Capsule Working Group. In pursuing this subject, the institute is working with (1) electrostatic wobble motors, (2) ultrasonic flaw detection sensors, and (3) micro fabrication technology. The electrostatic wobble motor is a micro motor with an outer diameter of 1.4 mm, manufactured by a non-assembly technique of the group's own design, in which various kinds of thin film and electrodes are formed on a cylindrical rotary shaft using a semi-conductor process, and then unnecessary parts are removed. This micro motor is scheduled for use in rotational scanning of ultrasonic beams.

Ultrasonic flaw detection sensors utilize the ultrasonic techniques for medical application which have been researched by Matsushita Research for many years. Seeking to make smaller sensors with higher resolution, piezoelectric polymer laminated film sensors and sensing algorithms are investigated. The institute is devoted to achieving increasingly minute and precise fabrication techniques, particularly for improving surface roughness, by refining 3-D fabrication and combining other fabrication technologies, based on the aforementioned micro electro-discharge machine.

To improve its capability in this area, the institute is active in joint research projects with universities both in Japan and in other countries and cooperates with other laboratories of the Group. Staff members vow that they are determined to incorporate these fantastic micromachines into actual products.



Prototype electrostatic wobble motor

Micromachine Technology (IV)

Fundamental Technologies

Machining Technology

Si process, LIGA process, and micro electro-discharge machining were explained in the previous sections. This section introduces other processing methods.

1. Photoforming Process

Photoforming is the creation of structures by photopolymerizing polymers, liquid resins which cure by being exposed to a laser beam or focused rays. In the photoforming process, as shown in Fig. 1(1), a thin film of photopolymerizing polymer is first formed and then it is exposed to beams which scan the surface to cure it, forming thin layer structures. The process is repeated to build up layers of cured resin to form an arbitrary three-dimensional geometry as shown in Fig. 1(2). Figure 2 shows an example of a product made by the photoforming process.

Minimum possible dimensions and accuracy in photoforming depend on both the beam diameter and the thickness of a layer of cured resin. Recently, structures of 100 μm or smaller, and those with movable parts have been produced. In another study, ceramic or metal powders are blended with liquid polymers to yield a wider diversity of materials. Although photoforming is basically single item production, mass production with dies made of resin structures formed by this process is also being studied.

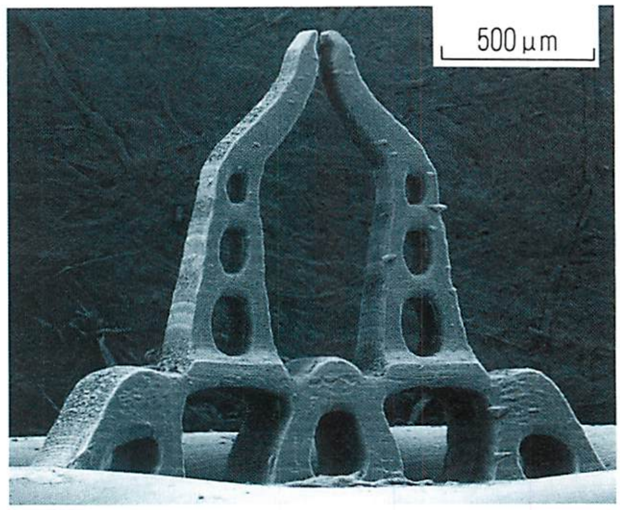


Fig. 2 Gripper fabricated by high-resolution photoforming process using photopolymerizing resin and argon laser
Processing accuracy in the vertical direction is improved to about 10 μm, enabling precise production of complex geometry. A piezoelectric actuator mounted in the substrate drives the gripper tips. (courtesy of Prof. N. Nakajima, The University of Tokyo)

