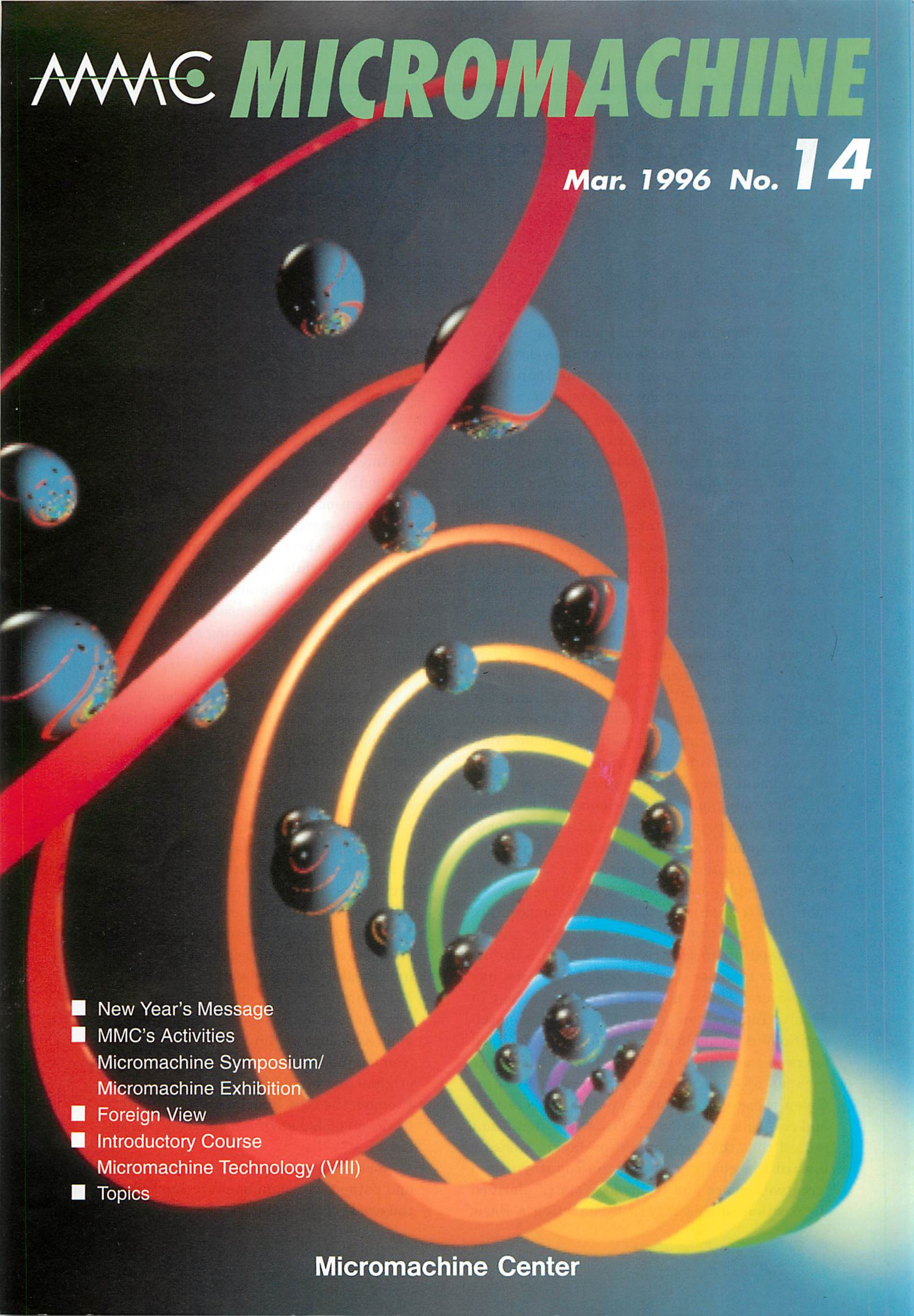
MMC

MICROMACHINE

Mar. 1996 No. 14



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Micromachine Center

New Year's Message

Dr. Jiro Hiraishi
Director-General
Agency of Industrial Science and Technology
Ministry of International Trade and Industry

At the beginning of 1996 I would like to offer my best wishes for the New Year to everyone. I would also like to take this opportunity to express a summary of my views on Japan's current and future industrial policy.

Today, with the twenty-first century approaching, we find ourselves in a truly competitive, free-trade world economy of increasing borderlessness. For its part, however, the Japanese economy continues to face difficulties. The old "catch-up" economic system that supported postwar development now serves to shackle progress. To eliminate the sense of uncertainty about Japan's economic future, increase the nation's economic vitality, and pave the way for its medium- and long-term development, Japan will need to reform its economic structure. This will encompass continuing the deregulation process, reforming financial and capital markets, and expanding economic frontiers by upgrading the nation's research and development and information bases.

The promotion of basic science and technology will be particularly indispensable to expanding the nation's economic frontiers and thus providing greater opportunities for the enrichment of people's lives. Indeed, people seem to be more aware than ever before of the importance of science and technology as assets that should be passed on to future generations. Unfortunately, however, the prolonged recession has had adverse effects on science and technology in Japan. Total private and public spending on scientific and technological research has declined for two consecutive years for the first time since records of such spending began to be kept. Given these two factors — public expectations and economic recession — it was very significant indeed that the government of Japan, working toward the goal of making the country into a "creative science and technology state," clarified its position in this regard by enacting a Basic Law on Science and Technology in November 1995 and mapping out a Science and Technology Basic Plan, by Cabinet resolution, in December 1995. The new law and plan are intended to integrate in a systematic way the nation's intellectual assets and to double annual government investment in scientific research and development by the year 2000 if possible. Also called for is the creation of a research environment that will allow researchers to work flexibly, and competitively, in their areas of interest and thus produce worthwhile, concrete results.

To fulfill its role under this new policy, the Agency of Industrial Science and Technology will actively promote the following measures in fiscal 1996.

First, the Agency plans to promote original and advanced research and development that will expand economic frontiers. Under the two supplementary budgets of fiscal 1995, the Agency held what turned out to be very well received public solicitations of research and development theme proposals on the seeds of future industrial technology. We estimate that the rate of competition at each solicitation was 20 times greater than rates achieved in the past. Our plans for fiscal 1996 are to

- Establish a system for soliciting proposals for original research and development in the industrial technology field;
- Maintain the present system of research and development in the fields of industrial science and technology, adding the new themes of "human media" and "creative technology for original and highly functional materials";
- Promote the New Sunshine Project, which works on global environmental and energy issues;
- Promote research and development in medical and patient-care equipment technology to meet the needs of the aging society;

- Promote the establishment of a regional technology research and development system that taps local potential;
- Promote in national research laboratories such strategic areas of research as basic optical technology and biotechnology;
- Select focal research themes and review them to ensure that worthwhile research and development is being undertaken; and
- Reexamine systems relative to personnel, funding, and research and development results.

Second, to facilitate the industrial application of research findings, the Agency plans to promote cooperation among the corporate, academic, and bureaucratic spheres and encourage the appointment of young researchers and foreign researchers, who are often the sources of original research and development. To this end, we will continue to utilize our Original Industrial Technology Research and Development Promotion System and expand our two programs — the Industrial Technology Fellowship Program and the Agency of Industrial Science and Technology (AIST) Fellowship Program — for personnel exchange within Japan and internationally.

Third, the Agency will promote the creation of an infrastructure in which advanced research and development can progress smoothly. Specifically, we will work toward
- Establishing an intellectual base, including measurement standards;
- Upgrading dilapidated facilities at national research institutes;
- Developing a research information infrastructure, encompassing networks and publicly available databases; and
- Providing improved methods of appraisal of research results.

Fourth, in an effort to raise the potential of research both in Japan and overseas, the Agency will promote international research exchanges. We will implement the Private-Sector Industrial Technology Cooperation agreement reached with the United States (one result of ongoing Japan-U.S. economic framework talks during fiscal 1995); the Human Frontier Science Program; and New Energy and Industrial Technology Development Organization (NEDO) grants.

Fifth, the Agency will support research and development that identify industrial applications in the results of private-sector technological research and that therefore serve to create entirely new areas of industry. We are currently proposing that a financial-support system for such activities be created in fiscal 1996.

Sixth, the Agency will promote the creation and coordination of industrial standards. Specifically, we plan to
- Promote the development of standards that protect consumers, that meet the needs of the aged and those in need of welfare services, and that protect the environment;
- From the standpoints of international harmonization of standards and systems and of the promotion of deregulation, focus on the coordination of domestic standards with JIS international standards and on the creation and dissemination of new types of standards for product quality systems and environmental management systems;
- Contribute to international standardization activities; and
- Develop a new standardization administration.

During the spring, the Agency will develop, and then implement, a long-term plan mapping out the basic direction of its standardization administration.

These are some of my views on the future of Japan's policy of technological development. The Agency of Industrial Science and Technology asks that those in the nation's industrial and academic spheres cooperate in carrying out the above-mentioned policies. We plan to do our utmost to promote scientific and technological research and development in Japan, to the end that the nation becomes a "creative science and technology state" in which its twenty-first-century citizens live active, fulfilling lives.

I would like to conclude my New Year's message by asking for everyone's continued cooperation and understanding.

First International Micromachine Symposium

Under the theme "Foundation of Industrial Technology in the 21st Century," the First International Micromachine Symposium was successfully held on November 1-2, 1995 at the Science Museum, Tokyo. Designed to promote and disseminate micromachine technology, this symposium was organized jointly by the Japan Industrial Technology Association and Micromachine Center (MMC).

The symposium combined the "Micromachine Symposium" previously held jointly by the Micromachine Society (Tokyo) and MMC, and the "R&D Presentation" held by the Japan Industrial Technology Association and MMC to publicize the R&D results of the Industrial Science and Technology Frontier (ISTF) Program "Micromachine Technology." Lecturers from the U.S. and Europe were invited to promote international exchange of information, and simultaneous interpretation was provided to all participants.

Symbolizing the importance and promise of micromachine technology, first day guest speeches were given by Mr. Osamu Watanabe, Director-General, Machinery and Information Industries Bureau, MITI; Dr. Jiro Hiraishi, Director-General, Agency of Industrial Science and Technology (AIST), MITI; and Mr. Hideyuki Matsui, Vice President, New Energy and Industrial Technology Development Organization (NEDO).

Then followed a keynote lecture by Dr. Keiko Nakamura of the Biohistory Research Hall. Nine micromachine technology-related researchers in Japan and overseas who are exploring ways to realize micromachine in industry spoke on the subjects: "The Path to New Industries in the 21st Century," "Activities in U.S.A. and Europe" and "Presentation on Innovative R&D."

Prof. Henry Guckel of University of Wisconsin-Madison, was invited but was unable to participate for health reasons. Fortunately his time slot was covered with lectures by Prof. Hiroyuki Fujita of The University of Tokyo and Prof. Susumu Sugiyama of Ritsumeikan University.

Invited lecturers were as follows:

- **Prof. Fumio Kodama,** The University of Tokyo
- **Prof. Shigeo Tanaka,** Nippon Medical School
- **Dr. Guido R. Tschulena,** sgt Sensorberatung Dr. Guido Tschulena, Germany
- **Prof. Henry Guckel,** University of Wisconsin-Madison, U.S.A. (Substituted by Prof. Fujita and Prof. Sugiyama.)
- **Dr. Constant Axelrad** and **Mr. Jean-Christophe ELOY,** CEA-LETI, France
- **Associate Prof. Nobuo Ohmae,** Osaka University
- **Prof. Yotaro Hatamura,** The University of Tokyo
- **Dr. Takehisa Matsuda,** National Cardiovascular Center
- **Prof. Kazuo Sato,** Nagoya University

A guest makes an address at the First International Micromachine Symposium

On the second day presentations were given regarding progress of the ISTF Program, "Micromachine Technology." The session began with an overview by Mr. Masayuki Kondo, Director for Machining and Aerospace R&D, AIST, MITI, followed by a total of 20 reports on the first phase results of the 10-year project started in 1991, including the briefings by researchers at the three AIST laboratories. The session was substantial in content and large expectations are placed on future progress of the project.

The number of participants at this international symposium far exceeded our original expectations, totaling 505 persons; on the first day new applications were temporarily declined because of a lack of vacancies. This indicates increasing interest in micromachine technology R&D.

The next (2nd) International Symposium is scheduled for October 31 (Thu.) to November 1 (Fri.), 1996 at the Science Museum in Tokyo.

Sixth Micromachine Exhibition

Under the cosponsorship of the Micromachine Society (Tokyo) and Micromachine Center (MMC), the Sixth Micromachine Exhibition (MST Japan '95) was held for three days from October 31 to November 2, 1995 at the Science Museum in Tokyo.

The five preceding exhibitions were entitled "Industrial Micromachine Exhibition," but this time, aiming at a broader application, the theme "Micromachine Exhibition" was used.

Sixty-nine organizations both domestic and foreign, including micromachine-related businesses, which are principally supporting members of MMC, and three national laboratories and universities participated in this exhibition. The exhibition floor area was about fifty percent larger than last year's. This is the final year of the first phase of the "Micromachine Technology" project and the research results for the past five years were reviewed. More than 3,500 people attended, many of whom listened attentively to the explanations, raising high-level questions and spending much time to carefully observe the exhibits.

Many supporting member companies employed their young researchers to provide explanations impressing visitors with their strong sense of involvement in and enthusiasm for micromachine technology R&D. This scene provided great hopes for the industry's future. Exhibits of 27 supporting members are outlined below (in order of booth number):

A scene from the 6th Micromachine Exhibition.

The next (7th) Micromachine Exhibition is scheduled for October 30 (Wed.) to November 1 (Fri.), 1996 at the Science Museum, Tokyo.

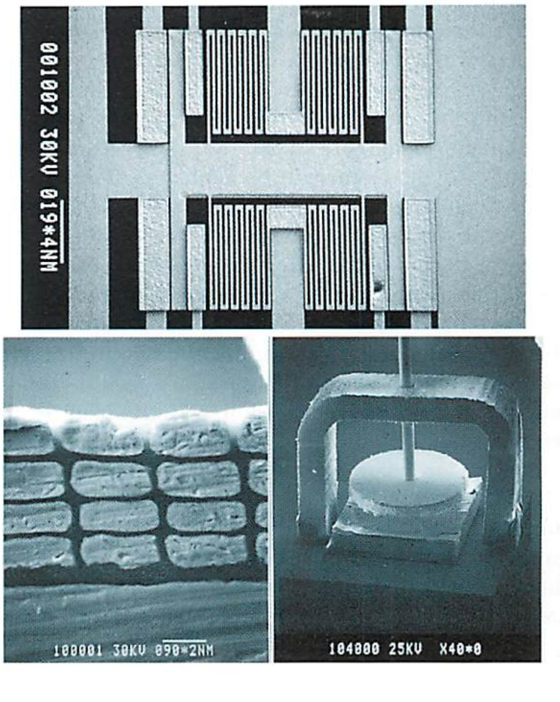
Electromagnetic and Electrostatic Micro Actuator

Fuji Electric Corporate Research and Development, Ltd.

Fuji Electric is conducting R&D into electromagnetic and electrostatic 1 mm in size microactuators to drive micromachine systems.

Employing a multilayer thin-film coil and a thin-film magnet for an axial gap motor, the electromagnetic actuator has been micronized into 1 mm in rotor diameter, while having the maximum speed of 24,000 rpm. For the multilayer thin-film coil, four layers of a 5-turn coil with 6 × 17 μm in the cross section are laminated to form a 33 μm thickness. Fuji Electric is researching the forming and processing of diamond film to increase output power by replacing the insulating material for the coil from polyimide to diamond, as diamond has larger thermal conductivity than polyimide.

The electrostatic actuator is a new type linear actuator. It achieves long-stroke linear motion by taking out only unidirectional movement from the reciprocating movement of small strokes such as mechanical vibrations. Using plating technique, Fuji Electric is developing an actuator array by integrating a metal actuator, whose unit size is 1 mm square.



Signal Transmitter

SUMITOMO ELECTRIC INDUSTRIES, LTD.

SUMITOMO ELECTRIC INDUSTRIES has developed a device that is mounted on submergible microcapsules and can communicate by transmitting ultrasonic waves. To transmit frequencies in water without attenuation, piezoelectric ceramics (PZT) usually used as the sound source are too large. Sumitomo Electric attempted to downsize the device using piezoelectric composites in which a PZT rod array is mounted within resin (Photo 1).

However in composites, energy conversion efficiency is reduced compared with bulk ceramics. To lower this reduction to minimal levels, micronizing the PZT rod array and increasing the aspect ratio (height/width) was found effective.

By developing a micro processing process for ceramic using deep-etch X-ray lithography technique, Sumitomo Electric succeeded in fabricating a PZT rod array of 20 μm in diameter and 140 μm in height (Photo 2). The micronization limits of ceramic have so far been about 100 μm, therefore a large improvement has been made. Using this process, Sumitomo Electric fabricated piezoelectric composites and was able to create a device that meets desired values in dimensions and energy conversion efficiency.

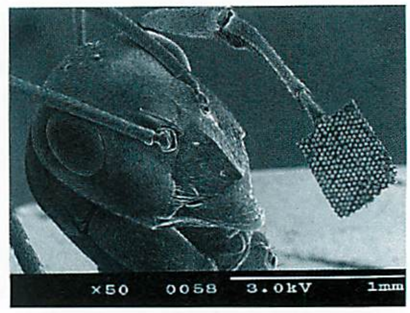


Photo 1 Signal transmitter

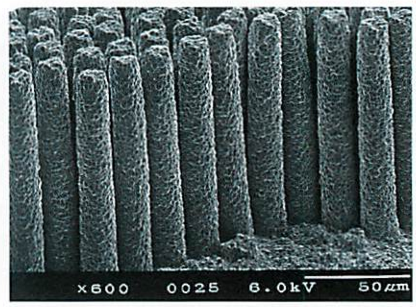


Photo 2 PZT rod array

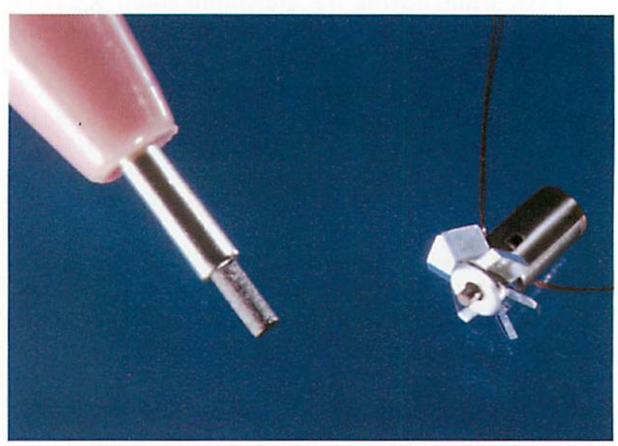
Micro-Generator

MITSUBISHI ELECTRIC CORPORATION

We have developed a micro-generator element technology in order to install a micro-generator in a micro capsule of diameter of about 2 mm and made a model generator of diameter 1.2 mm.

As the element technology, a rotor of sub-millimeter-size was constructed with a radial anisotropy by aligning the crystal orientation to the film thickness direction for forming a thin film magnet. By increasing the energy density in the radial direction, the high output of a generator can be achieved. For coil winding, we have developed a low stress film forming technology for thick films made of silicon oxide that is a highly reliable inorganic material in comparison to insulation resin, which is an organic material. Using the etching technology with the high aspect ratio of the film and electric plating technology to fine groove patterns, micro coils of high space factor and high density can be produced. For a high-speed bearing, we have developed a fine spiral groove forming technology by ion beam etching and a technology for forming titanium nitride surface modified films by ion mixing. As a result, pneumatic bearing of high load capacity and high abrasion resistance can be produced. By developing a specific fabrication technology called a cylindrical winding method, a highly efficient cylindrical stator that contains fine winding in a complicated three-dimensional shape can be produced with fewer process stages.

We created a model generator of diameter 1.2 mm through these technologies, installed a turbine along the shaft edge, and rotated it with air flow. The model generator generated a no-load induced voltage of several ten of millivolts and the function of a generator was verified. Our future aim is to improve the output by enhancing the element technology.



Nondestructive Testing Device

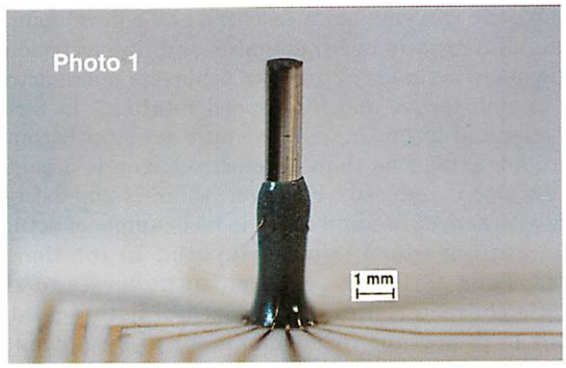
MATSUSHITA RESEARCH INSTITUTE TOKYO, INC.

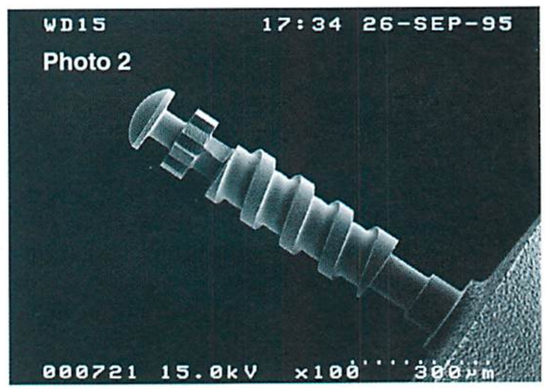
We have developed an ultrasonic scan mirror and an electrostatic wobble motor with an ultrasonic nondestructive testing sensor for a nondestructive testing device that inspects for pipe damage inside of the pipe without destroying the pipe for a group of fine pipes filled with water.

The ultrasonic nondestructive testing sensor that is made of piezoelectric ceramic is compact 1.4 mm in diameter and 1.5 mm in length, center frequency 20 MHz, and can ascertain the level of damage to satisfy the pipe inspection standard.

The compact electrostatic wobble motor (outer diameter 1.4 mm: Photo 1) can rotate at a low speed within the range from 0 to 380 rpm. A process method for manufacturing this motor has been developed. In the method, various thin films including a sacrificial layer are deposited on a cylinder, the components comprising those from a rotor to a stator are completed in batch and finally, a motor is completed by removing the sacrificial layer. In this way, a sub-millimeter-size motor can be developed without an assembling process.

To achieve a motor shaft and a scan mirror in an integrated manner, an advanced surface finishing process was developed. In order to achieve this surface finishing process, 3-D fabrication method (Photo 2) by micro electro-discharge machining and mixed particles and electrolysis are combined. As a result, 3-D machining that can produce dimensional precision of 0.11 μm and surface roughness of 32 nm could be achieved.