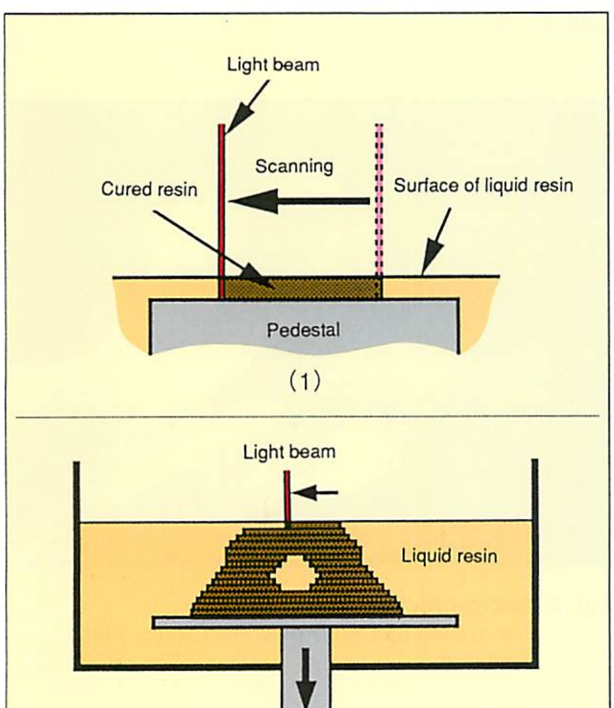


Fig. 1 Photoforming process

2. Beam Machining Process

The beam machining process is a local processing method whereby the material surface is irradiated by a thin energy beam of light, electrons, or ions. Thus, in a broad sense, the term covers electro-discharge machining and photoforming. The beam machining process is classified not only by the kinds of energy beam itself but also by the effect caused by the beam: it may accelerate chemical reaction on and near a solid surface, or it may remove the surface by mechanical force or heat.

Apart from the photoforming process explained above, there are other micromachining processes where light beams are used. In one such method being studied, a silicon wafer is placed in a reactive gas (SiH_4) atmosphere and irradiated with laser beams to bring about local growth of silicon crystals which form micro structures.

Micromachining with electron beams is also being studied. In this approach, a very small electron gun made by micromachining (see Fig. 3) would produce an electron beam for forming three-dimensional micro structures.

As for ion beam machining, focused ion beams (FIB) are frequently used. In the example shown in Fig. 4, very small characters on the surface of the diamond indentator engraved by FIB are transferred to a metal sheet. This method enables mass production.

Another ongoing study uses ion beams of various atoms for local modification of materials. The beam machining process using fast atom beams (FAB) and cluster beams are also being studied.

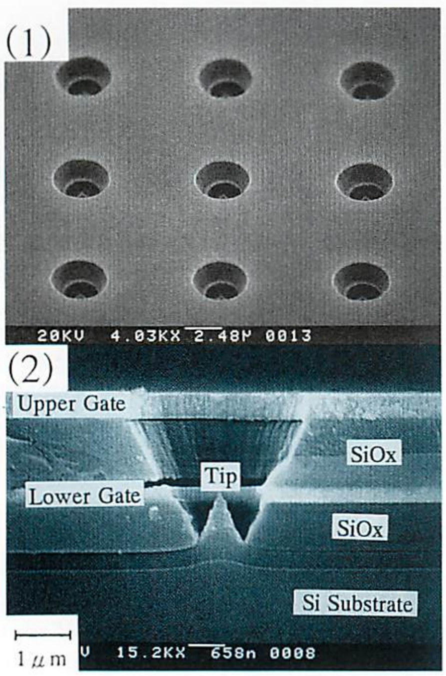


Fig. 3 Development of electron beam machining
Arrays and cross section of micro electron gun (courtesy of Dr. J. Itoh, Electrotech. Lab.)

3. Others

Mechanical machining such as turning and grinding inevitably incur machining resistance. As the size of the workpiece is reduced, the relative effect of machining resistance increases, degrading geometrical precision. On the other hand, mechanical machining can be applied to any solid material and is capable of three-dimensional forming. Various mechanical micromachining processes are under study. Figure 5 shows an example of manufacturing micro gears by grinding.

The Industrial Science and Technology Frontier Program, "Micromachine Technology," carried out by the Ministry of International Trade and Industry, also promotes research and development of various micro-processing methods, such as a concentric build-up process, micro-injection mold process, and shell body process.