Micro-Gyroscope

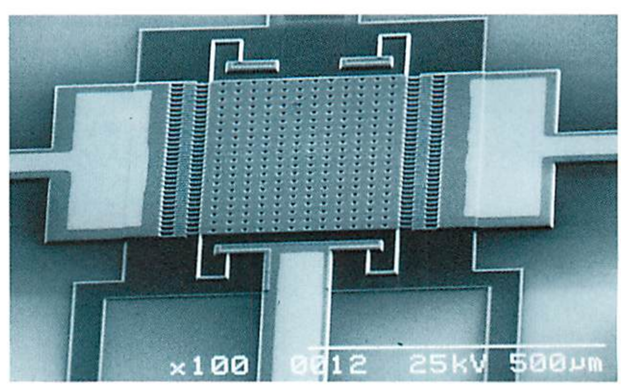
Murata Manufacturing Company, Ltd.

We developed an ultra-compact vibrating gyroscope which is required for a micro capsule to recognize its position. The resonator of the micro-gyroscope is formed on a silicon chip by processing polysilicon of thickness 5 μm by the surface micromachining technology. The size is 400 μm × 800 μm and was reduced drastically in comparison to the existing vibrating gyroscope produced by the existing machining and assembling process.

The sales points of the micro-gyroscope manufacturing technology are high precision vertical process of polysilicon and sacrificial layer etching technology of a narrow gap structure between a substrate and a resonator. For these process objectives, we could produce the device with the specified size by applying the reactive ion etching technology that cools a substrate temperature down to near -150°C and the freeze-drying technology.

The micro-gyroscope that has been manufactured vibrates towards the direction of the substrate surface by static electricity when a voltage is applied between the comb-shape electrodes. By matching the frequency of the voltage to be applied with the resonant frequency, the micro-gyroscope can be vibrated with the amplitude of 10 μm. When the device rotates alongside the axis that is normal to the vibration direction and is within the substrate surface in this condition, a Coriolis force is generated in the substrate vertical direction and the resonator vibrates with deflection. By detecting the deflection as a capacitance change of the substrate and resonator, the rotation speed can be detected.

The micro-gyroscope that was produced as a model achieved angular rate resolution of about 2°/s which achieved in the vacuum atmosphere. By applying integration processing for the output signals sent from the micro-gyroscope, we could verify through the experiment that angle changes can be detected from the initial position. In the future, we are planning to develop a compact packaging technology as well as further down-sizing and improvements of precision for the device in order to apply the device as a sensor of micromachine.



Rotary Micro Actuator

YASKAWA ELECTRIC CORPORATION

We are carrying out a research and a development of an electrostatic micro actuator and an electromagnetic micro actuator in order to achieve a micro actuator of high torque and high-speed rotation. In terms of generated torque, an electrostatic actuator becomes more advantageous than an electromagnetic actuator as the size is reduced. However, there is no past history of practical use and there is no example of actually indicating which is more superior in relation to size. Therefore, the research to understand the torque characteristics of the sizes of both actuator types is important in development of an optimum micro actuator of high torque and high-speed rotation. Fig. 1 shows the result of comparison between the rotor sizes and torque values of both types based on the FEM (Finite Element Method) analysis and actual measurement. The comparison shows that the superiority of both types is reversed on the rotor diameter of approximately 0.7 mm as the borderline. Fig. 2 shows microtorque measurement instrument that was developed for torque evaluation. This device has enabled the measurement of torque within the range from 10^{-7} to 10^{-5} Nm that could not be measured with the existing device and has enabled the evaluation of micro actuators.

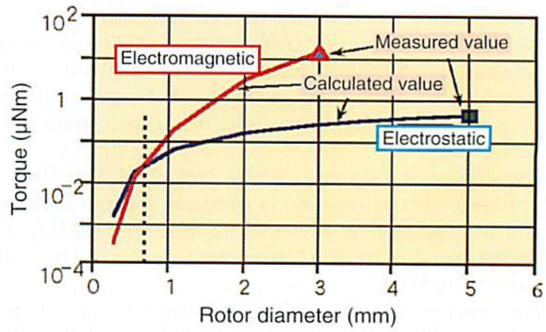


Fig. 1 Relation between rotor diameter and torque

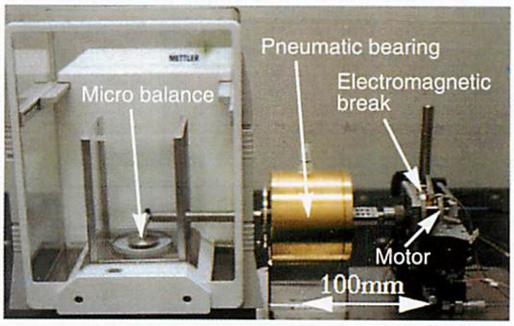
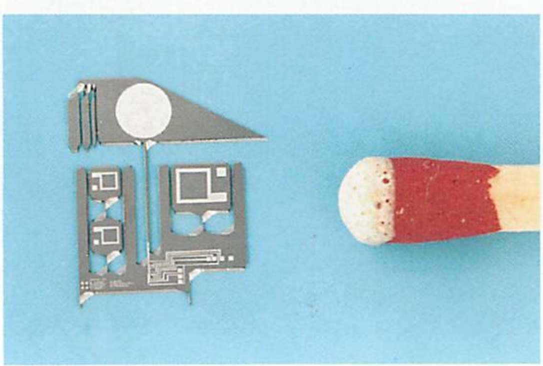


Fig. 2 Microtorque measurement instrument

Micro Scanners

OMRON Corporation

OMRON is conducting R&D into micronization of a scanning-type shape recognition sensor that scans a light beam two dimensionally. This sensor is expected to be used to guide self-mobile machines. To develop this sensor, it is necessary to micronize the light scanner that scans light two directionally, and reduce the number of components by integrating various functions into one device. After experimenting on micronization and integration through the combined use of silicon processing and micromachining technologies, OMRON completed a microscanner capable of two dimensional scanning in which photodetectors and piezoresistors are integrated on a silicon resonator (Refer to the photograph). This microscanner is 10 mm × 10 mm in size. It allows the resonator to generate two modes of resonance by oscillating the piezoelectric actuator, and enables two-dimensional light scanning by rotational vibration of a torsion spring which supports a mirror. Also, light detection is made possil le with a photodiode formed on this resonator. Simu.ltaneously, the scanned position can be always monitored with piezoresistors positioned on the torsion spring to detect spring strain. Thus, the scanner, photodetector, and vibration detection sensor, which were previously separate elements, are integrated into one device and the sensor is micronized.

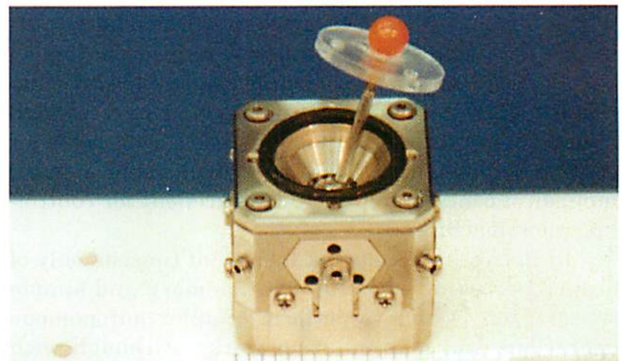


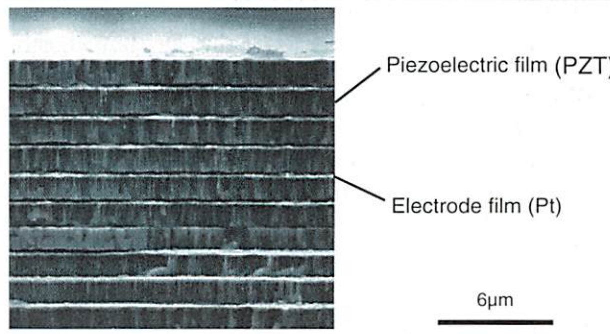
Also, a sensor of 22 mm in outer dimension, on which this microscanner is mounted, was trial-manufactured to inspect the inside of a pipe 25.4 mm in diameter. 3-D pipe inspection was made possible by employing a method to spirally scan the interior wall. To further micronize scanners, it is necessary to micronize and integrate the actuator that drives the scanner. To accomplish this, OMRON developed thin film processing technology for piezoelectric materials, and succeeded in processing PZT thin film approximately 1 μm thick with a high piezoelectric constant (d_{31} = −100pC/N).

Piezoelectrically Driven Rotational Joint with Three Degrees of Freedom

KAWASAKI HEAVY INDUSTRIES, LTD.

In order for a mother machine to freely move within piping, it is necessary to change its configuration at bending and branching parts. This requires a coupling device to allow the mother machine to be transformed into the desired shapes. To develop such a coupling device, KAWASAKI HEAVY INDUSTRIES (KHI) is working to establish the technology for a 3 degrees of freedom (d.o.f.) rotational active joint employing piezoelectric elements as its driving source. This joint is characterized by a structure that whereby multiple force generators of combined piezoelectric elements are placed around a spherical rotor, and the rotor ball is friction-driven. KHI has established the fine motion control technology that gives full orbital control to the front end of the force generator, and the rotor ball rotation control technology that coordinates the moving direction of the front end of the multiple force generators. These control technologies are the common basic technologies to achieve the integration and coordination of the operations of multiple micromachines. To miniaturize the 3-d.o.f. rotational active joint, KHI has created the technology to micronize multilayered piezoelectric elements using piezoelectric thin film forming technology by sputtering and 3-D wiring technology by focused ion beam (FIB). Also, through micronization, the driving voltage of piezoelectric elements has been greatly reduced.





Laminated piezoelectric micro actuator

Holonic Mechanism and Form Changing Control

MITSUBISHI HEAVY INDUSTRIES LTD.

As a mechanism suitable for composing micro machines, we suggest the mechanism that basically connects a number of function elements of the same or similar type in terms of hardware. This function element is called a "holon" and the mechanism is called a "holonic mechanism". An operation model consisting of 40 holons was created as shown in Photo 1. Thirty-six holons of the same structure are connected in the sequence of flexion, rotation, flexion, and so on. The function of each holon is simple, however, since many holons are connected, the entire degree of freedom is large and various shifting modes can be made available. As a controlling technique having the unprecedented degree of freedom, we suggests "form changing control" that drives only the degree of freedom required for each basic mode by setting the basic mode according to the work and shift environment. An experiment of this method was carried out in the "consecutive simulation of shifting" that is shown in the consecutive photograph (Photo 2). The operation model drops in stages from the four-leg mode, changes to the "crawling" mode, passes under piping, changes to a four-leg mode again, and starts walking. By controlling a series of these operations, it could be verified that this mechanism can achieve operations such as moving by changing forms.

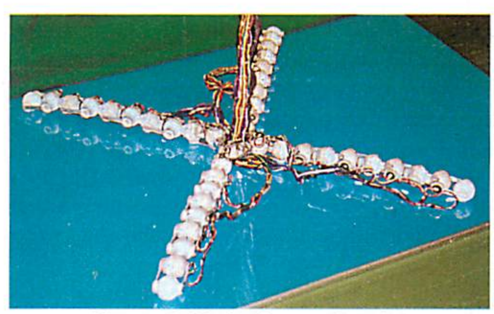


Photo 1 Holonic mechanism

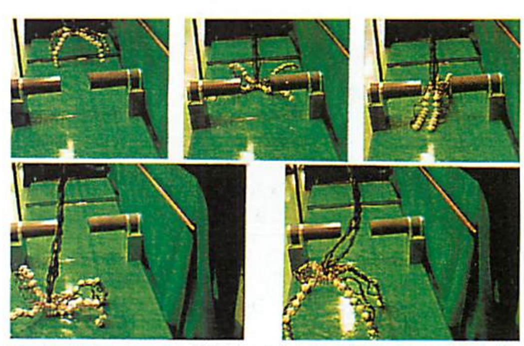


Photo 2 Demonstration of form changing control

Behavior Control of Micromachines

IS Robotics Inc.