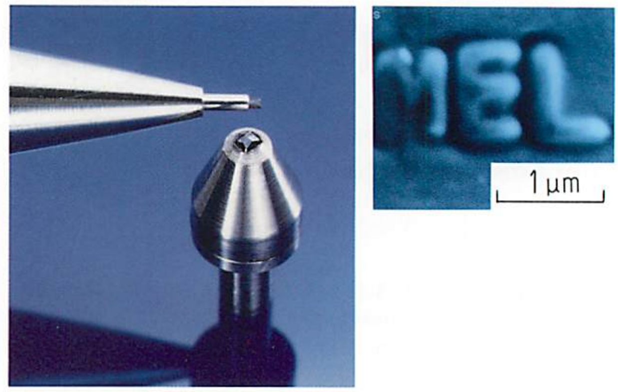


Fig. 4 Micro-processing by FIB
Diamond indentator and transferred characters (courtesy of Dr. K. Yamanaka, Mech. Eng. Lab.)

4. Future of Micromachining

We have introduced several micro-processing methods that are currently being studied to serve micromachine technology. There are many other eligible micro-processing methods, and new ones will arise as well. Each has its merits and demerits.

Since a micro mechanism part must take on not only a specific three-dimensional geometry but also provide mechanical strength and durability, its manufacture requires various processing methods that complement each other. Therefore, development, enhancement, and combination of micro-processing methods will be an important theme for micromachine technology.

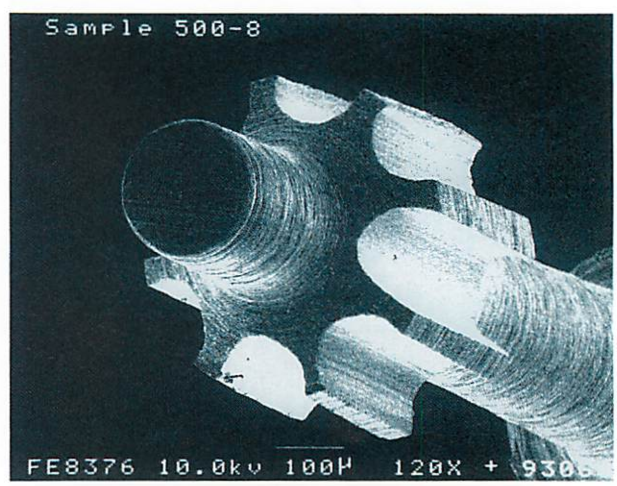


Fig. 5 Micro-processing by grinding
Micro gear (courtesy of Dr. K. Okano, Mech. Eng. Lab.)

Micromachine Summit Held

MMC organized a 3-day Micromachine Summit from March 13 (Mon.) to 15 (Wed.), 1995, in Kyoto. This is one of the international exchange activities held to build awareness of micromachines. This meeting brought together leaders from micromachine-related universities, research institutions, and industries for an exchange of opinions on all aspects from R&D to commercialization, stimulated recognition of the value of micromachines in Japan and other countries.

Chief delegates were:

Country	Chief delegate	Institution
Australia	Prof. D. Beanland	Vice-Chancellor of Royal Melbourne Institute of Technology
Canada	Dr. G. Guild	President of Micromachining Technology Center Ltd. Simon Fraser University
France	Prof. D. Hauden	Director of Laboratorie de Physique et Metrologies des Oscillateurs, L'institut des Microtechniques des Franche-comite
Germany	Dr. W. Menz	Karlsruhe Nuclear Research Center
Italy	Prof. P. Dario	ARTS Research Institute
Netherlands	Prof. J.H.J. Fluitman	University of Twente
Switzerland	Prof. N.F. de Rooij	University of Neuchâtel
U.K.	Prof. H. Dorey	Chairman of UK Microengineering Common Interest Group
U.S.A.	Dr. R.S. Muller	University of California, Berkeley
Japan	Prof. Naomasa Nakajima	The University of Tokyo

Prof. Naomasa Nakajima of The University of Tokyo, chairman of the International Committee of MMC, took a general chairmanship of the Summit.