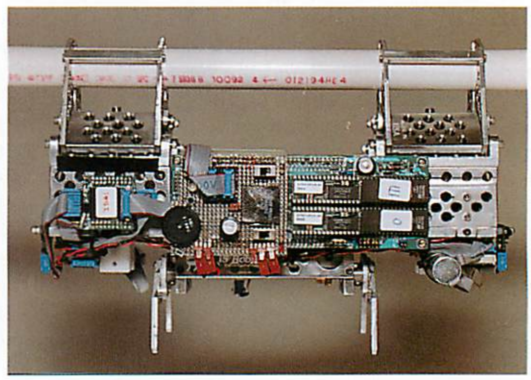
IS Robotics is conducting R&D into behavior control, which is necessary for micromachine systematization and controlling multiple micromachines.

In the control of micromachines, from the mounting requirement, it is necessary to reduce the control circuit's size and power consumption, and for information communications simple methods at narrow-band frequency are unavoidable. For this reason, behavior control achieves autonomous control using a small number of control circuits and is excellent for controlling micromachines.

IS Robotics developed a robot that consists only of a microprocessor with 10k-byte memory and simple sensors, but is able to perform complex autonomous operations and manipulation work. Although with previous controls, control circuits were formed for each function, with IS Robotics' behavior control, controls are formed for each work unit. Thus, each operation can be performed with a simple control circuit. The behavior control can be achieved less than 100 gates and an autonomous control system appropriate for miniaturization and mounting on micromachines.

To demonstrate the controllability of the behavior control, IS Robotics trial-manufactured a prototype robot called "Remus Robot," which performs piping inspections, as shown in the photograph below. This robot was improved from the previously developed KAA, Piper-1, and Piper-2 robots, and used to confirm the controllability from sensor signals to actuator operations.

Behavior control enables us to control complex operations on a real-time basis with a minimum number of control circuits and is ideally suited as the control system for micromachines.



Research of Artificial Muscles

SRI International

SRI International is investigating artificial muscle for small robots using electrostrictive polymers. This muscle has compliant electrodes on the surface of the polymer film, contracts in thickness and extends in length and width due to the electrostatic forces when a voltage is applied. The polymer enhances the electrostatic force because of its dielectric constant. The net result is a muscle with large strain (>30%) and a large actuation pressure (0.21 MPa in silicon, 1.9 MPa in polyurethane). The performance of the artificial muscle is comparable to the natural muscle, but with higher efficiency and faster response.

Artificial muscle can be fabricated using spin coating, dipping, or casting. Once the muscle is fabricated, it can also be folded or rolled to make the muscle actuator more compact. The artificial muscle actuator shown in Fig. 2 uses a spin coated film which is first folded then rolled, followed by folding and to achieve 20 layers. The active muscle for the actuator is 10 mm in length and 3 mm in diameter, and gives a maximum stroke of 1 mm and maximum force of 2 grams (2×10^4 μN). Its weight is approximately 0.1 g.

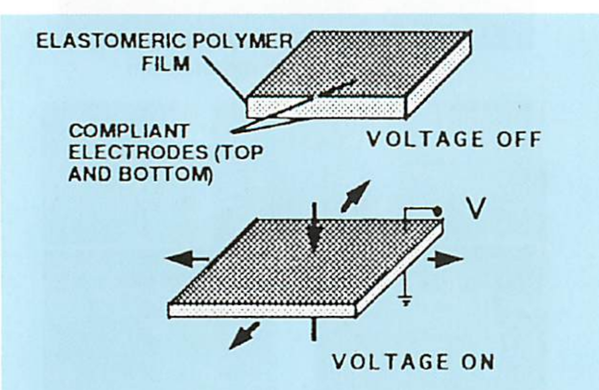


Fig. 1 Schematic of the actuator functional element showing the effect of applied voltage

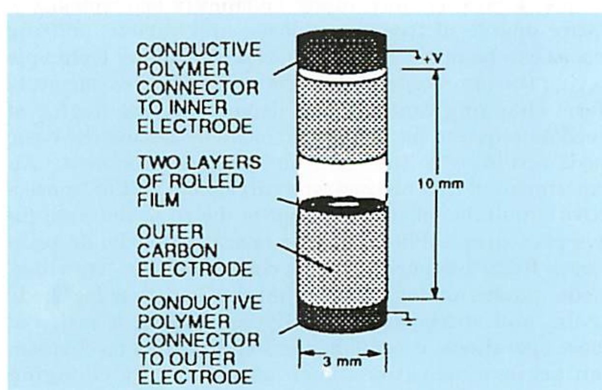
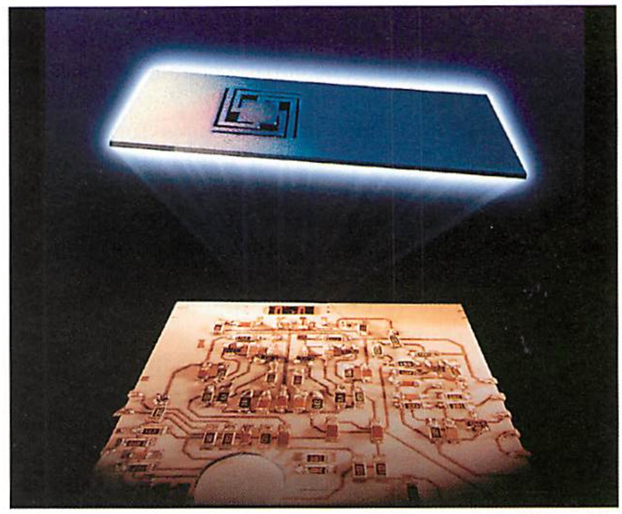


Fig. 2 Construction of the rolled-film demonstration actuator with cross sectional view

Micro Suspension System

Royal Melbourne Institute of Technology

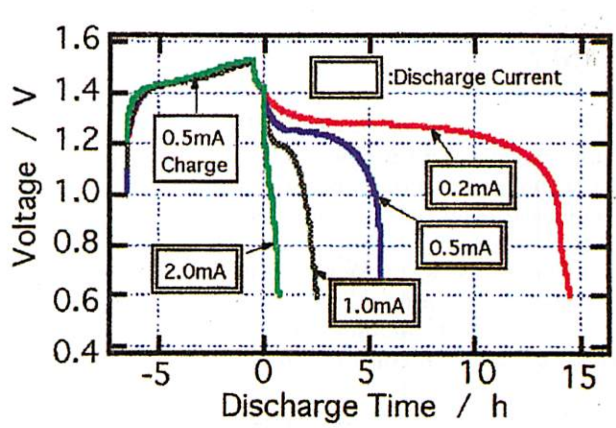
We are carrying out a research on the driving and suspension system that minimize the friction between the moving components of a micromachine. The smaller the component, the greater the influence by a surface force such as frictional force. Therefore, the research for minimizing friction is an important element technology of the micromachine technology. As the first step of this research, we have developed a one degree of freedom suspension system. This system consists of a multi-layered coil, a silicon stereo-beam structure, a permanent magnet, and a sensor coil. With the system that structurally constrains any other degree of freedom, research on the design technology of micro suspension is being carried out. The element technologies that are currently studied include micro processing technologies such as lithography, etching, and plating for producing a micro suspension system, and a Nd-Fe-B permanent film magnet formation technology. Using a millimeter-size magnetic bearing a micro suspension control technology is also being studied based on the most advanced control technology such as neural network and H_∞ control. Our future objective is to develop an integration technology for micro magnetic bearing and micro gear based on the technologies that have been developed.



Microbattery

MITSUBISHI MATERIALS CORPORATION

We exhibited a secondary battery (battery device) that is one of the energy supply sources of micromachines. At the first stage, we set the development targets to down-sizing and high discharge capacity. We established a membrane electrode forming technology (plasma ion deposition method, screen coating method, and micro mold method) and a microbattery assembly technology that are imperative for down-sizing. A hydrogen storage material that demonstrates a high electric discharge capacity is used for the electrode in order to minimize decrease of the electric discharge capacity occurring as a result of down-sizing. The size of the battery that has been exhibited is 5 mm in diameter and 1.5 mm in thickness. This size is the thinnest possible size (battery thickness 1.5 mm) compare to the current miniature battery and also achieves one order higher capacity than that of the current battery, which is 1 mAh. By using this battery, a large wall clock, a display panel that uses 12 LEDs, and a liquid crystal display thermometer could be operated, as well as operating a small vehicle model (mini car) with the run time of about 20 times more of that condenser as a driving energy source. In the second stage, we are planning to achieve high voltage and shape flexibility in order to enhance the functions of the microbatteries.



Charge/discharge characteristic curves

Superprecision Micromachining

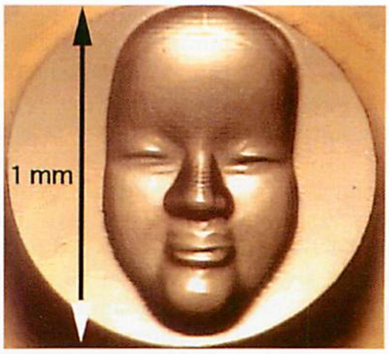
FANUC LTD

In realizing the fabrication of micromachines, it is indispensable to have a technique that allows high-precision machining of complex 3-D forms.

FANUC's superprecision micromachining tool consists of a diamond milling tool rotating at high speed on a superprecision positioning table with nanometer resolution. The cutting edge is offset a few microns from the revolution center. With this technique, FANUC succeeded in relief engraving a mirror surface minute Noh-mask on a 1 mm-diameter column. To accomplish this machining, FANUC developed a special diamond tool and a superprecision holding device that holds the tool with misalignment reduced to submicron values.

The machine is newly equipped a non-contact type form measuring device. Different from conventional contact type devices, the new device allows measurement in horizontal direction, and so it enables on-machine measurement of form precision and surface roughness without reclining a workpiece, and also measurement of the starting point of machining.

Thus, FANUC has realized a superprecision micromachining technique that allows mirror finishing in any direction except in narrow groove.



Antenna-Coupled Rectifying Diode for IR Detection

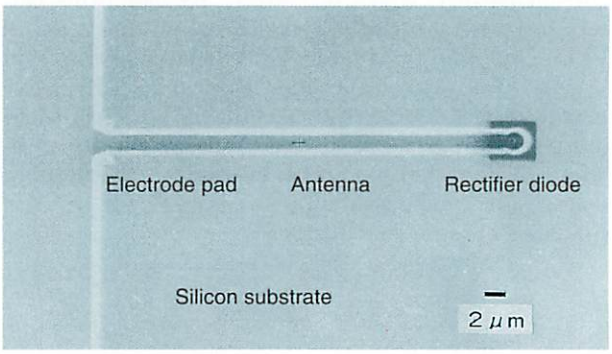
Yokogawa Electric Corporation

Yokogawa Electric Corporation has produced a model of a device of new concept that catches light with a micro antenna as a radio wave, detects the ultra-high frequency current of 30 THz (tera hertz) that occurred in the antenna with an ultra high-speed rectifying diode, and converts the current to signals. This device enables the measurement of electromagnetic waves and infrared light over a wide range from a microwave range (GHz) to an infrared range (30 THz).

By using this device as an infrared ray detection device, the existing spectroscopic analyzer can be integrated on a chip of several millimeters square and pipe inspection of a power plant can be carried out from the inside of the pipes and a human body can be diagnosed from inside. Thus, the device will cause a significant change in the future inspection methods.

The device is structured based on the fact that the infrared ray is an ultra-high frequency electromagnetic wave. A micro antenna of 30 μm in length is fabricated on a silicon chip by the thin-film process and a rectifying micro diode is formed on the edge. The figure shows the antenna of 30 μm in length and 1 μm in width as well as the diode. Since the device consists of an antenna and a rectifier, this is a radio reception circuit on a silicon chip. The device does not require a cooling means unlike the existing infrared detection device. The size of the diode is extremely small, 0.03 μm in diameter, and focused ion beam milling technique with the newly-developed milling monitor function is used.

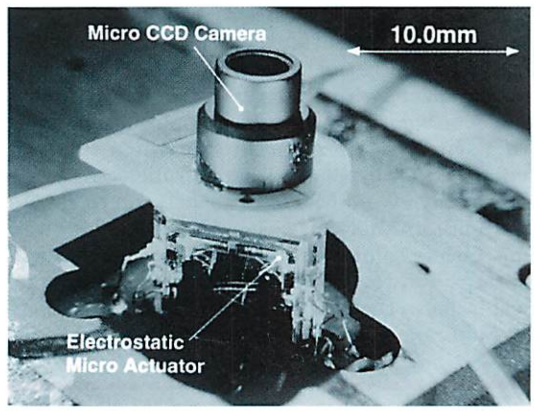
For future development, we are planning to enhance the features of the infrared detection device as well as the development of an element required for spectroscopes such as light source and integration into a silicon chip in order to achieve a device with spectroscopic functions.



CCD Microcamera

TOSHIBA CORPORATION

The most basic visual inspection is required when inspecting the inside of narrow pipes at a power station or various types of complex and narrow equipment. Previously for such jobs, industrial endoscopes were used. Yet, in this case, either the picture was poor or difficulties were involved in the observation because of large distances between the endoscope and monitor and problems with fine positioning. Toshiba developed a 10 mm in diameter and 14 mm in length CCD microcamera that could be mounted on a robot, which moves in a narrow space. Developing a 3 mm in diameter and 1.3 mm in length catadioptric system fabricated with an ultra-minute process using an ion beam, Toshiba achieved a lens 1/3 the length of the previous compound lens system. The F number ranges between 2.1-6.4 and the resolution is better than 20 µm, allowing observation from the close range of 10 mm to infinity. Toshiba has also developed a "3-D mounting technology," which takes out the CCD and the image-processing IC from the package and directly laminates them to achieve high compactness. This technology allows terminals to be formed on the side of an IC for electrical connection, a practice previously impossible due to its extreme thinness. The optical system and CCD are mounted on the universal head, allowing the photographing direction to be minutely adjusted within the range plus or minus 10 degrees either vertically or horizontally. On this mechanism three units of a newly developed vibration driving control type "electrostatic actuator" are mounted to reduce friction force, which is harmful to micromachines. The unit size is 8.4 mm wide, 8 mm long and 1.2 mm thick. When observations are made in a pitch-dark narrow space using a light, the difference in illuminance between the reflected light from accumulated materials and metal flaws and the surrounding dark area is so large that it was impossible for ordinary cameras to take a good photograph. With this camera, Toshiba developed the CCD image signal processing technology, which gives 16 to 170 times wider dynamic range than previous types, allowing observation of the image equal to 400,000 pixels even in a poor lighting environment mixed with bright and dark parts. Further downsizing and expansion of applications are intended.



Application System of Cooperative Control

MEITEC CORPORATION

The major exhibit, "Application System of Cooperative Control" is an integrated inspection system that uses the piezoelectric actuator technology and communication control technology that were developed by MEITEC. In this system, two inspection modules with micro CCDs (developed by Toshiba Corp.) and the micro IR sensors (developed by Fujikura Ltd.) move inside the pipe at a high speed and inspect the pipe efficiently via both a virtual environment operation and cooperative module control. The features of this system are described below.

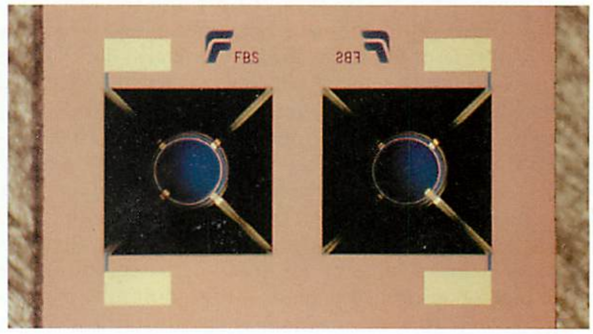
- **Advancement and distribution of the functions and decentralization of the device**
  The space efficiency is enhanced by advancing and multiplying the functions of each device and the functions are decentralized to two modules. The device is equipped with an ultrasonic distance measurement function by pipe wall vibration that uses a piezoelectric actuator in order to detect the position of each module.
- **Efficient cooperative control**
  By the cooperative operation of two modules whose work load was shared corresponding to the two inspection stages, rough inspection and detail inspection, efficient inspection is achieved.
- **VR interface**
  Intuitive remote operations of two modules under an invisible environment is enabled by the man-machine interface via a virtual environment.

Other exhibits include in-pipe moving modules (circuit built-in type model in 36 mm diameter and miniaturized model in 18 mm diameter) that use pin-type piezoelectric actuators and a micro substance observation system that uses a man-machine interface (intention understanding function).

Application of Block Technology for Self-Package

FUJIKURA LTD.

FUJIKURA has been researching the subject of "linking technology of functional blocks," which involves assembling a micromachine with various standardized functional blocks by using assembling/disassembling methods like Lego toys. Since individual blocks can be assembled or disassembled, once this is realized it would become easy to disassemble a micromachine then assemble it again to add new functions or remove existing functions. As its element technologies, we have examined: (1) bonding, (2) through-hole interconnection, (3) micromachining, and (4) film physical constant measuring technologies. In this exhibition, FUJIKURA displayed the bonding technology by using sodium silicate solution and direct bonding technology for hetero materials from (1) and (2), and shows the future direction of the research. To demonstrate the usefulness of these technologies, FUJIKURA operated a self-package type compact infrared sensor, which was trial-manufactured using these technologies. Employing micromachining technology, this sensor has a structure in which the infrared detection part is suspended from four dielectric bridges of approximately 10 µm wide and about 1 µm thick (See the photograph). In this sensor, bonding technology by using sodium silicate solution, direct bonding and through-hole interconnection technologies are employed to bond the cap wafer, leave the single crystal silicon on the dielectric bridge, and take out signal current from the underside of the chip, respectively. Bonding technology by using sodium silicate solution allows bonding at low temperatures, therefore allowing the previously mentioned micro-structured sensor to be assembled without residual stresses. The single crystal detection part made by the direct bonding of Si is highly sensitive, and the through-hole connection part with which metals are in contact had low resistance, allowing small current change in the sensor to be taken out of the electrode of the underside. It was also identified that this sensor is more compact in size and quicker in response than conventional ones. In the future, FUJIKURA will further develop these technologies to create microjoints that bond various devices.



Photovoltaic Microdevices

SANYO Electric Co., Ltd.

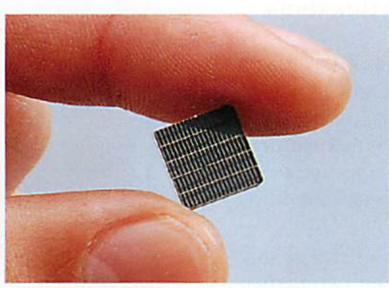
By development subject, photon energy supply technologies for micromachines are classified into the high voltage, high output-power, and curved surface mounting technologies for photovoltaic microdevices.

Regarding high voltage technology, to allow it to be directly connected with unit cells in series in a small area as the energy supply source to drive piezoelectric or electrostatic actuators desirable for micromachines, which require high voltage, SANYO created the 3-dimensional wireless highly integrated series connection by vertically stacking photovoltaic materials and by selectively patterning multilayered thin films with a laser in the horizontal plane. Thus, SANYO succeeded in connecting 285 unit cells in series within a 1 cm^2 area and developed a device that generated the world's highest voltage — 207 V.

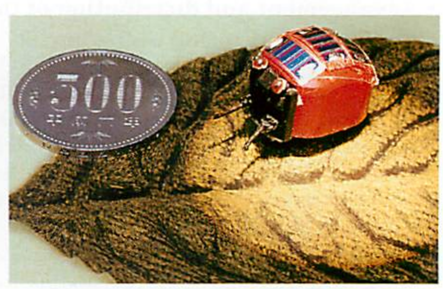
Regarding the high output-power technology, when photon energy is supplied via the surface of a micromachine, the angle of light incidence changes with the movement of the micromachine. Therefore, for light incidence from all directions, it is necessary to increase the optical absorption ratio by light trapping effects through multiple reflections. By employing surface micromachining techniques, SANYO formed high-aspect-ratio uneven structures with about 4 µm pitch on the surface of the photovoltaic device and achieved similar optical absorption ratios to those for vertical incidence also with the light incidence from approximately horizontal directions with incidence angles starting from 80 degrees.

Also, to effectively use the surface of a micromachine, SANYO formed a photovoltaic device on a flexible substrate so that it could be mounted on any curved surface, and succeeded in mounting it on curvatures of less than 2 mm radius. By mounting these devices on an actuator, it has been demonstrated that it can be driven entirely by a photon energy supply.

Furthermore, by employing an inspection system of supposed conditions in the piping of a power station, SANYO has demonstrated that photon energy could be supplied without wiring and micromachines could be controlled by optical communication.



High voltage photovoltaic microdevice



Actuator driven by photon energy

In-pipe Micro Inspection Machine

NIPPONDENSO CO., LTD.

We are conducting R&D into: in-pipe locomotive micromechanism, ultrasonic devices for environment recognition, microwave energy transmission systems, and the processing technology common to all of these items.

In the in-pipe locomotive micromechanism field, we have developed an inching device capable of moving backwards and forwards inside a bent pipe and a micro-inspection machine mounted with two eddy current sensors capable of detecting cracks as much as several micrometers wide. To realize a high grade locomotive mechanism for branch pipes, we have also developed a bending and expanding motion actuator, produced by multi-layered piezoelectric unimorphs with electrodes divided into three sections.

For ultrasonic devices, we developed a piezoelectric composite array capable of highly effective transmission, which can get one-dimensional images by the electronic convergence and deflection of ultrasonic waves. Also developed was an ultra-high speed micromotion measuring system with the resolution of 1 nm at 30 MHz.

In the field of the microwave energy transmission systems, we developed a high-frequency and high-breakdown voltage Schottky barrier diode with a 107 GHz cut-off frequency and a 27 V breakdown voltage, which allows a piezoelectric actuator to move inside a pipe without a cable.

For common processing technology, the direct bonding of hetero materials, such as Al-Si, Al-PZT, and Cu-PZT, which was previously impossible, was achieved with a new method using hydrogen bonding. Also developed was a shell body forming technique, which involves forming 3-D ultra-thin structures with metallic materials.