Ten subjects were on the agenda for discussion:

(1) Scope of micromachine technology
(2) Effective research and development
(3) Multi-disciplinary knowledge
(4) Intellectual property rights
(5) Standardization
(6) Exploiting applications
(7) Coexistence and competition with the conventional technologies (including materials)
(8) New potential industries
(9) International relations
(10) Government role

The details of the Summit will be appeared on the next issue.

Lectures at the Symposium (Miniaturization and Microsystem Technologies) in the Netherlands

A symposium on micromachine technology was held September 19-20, 1994, at Veldhoven, the Netherlands.

The main agenda was presentation of survey results of MST (MICRO SYSTEM Technologies) by STT, a Dutch research institution, on investigations made over a two year period with the support of the Dutch government. Lecturers were also invited from EU, Germany, the U.S., and Japan and activities in these countries were reviewed.

About thirty lectures related to the researches done primarily in the Netherlands, and covered a broad range of areas:

- Medical systems
- Industrial systems
- Production technology
- Agriculture
- Consumer products
- Miniaturization
- Worldwide activities

From Japan, Mr. Takayuki Hirano, Executive Director of the Micromachine Center (MMC) spoke on ***"Activities in Japan,"*** outlining MMC's activities and research carried out under MITI's Industrial Science and Technology Frontier Program. It seemed to give some new ideas that comprehensive technological emphasis has been devoted largely to mechanisms in Japan, because much of the other micromachine research and development described at this symposium involved mainly Si technology.

Fifth International Symposium on Micro Machine and Human Science

The Fifth International Symposium on Micro Machine and Human Science (MHS '94) was held from October 2 (Sun.) through 4 (Tue.), 1994, at the Nagoya Congress Center. The theme was "Micro Machine and Human Science," and the cosponsors were the Micromachine Center, the City of Nagoya, the Chubu Industrial Advancement Center, the Federation of Micromachine Technology and others (a total of 14). Nine organizations extended cooperation, notably the Chubu Bureau of International Trade and Industry of MITI and the Aichi Prefectural Government.

The daily programs were as follows: Oct. 2, a maze contest; Oct. 3, keynote lectures and plenary lectures; and Oct. 4, a technical session. The three-day symposium attracted 1,040 participants, including visitors to the exhibition booths. Thirty-five participants came from seven foreign countries, including the United States, Germany and Switzerland.

The following people gave the lectures on Oct. 3:

- **Keynote lectures**
  (1) Atsuo Hirai, section chief, Industrial Machinery Division, Machinery and Information Industries Bureau, MITI
  (2) R.T. Howe, professor, University of California, Berkeley, U.S.A.
- **Plenary lectures**
  (1) W. Menz, professor, Karlsruhe Nuclear Research Center, Germany
  (2) Iwao Fujimasa, professor, Research Center for Advanced Science and Technology, The University of Tokyo
  (3) M.G. Allen, associate professor, Georgia Institute of Technology, U.S.A.
  (4) Hiroyuki Fujita, professor, Institute of Industrial Science, The University of Tokyo
  (5) J.B. Bates, research staff member and group leader, Oak Ridge National Laboratory, U.S.A.
  (6) M. Elwenspoek, associate professor, University of Twente, The Netherlands

At the technical session on Oct. 4, 29 papers were presented by invited lecturers and applicants from Japan and abroad. The research topics were:

(1) Micro robots	(5 papers)
(2) Micro devices	(5 papers)
(3) Micro systems	(4 papers)
(4) Micro actuators	(5 papers)
(5) Micro fabrication and materials	(5 papers)
(6) Applications	(5 papers)

Nine teams, including a Swiss team, competed in the Third International Micro Robot Maze Contest on Oct. 2. First prize went to "Ken Ken ver2.1" made by the team from Nippondenso's Research Laboratories. The team from Toshiba's Manufacturing Engineering Research Center and the Meitec team finished second and third, respectively.