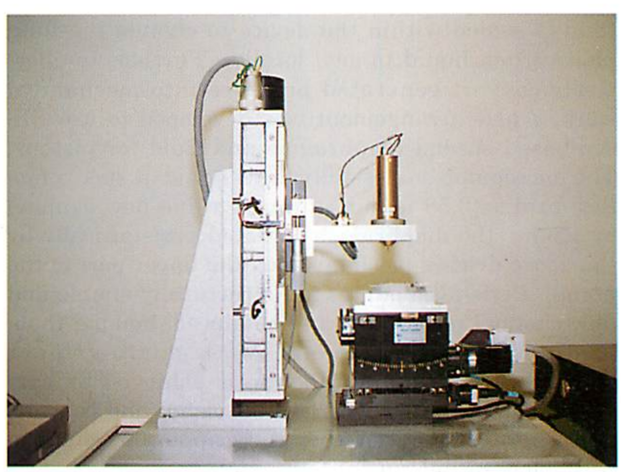
Micro Processing Technologies and Micro Piezoelectric Motor

Seiko Instruments Inc.

Seiko Instruments is researching two new micro processing technologies to create micromachines. One is electrochemical machining using a scanning tunneling microscope (STM) as a precision positioning device to perform electrochemically process in minute areas. Electrochemical etching and electrochemical plating can be performed in a solution by placing the machining probe with a submicron diameter tip close to a workpiece and applying voltage between the two. Since the system is based on STM, the shape of machined parts can be observed before and after the machining. The results so far obtained are 200-300 nm in resolution, less than 10 µW in applied energy, and 150 × 150 µm in machined area.

Another technology is micro-optical processing that involves processing photosensitive materials such as photoresists by irradiating light on very small areas employing the scanning near-field optic/atomic-force microscope (SNOAM). Since exposure is done by the evanescent light radiated from the tip of the putting probe, which is fabricated from optical fiber, by bringing the probe close to a sample surface, the resolution beyond the diffraction limit of light is possible. It has now become possible to form a 100 nm wide line using the 488 nm Ar laser.

Simultaneously, Seiko Instruments is conducting R&D into micro piezoelectric motors as a key device for micromachines. For the piezoelectric motor which theoretically will have a high torque, Seiko Instruments is examining a structure appropriate for downsizing and is also researching fabrication techniques for the batch process.



Environment Sensing Device

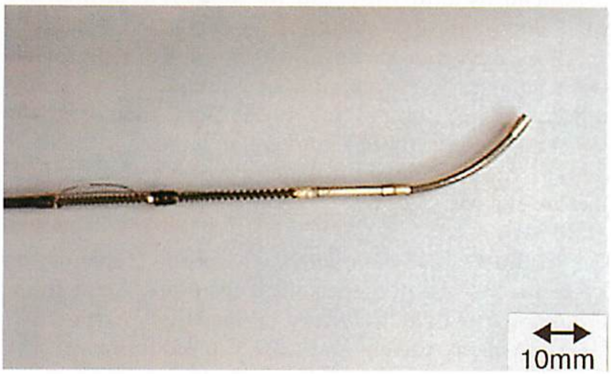
Mitsubishi Cable Industries, Ltd.

We are studying a special environment sensing device that can observe objects in the locations that cannot be observed with the existing technology. The functional target of this device is to achieve advanced function observation such as stereoscopy and flexion of the end section.

In the fiberscope research, a high numerical aperture has been achieved (reducing the pixel diameter from the existing 3.7 μm to 2.8 μm) by maximizing the difference of the refractive index between the core and clad. As a result of optimization of the preform fabricating process and research into the high density light transmission technology, we succeeded in development of the fine image fiberscope of outer diameter 0.2 mm (with lighting function, 2000 pixels, resolution 80 μm), which is the thinnest in the world.

In the research of a shape memory alloy (SMA) micro coil actuator, we have succeeded in the fabricating of a coil spring of minimum outer diameter 76 μm. Since a coil spring is used for this actuator, a large displacement, high control performance, and flexibility can be expected. In addition, because of its large output power per unit cross section and reduction of heat capacity due to micronization, the response has been improved. As a flexible actuator that performs expansion-contraction operation by heating and cooling, this device will be suitable for a micro mechanism that enables free curvature operations for the end of the cabled micromachine with the built-in fiberscope described above. We also have designed and produced a tip-articulation structure of outer diameter 2 mm that incorporates an image fiberscope of outer diameter 0.4 mm. In the operation test, the specified curvature operation and clear images that follow as a result could be obtained. The photograph shows the tip-articulation operation of this structure.

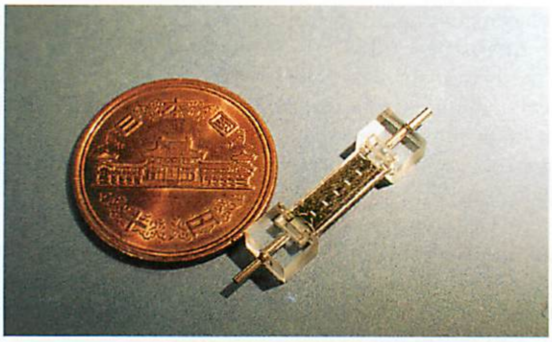
In the future, an environment sensing device that can observe objects with less dead angles in the narrow areas would be achieved the future by developing this technology further.

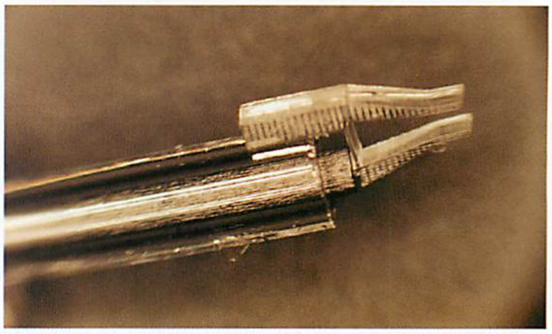


Light Driven Micro Devices

AISIN COSMOS R&D CO., LTD.

AISIN COSMOS is researching micropumps and microgrippers powered by light as the driving energy. In researching micropumps, it adopted a driving mechanism by converting light energy into thermal energy using a light absorber placed within the device to increase the internal pressure of the device and provide it with power. Also, to effectively obtain high pressure in a short time, a low-boiling-point working fluid is sealed within the device to change the fluid phase (from liquid to gas) locally. Further, to effectively convert generated pressure into mechanical work, a new arrangement was developed to use silicon-based special diaphragms and fluid for pistons. The micropump successfully feeds liquid at such a fine flow rate as 0.58 μl/min, through a fine flow channel by having the diaphragms operated peristaltically by the above driving mechanism on the upper part of the pump. Peristaltic pumps are structurally simple and flow channel resistance can be reduced, making them useful for micronization. With micro-gripper research, the gripping function is achieved by harnessing shaft output with a fluid piston and converting it into gripping force by the gripping mechanism with a low spring constant bias spring.





Photoelectric Generator and Booster System for Micromachines

TERUMO Corporation

By attempting to supply electric signals or electrical power to a micromachine by wire, rigidity or weight of the wire may interrupt the movement of a micromachine. To overcome this problem, TERUMO developed a wireless photoelectric generator and booster system for energy supply to the micromachines.

This system incorporates a photocell that converts light into electricity and a micro transformer that boosts the output of the photocell. While there exist some different size and specifications depending on applications, the photocell with the light receiving area of 0.5 mm × 0.5 mm (Photo 1), which is capable of supplying enough power to drive a commercially available DC motor in the size of 20 mm in diameter and 30 mm in length. Further the photocell mounted on a bottom of millimeter size DC motor (4 mm in diameter, 12 mm in length) can drive the motor by laser irradiation without wiring, as shown in Photo 2.

The microtransformer consists of four folded planer coils and a soft magnetic material core outside the coil to improve efficiency. A 64-turn coil set in total of the primary and secondary sides is provided for the microtransformer in the 2.9 mm × 1.9 mm area. The voltage increase of 1.2 times greater is accomplished.

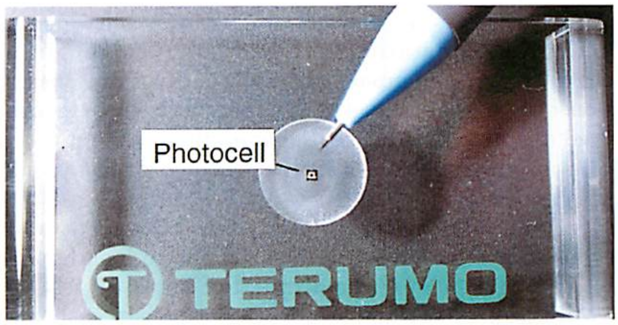


Photo 1 Fabricated miniature photocell (light receiving area: 0.5 mm × 0 .5 mm)

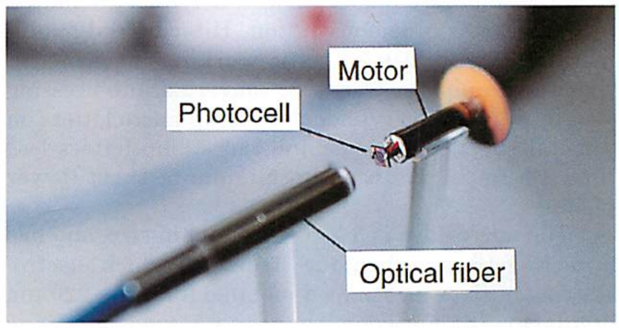
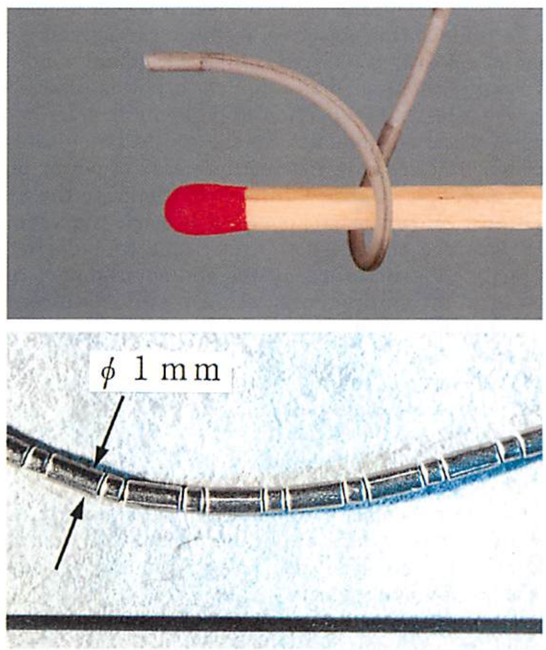


Photo 2 A photocell is mounted on the bottom of a DC motor to drive it by optical energy supply.

Tubular Manipulator

OLYMPUS OPTICAL CO., LTD.

OLYMPUS OPTICAL has conducted R&D into: microactuators, such as shape memory alloy (SMA) and chemomechanical gel, with large displacement and high power output; integration technology including multi-function integrated film (MIF) for actuators, sensors and control elements; processing and assembling technologies, such as metal injection molding (MIM) and micro mold surface finishing technology, for 3-D micro structures; and control technology for microactuators and tubular manipulators. These technologies are designed to realize a tubular manipulator that performs the access function (arm) of the cabled operation module in narrow piping. The tubular manipulator exhibited here is 1 mm in outer diameter, has 5 degrees of freedom longitudinally, is hollow inside through which optical fiber or wire can be passed, and curvature is controlled by an MIF attached to an SMA plate. As an element technology for obtaining tubular structures, a ball-joint-type structure prepared by MIM is also exhibited. This is also 1 mm in outer diameter and formed by a single process that requires no special assembling.



Microfluid Operation Device

Hitachi, Ltd.

Hitachi has developed a high-power micropump and an electrostatically driven microvalve. In a microfactory, a compact but high-power fluid operation device is required to undertake high-pressure fluid operations, such as supplying fluid at high pressure and high rates and driving heavy load pressing devices.

The newly developed micropump (upper photo at right) is 7 mm in diameter and 7.5 mm in length, and has a high power and high flow rate of 1 MPa hydraulic pressure and 2 ml/min flow rate, respectively. This pump features a trochoid gear rotary drive incorporating a screw seal and bearing, and high precision assembly using a surface activation bonding technique. As a demonstration, Hitachi trial-manufactured a miniature plastic working machine, in which hydraulic pressure was converted into pressing load by a hydraulic cylinder, to stamp micro letters on a metal sheet. This machine can stamp letters less than 10 μm in width on an aluminum sheet (lower photo).

The microvalve is 5 × 5 × 1.4 mm in size, and has a micro-actuator of unique structure, which electrostatically drives a S-shaped metallic film. Its 220 μm displacement between open and closed positions reduces pressure loss in fluid operation.

Maintenance Systems for Power Plants

JAPAN POWER ENGINEERING AND INSPECTION CORPORATION

Our objective is to clarify the course of development of advanced maintenance systems to which micromachine technologies might be applied, in future power plants, by studying on the concept of maintenance micromachines based on the needs of electric power industries.

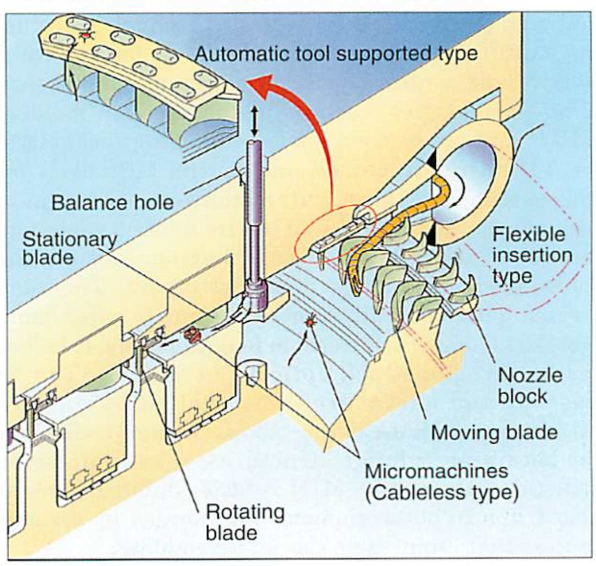
To achieve this objective, we have carried out a wide range of investigations regarding the actual conditions and requirements of maintenance in power plants, concentrating on the inspection and repair in narrow portions of plant equipments considered to be suitable for micromachines. Since the requirements of power plants were various, it was very difficult to integrate the micromachine's concept corresponding to each requirement. Therefore, we classified the functions considering the similarity on structural features and environment conditions of plant equipments. As a result, maintenance micromachines were selected for the following five types of objects.

(1) Outside of capillary bundle
(2) Inside of equipments
(3) Under-water structures
(4) Outside of tube bundle
(5) Inside of tubes

Moreover, we selected some typical equipments and parts from the various applicable objects and examined the functions and the concept of micromachines required in each maintenance work.

The figure shows the concept of a micromachine for inspecting the inside of a steam turbine as one of typical examples.

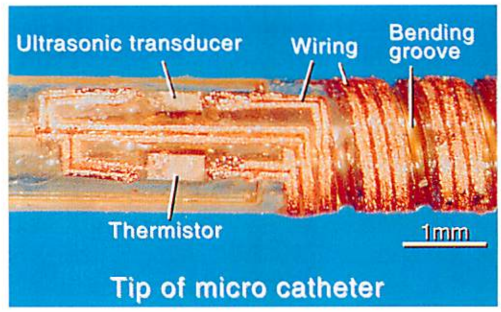
It is necessary to further examine and clarify the application objects and specifications while considering the progress of the maintenance technologies in power plants and of micromachine technologies to apply the micromachines to practical maintenance work in the future.



Micro Laser Catheter

TERUMO Corporation

We are developing a micro catheter that is an installation host of a diagnosis sensor and micro laser as a therapy means in order to develop micro laser catheter used to achieve accurate diagnosis and safe therapy in the micro region deep within a human body without the need for surgical operation. In the micro catheter, we are tackling micro process technology development for polymer materials in order to install multiple sensors on a catheter that are required for diagnosis. Micro wiring and sensor installation ports were formed on the outer wall of the catheter using excimer laser and ion assisted vapor deposition method and a catheter with two sensors installed were created as a model as shown in the figure. We are also proposing and developing a laser of new structure in which a laser oscillation section is set at the top end of optical fiber in order to radiate near-infrared laser that cannot be transmitted easily through a normal optical fiber.

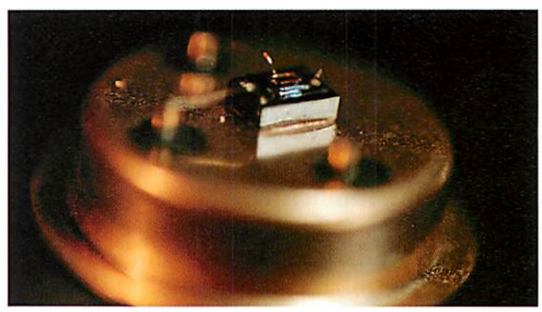


Optical Tactile Sensor

OLYMPUS OPTICAL CO., LTD.

Anyone who has received an inspection by an endoscope must know that to insert an endoscope into a body, an experienced doctor must operate the endoscope based on the visual and tactile information transmitted via the endoscope itself. However, if an extremely fine and flexible catheter for brain blood vessel can be made available for use in the future, insertion may become difficult because the operator may not have sufficient tactile information through such catheter.

Therefore, it is important to develop a system that facilitates insert operation by installing a sensor that detects contacts at the end of the catheter. The "Optical Tactile Sensor" shown in the photograph is being developed as a part of the system. This sensor incorporates a micro interferometer that uses surface emitting laser, detects the deformation amount of the sensor itself when an external force is applied and converts it to an electrical signal. Since the sensor is compact, highly sensitive, and has a high electromagnetic noise resistance, the sensor is suitable for multi-function micro catheters that uses a micromachine technology.



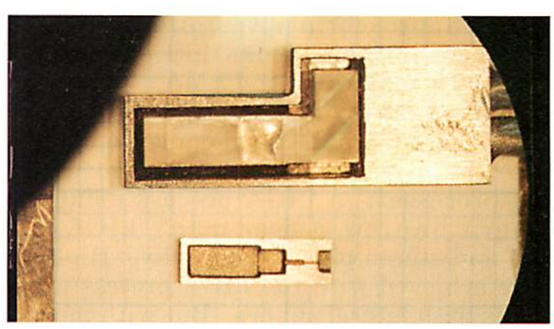
Micro Blood Pressure/Blood Flow Sensor

OMRON Corporation

We are developing a micro blood pressure/blood flow sensor for monitoring the conditions at cerebral diagnosis, treatment and checking treatment effects.

On pressure sensing technology, a design guideline of the sensor structure, mainly photo-elastic type, in which process and assembly errors have minimum influence on the sensitivity instability was proposed. Photo-elastic sensor is quite safe, can be used concurrently with other diagnosis/treatment devices, is compact, and can be easily attached to outside of a catheter. A model sensor produced based on the guideline has been exhibited and demonstration of pressure sensing was provided.

On flow velocity sensing technology, we tackled integration of a pressure sensor and a flow velocity sensor for reducing of space of the entire sensor. We showed a concept of a pressure/flow velocity composite sensor based on the following two points; idea of sensor peripheral shape in order to emphasize the flow velocity dependent information that is detected on the pressure sensor and signal processing technique for fetching a flow velocity component from the change of the pressure signal that was obtained. We exhibited a fluid simulation model for examination of the concept.



Interview with Prof. Daniel Hauden from France

Prof. Daniel Hauden who is a director of the Institute of Microtechniques of Franche-Comte (IMFC), Centre National de la Recherche Scientifique (CNRS), took part in the first International Micromachine Symposium at the Science Museum in Tokyo as a member of the advisory board. We had an opportunity to interview him regarding current micromachine research in France.

Prof. Daniel Hauden

Q: *Could you tell us something about your institute ?*
A: With LETI-CEA and LAAS-CNRS, my institute, IMFC-CNRS in Besancon is one of the largest French institutes working in the micromachine domain. IMFC is a joint project of four-CNRS laboratories. They have been researching optics, mechanics, electronics, computer science, flexible manufacturing, control systems, etc. At present, 130 scientists including 45 Ph.D. students are conducting a variety of research into micromachines concerning 15 major projects.

Q: *What kind of research concerning micromachine technology is being carried out at your institute?*
A: IMFC is researching two very promising domains of micromachines: microsystems and nanotechnology. The microsystems domain includes materials for microsystems, 2-D and 3-D technologies, microcomponents, and engineering for microsystems. And in nanotechnology domain, topics include the interferometer high-precision measurement system, the opto-mechanical measurement system, and near-field microscopes. Applied fields of research are in telecommunications, microassembly, microrobotics, medicine, sensors, etc.

Q: *Would you please let us know about the material technologies and fabrication technologies being developed at your institute?*
A: One approach is the mechanical characterization of material properties in small scale. Another approach involves intelligent and/or smart materials, e.g., bulk, thick- and thin-film piezoelectric materials, and SMA. We've started researching on laying thin film SMA on Si or SiO_2. It is fabricated by chemical etching and sputtering methods. We are also researching three processes: a LIGA process using X-ray with synchrotron, a poor man's LIGA, and a micro and stereo photolithography. High precision is achieved with the LIGA process for components with lateral shapes. But with micro and stereo photolithography, more complicated, 3-dimensional structures can be fabricated. In our laboratory, the resolution of micro and stereo photolithography is about 12 μm. Modules of actuators for microrobots were fabricated and linked.

Q: *How is your institute financed?*
A: If wages are excluded, 50% comes from the government, and the other from industrial grants.

Q: *How do you feel about research activities on micromachines in Japan?*
A: We have a very good relationship with Japanese institutes. One and a half years ago, we opened a new branch in the Institute of Industrial Science, The University of Tokyo. Five scientists from CNRS and students are studying there. Also, after two official missions for the evaluation of micromachines in Japan, I have learnt the pragmatic approach of the micromachine program developed by Japanese industry. Originality is based on the combination of innovative products made jointly with standard machining and new technologies. That is the axis we try to promote also in France and especially in Besancon with the CETEHOR (Technical Center for Watch and Clock Industry).

Q: *Could you tell us your outlook about micromachine technology?*
A: In the sensor domain, I think there is a large market for applications in automobiles, in environmental surveys, and in disposable medical microsystems. More generally, micromachines can find markets in control systems such as NDT (Non-Destructive Testing evaluation) for nuclear power plants, chemical reactors, medical telediagnostics, teleoperations, and space applications.

(MMC, Editorial Staff; Takashi Kurahashi)

Micromachine Technology (VIII)

Device Technology

Up to the previous documents, the fabrication technologies for micromachines and the science and engineering that support the technologies were mainly discussed. This document discusses a micro actuator as a functional device that has been manufactured using such technologies.

Micro Actuator

Including vacuum cleaners and video equipments, many familiar devices use electromagnetic actuators (electromagnetic motors). This is because an electromagnetic motor is extremely superior in terms of the energy conversion efficiency, controllability, and a wide use.

A micromachine also requires an actuator, however, if the size is reduced, the superiority of the electromagnetic motor may not be recognized. Therefore, micro actuators that use various physical or chemical actions are being studied. Table 1 shows the features and utilization modes of micro actuators.