Report on the Operations Council of the Federation of Micromachine Technology

The Third Operations Council of the Federation of Micromachine Technology was held on October 3 (Mon.), 1994, at the Nagoya Congress Center. Executive director Hiroyuki Fujita, professor, The University of Tokyo, was joined by 15 other members. The attendees received a list of the 32 member organizations of the Federation of Micromachine Technology and the annual schedule of each organization. They discussed the following subjects:

- The 6th MICRO SYSTEM Technologies Japan, MST Japan '95 (planned for October 31 through November 2, 1995)
- Announcement of the R&D Presentation on Micromachine Technology in Fiscal 1994
- The Second Micromachine Technology Research Grants (in 1994)
- Other matters

Member List of the Federation of Micromachine Technology

(as of Feb. 1995)

- Intelligent Materials Forum
- The Society of Instrument and Control Engineering (Technical Committee for Robotics)
- The Society of Polymer Science, Japan
- Japan Society of Next Generation Sensor Technology
- Japan Society of Precision Engineering (Micromechanism Technical Committee)
- Japan Society of Precision Engineering (Committee for Micro-Assembly)
- Advanced Machining Technology & Development Association
- The Institute of Electrical Engineers of Japan (Technical Committee on Industrial Instrumentation and Control)
- The Institute of Electrical Engineers of Japan (Technical Committee on Sensing and Processing Technology)
- The Japan Society of Applied Physics
- The Japan Society of Medical Electronics and Biological Engineering
- The Japan Society of Mechanical Engineers (Machine Design and Tribology Division)
- The Japan Society of Mechanical Engineers (Design and Systems Division)
- The Japan Society of Mechanical Engineers (Robotics and Mechatronics Division)
- The Japan Society of Mechanical Engineers (Computer Mechanics Division)
- The Japan Society of Mechanical Engineers (Materials and Mechanics Division)
- The Japan Society of Mechanical Engineers (Thermal Engineering Division)
- The Japan Society of Mechanical Engineers (Information, Intelligence and Precision Division)
- Japanese Society for Artificial Organs
- The Japan Society of Drug Delivery System
- The Biophysical Society of Japan
- Personal Computer Users Association (Micromechanics Technology Association)
- Japanese Society for Biomaterials
- The Robotics Society of Japan
- Micromachine Society (Tokyo)
- Micromachine Center
- Research Committee on Micromachine (Nagoya)
- World Micro Systems Technology Association
- MESAGO JAPAN CORPORATION
- The Japan Society of Mechanical Engineers (Dynamics, Measurement and Control Division)
- NAGOYA INDUSTRIAL SCIENCE RESEARCH INSTITUTE (INVESTIGATION COMMITTEE ON MECHATRONICS)
- FOUNDATION FOR PROMOTION OF ADVANCED AUTOMATION TECHNOLOGY

Invitation to Join the General Supporting Membership

Micromachines are minute devices capable of performing complex, microscopic operations, despite being composed of functional elements less than a few millimeters in size. It is believed micromachines have strong potential use across many industrial spectra, particularly in areas requiring sophisticated, advanced maintenance technology in response to increasingly complex and precise machine systems and in medical services where sensitive, advanced medical technology is required, but with minimal discomfort to patients.

The Micromachine Center (MMC) was established on January 24, 1992, with the approval of the Minister of International Trade and Industry. Its objective is to promote the dissemination of micromachine technology in Japan, and contribute to the development of Japan's industry, economy, and the advancement of international communities.

MMC promotes research and development work under the Industrial Science and Technology Frontier Program "Micromachine Technology," a 25-billion-yen mega-project begun in 1991, delegated by the Ministry of International Trade and Industry's Agency of Industrial Science and Technology.

The center will also engage in independent research, promote cooperative research involving industry, government, and academia, and organize international symposia on micromachine research and development.

MMC would like to invite your interest and support for its projects and activities—and call for your direct support through membership in MMC itself.

Membership privileges include:

1. Participation in surveys and research undertaken by MMC, and use of the results.
2. Use of delegated survey, research and development results not classified as secret.
3. Participation in study groups and other activities of the center.
4. Use of MMC's data bank.
5. Receipt of publications.

To apply for membership, please fill in the designated application forms and submit them to the secretariat.

Membership requires an initial payment of ¥ 4 million and annual dues of ¥ 2 million.

For further information, please contact the General Affairs Department of the Micromachine Center.

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