Several of methods are available for using electrostatic force. One of the method is to arrange mutually insulated electrodes on inner surface of a cylinder and place a rotor within the cylinder via an insulation layer as shown in Fig. 1. When impression of positive charge is switched from A1 electrode to A2 electrode, negative charge is collected in the local section of the rotor opposite to A2, electrostatic attraction force is generated between them, and the rotor rotates in the direction of the arrow. Fig. 2

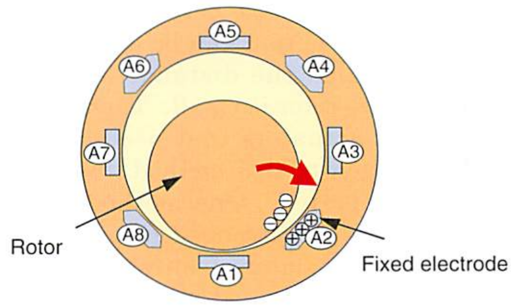


Fig. 1 Example of Using Electrostatic Force

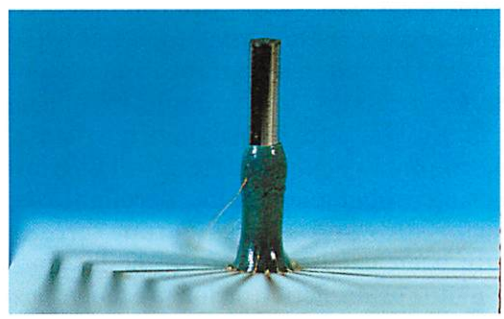


Fig. 2 Electrostatic Wobble Motor (Provided by MATSUSHITA RESEARCH INSTITUTE TOKYO, INC.)

Table 1 Major Types of Micro Actuators

Principle	Features and utilization mode
Electrostatic force	Surface force can be used effectively by micronization. A high precision is required. Film type, wobble type, rotary type, rectilinear motion type.
Piezoelectric effect	A large force can be obtained and response characteristic is excellent. Displacement is small and hysteresis is comparatively large. Laminated type, bimorph type, ultrasonic motor.
Shape memory effect	The response characteristic is improved by micronization. A large force can be obtained. Coil type, thin-film type, structure/actuator integrated type.
Electromagnetic force	High efficiency and flexibility can be expected for a comparatively large size. Rotary type, rectilinear motion type.
Gas/liquid phase change	The response characteristic is improved by micronization. Diaphragm type.
Thermal expansion	The response characteristic is improved by micronization and a large force can be obtained. Bimorph type.

shows an example of a rotary electrostatic motor using this method. The rotor of diameter about 1 mm performs circular motion of an extremely small radius by rolling on inner surface of the cylinder in which the fixed electrodes has been arranged. In this case, the magnitude of the electrostatic attraction force between the electrode and rotor is proportional to the product of charges of both and is inversely proportional to the square of the distance between the surfaces. Therefore, a large output can be obtained in the structure in which the distance between the electrode and the rotor is small. There are many types of micro actuators that use electrostatic force. In addition to this method, the following methods are reported. One method is that in which electrodes are arranged near the surface of a film-shape insulator at an extremely small spacing and a film-shaped moving part set on the top is driven. Another method is that movable segments and fixed electrodes, both having the same comb-like shape, are combined and the movable segments that are supported by several springs are driven in a reciprocating motion.

Some ceramics, for example PZT [composition: $Pb(Zr,Ti)O_3$], extends slightly when a voltage is applied (piezoelectric effect). Since the piezoelectric phenomenon has excellent response characteristics and a large output force, it has already been used as an actuator for an ultrasonic motor or an actuator for precision positioning. In the example shown in Fig. 3, three legs are driven by PZT to move the micromachine (in the photograph, the cover is removed) inside of a fine tube.

Some materials have a characteristic to recover the original shape memorized at higher temperature by heating the materials up to the temperature at which the crystal structure changes even if the shape has been deformed at a lower temperature (shape memory effect). In addition, the materials have a characteristic such that the Young's modulus (elastic rigidity) is small and the yield strength (strength at which plastic deformation starts to happen) is low in comparison to the higher temperature case. A material that has these two characteristics can be used as an actuator. Fig. 4 shows an example in which TiNi alloy, typical shape memory alloy (SMA), is processed into an extremely fine wire and is used as a micro actuator of 100 μm (O.D.). Using two or more actuators of this type, various micro mechanisms can be operated. The results of manufacturing SMA thin-film micro actuators by the Si process have also been reported.

As a micro actuator that uses a phase change between a gaseous phase and a liquid phase, a type that vaporizes liquid sealed within a micro diaphragm by heating and fetches the force and

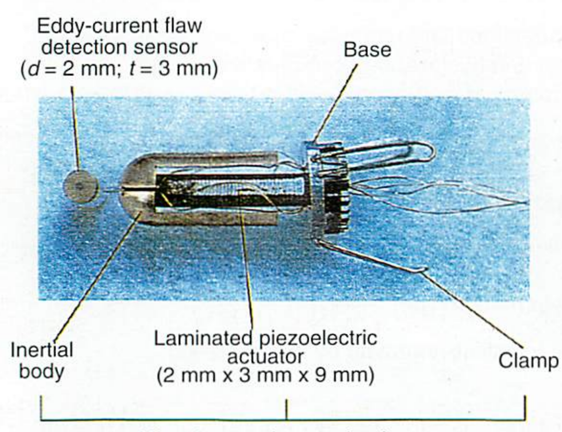


Fig. 3 Actuator for In-Pipe Traveling Micromachine (Provided by NIPPONDENSO CO., LTD.)

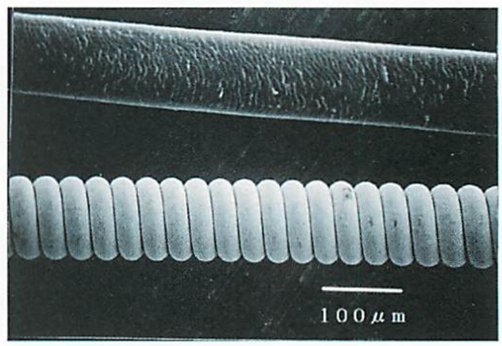


Fig. 4 SMA Micro Coil (Provided by Mitsubishi Cable Industries, Ltd.)

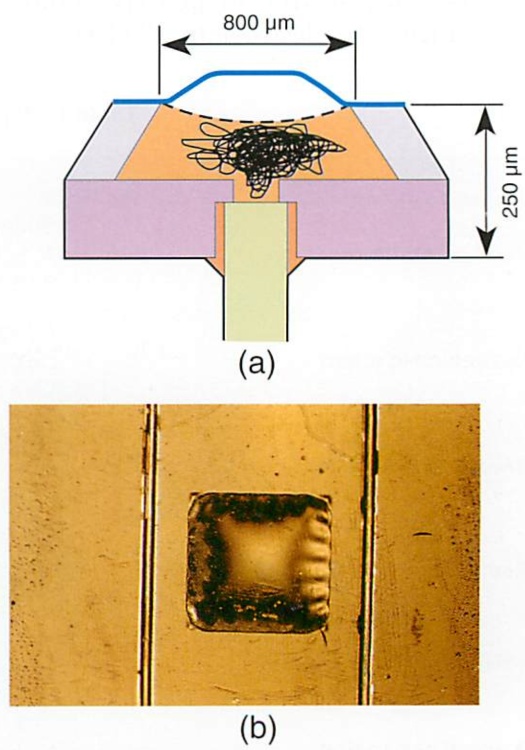


Fig. 5 Light Driven Micro Actuator (Provided by AISIN COSMOS R&D CO., LTD.)

displacement from the diaphragm is manufactured. The example in Fig. 5 uses the method in which CFC (chlorofluorocarbon) is sealed in the micro diaphragm that was manufactured by the Si process and heated by a laser beam. As a practical device that uses a gas/liquid phase change, an ink-jet printer head is available.

Most of the actuators that are incorporated in information communication devices are micro motors that use the electromagnetic force. For a micro actuator that uses the electromagnetic force, the fabrication method of a micro stator produced by forming a spiral micro coils on a flat plate and laminating them to achieve a high density is being studied.

Research is also being carried out for a micro actuator that uses a combination of two materials with largely different thermal expansion coefficients, PLZT (material produced by adding La to PZT) with opto-strictive effects, phase transition of high molecular gel by solvent, and so forth. Since a micro actuator that can be used over a wide range of purposes has not yet been discovered, various actuator (or its principle) must be put to proper use according to the purpose suitable for its feature. A micro device that integrates an actuator and mechanism would become popular in the future.

★ TOPICS

International Conference on Precision Engineering '95

The International Conference on Precision Engineering '95 was held for four days from November 21, 1995 in Singapore. Mr. Toshiyoshi Okazaki, General Manager, the Micromachine Center's (MMC) International Exchange Department was invited and gave the keynote address: "R&D and Future Prospects for Micromachine Technology in Japan."

The conference was sponsored jointly by the Japan Society of Precision Engineering and the Gintic Institute of Manufacturing Technology, a research institute of Nanyang Technological University, Singapore. It was held as part of Manufacturing Asia '95, which included five exhibitions of metal processing, welding techniques and others, along with the Woodmac '95, an exhibition for the woodworking industry. At the opening ceremony, guest addresses were given by a minister of the Singapore government, indicating the importance of the event.

The sponsors think that precision engineering will play an important part in future industrial development in Singapore, particularly its manufacturing industry. This conference was held in recognition of the fact that the micronization of products and improvement in quality are indispensable, and that a key technology for such developments is precision engineering. At the conference, besides Mr. Okazaki, Prof. N. F. de Rooij of the University of Neuchâtel, Switzerland, gave another keynote address, describing the current status and future prospects of R&D in Switzerland and Europe.

The conference consisted of four sessions held in parallel, and 162 papers were presented, 99 of which were from Japanese researchers. Since many Japanese served as coordinators, it appeared just like a symposium conducted in Japan, though English was used as the official language. Besides Singapore, it was apparent that China is also enthusiastic about conducting R&D in the machining area.

★ TOPICS

JETRO European Seminar

MMC sent three lecturers to the micromachine-related seminars sponsored by JETRO (Japan External Trade Organization) in Stuttgart, Germany (November 28) and Milan, Italy (December 1).

At both seminars people showed great interest in micromachine technology and a large response was received particularly for MMC's activities and, the Industrial Science and Technology Frontier (ISTF) project, which coordinates a broad range of technologies.

The three lecturers and their subjects were as follows:

- "Future prospects of micromachines" by Takayuki Hirano, Executive Director, MMC
- "Current Status of Micromachine Technology in Japan" by Tadashi Hattori, Vice President, Research Laboratories, NIPPONDENSO CO., LTD.
- "Current Status of Processing and Assembling Techniques in the ISTF Project" by Tatsuaki Ataka, Manager, Research Laboratory for Advanced Technology, Seiko Instruments Inc.

About 60 people attended the Stuttgart seminar, mostly researchers and engineers from business circles. In the discussion session, questions were received about prediction of the future market and the management setup of the ISTF project. At the social gathering after the seminar, favorable evaluations were made about the development of micromachines and Japan's willingness to make public information on this topic.

Milan seminar

The Milan seminar was held to introduce Japan's future technology as a part of the Japan Festival (November-December) sponsored jointly by JETRO, the Milan Chamber of Commerce and Industry, and others. About 90 people participated in the seminar, including many students. In the discussion session, questions were asked comparing the Italian attitude with the Japanese attitude and the definition of micromachines. In the evening a reception party was held, at which the Japanese ambassador to Italy gave an address. At the exhibition held simultaneously, NIPPONDENSO's pipe inspection micromachine and microcar, and SANYO Electric's "ladybug" were presented, attracting much interest among visitors.

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