MMC Micromachine
マイクロマシン

Aug. 1998

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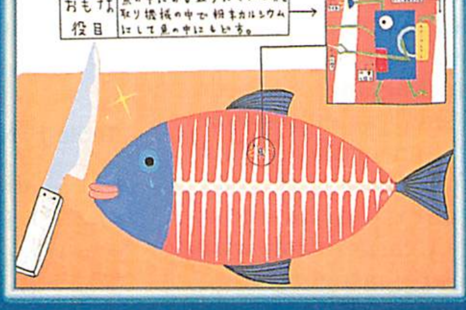

No. 24

MICROMACHINE CENTER

Essay

Piggy-Back Satellite and Micromachines

Hirofumi Miura
Professor, Kogakuin University
(Professor Emeritus, The University of Tokyo)

I have had the chance to be engaged once a week with space technology at the Tsukuba Space Center, as a guest researcher of the National Space Development Agency of Japan (NASDA). As it has been a long time since I had a real chance to confront space technology, I am having an exciting time with all kinds of stimulation. A recent notable focus in space technology, I observed, is in its respect to economics.

By this I mean that more and more private-sector appliances are in use, which was unthinkable just some years ago. Fewer people consider space development to be a mega-project. The fact that more effort is being made around the world to build smaller artificial satellites is a good example of how people are emphasizing economics. An example of a Japanese small satellite is the piggy-back satellite. The term "piggy back" is explained in the dictionary as "riding on the back" or "riding on other vehicles as when a small plane is carried by larger plane."

In short, piggy-back satellites are small satellites launched with a larger satellite, to make use of the excess launching capacity. Basically, a smaller satellite is loaded in the air-space of the rocket to reduce launch expenses. In Japan, we are considering 50-kg class satellites to be loaded in the extra space of the H-II rocket, for new computer, power technology by PPT (peak power tracking) control, or high technology orbit validation experiment missions such as 3-axis attitude control technology. This is a very good idea to decrease the cost for satellite experiments.

The piggy-back satellites are not the only type of small satellite. Development of small satellites is active overseas. The SST (Surrey Satellite Technology LTD. in England) has been insisting on the potency of small satellites from the 1980s, and has already launched more than ten satellites for earth observation and the like. The German Benz Corporation has also launched small satellites in corporation with Russia. Small satellites are categorized as shown in Table 1, according to their weight. Japan has no specific definition as yet.

The miniaturization of satellites has been made possible by the miniaturization of electronics technology. Significant progress has been made on the miniaturization of home electronic appliances such as small CCD cameras, light cellular phones, portable compact disc players, etc. There once used to be a distinct difference between home appliance technology and space technology; even computers had to be one-generation-old thoroughly debugged computers. However, now, that the reliability of home appliances has remarkably improved, they can well be applied for space use. This has become the grounds for the recently thriving development of small satellites.

Small satellite development is also trying to do away with mobile parts, because the mobility of mobile parts produces reaction force that upsets the attitude control of the satellite. This also means that the visible range is narrow because there will be no scanning as by mirror reciprocation used in larger satellites. So, this can also be a chance for a micro-scanning structure adopting micromachine technology to make its debut. Wheels for attitude control are also not appreciated, with magnetic torquers used instead. Relays are also not cherished. In micromachines, mobile parts are small enough to keep the reaction force to a minimum; even an additional counterweight to cancel the reaction force can be made extremely small.

Where there are no mobile parts, it is always welcome for the satellite to be made very small. Although microelectronics triggered the miniaturization of satellites, there is no doubt that micromachine technology is pushing this trend forward.

Table 1 Names of small satellites and their weight

1	Mini-Satellite	100-500 kg
2	Micro-Satellite	10-100 kg
3	Nano-Satellite	1-10 kg
4	Pico-Satellite	< 1 kg

Department of Mechanical Engineering, Faculty of Science and Technology, Keio University

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1. Introduction

Micromachines are the center of attention as machine technology for the next generation. If this is to happen, numerous standard parts must be supplied, and methods for evaluating the accuracy of shape and dimension of the parts will also be required. Our laboratory is working on the evaluation methods for accuracy of shape and dimension of microparts.

2. Measuring principle and system configuration

Using a measurement device with the configuration shown in Fig. 1, the approach of the probe and the target can be detected by detecting the tunnel current between the probe and the conductive measurement sample. This method has several advantages; a complex device is not required to generate the tunnel current, the response to the approach of the probe is fast and measurement is possible even when the inclination of the target surface is large, unlike measurement using light.

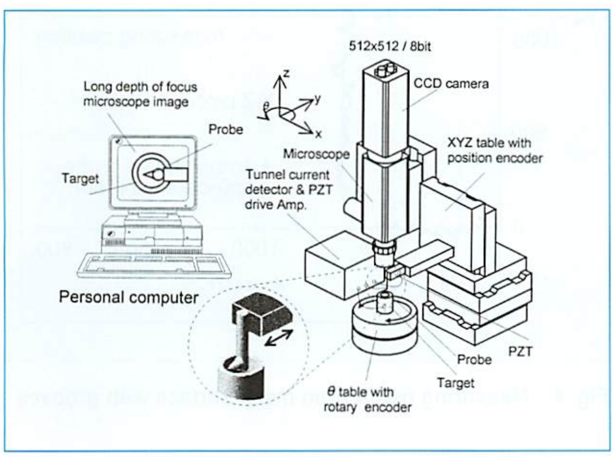


Fig. 1 Configuration of measuring system for microparts

Linear encoders incorporated in the precision mechanical stages detect the coordinates of the measuring position. A personal computer is used for controlling the precision mechanical stages and for data processing.

3. Fabrication of probes by micro electric discharge machining

Measuring shapes of various micro parts requires probes suitable for individual parts. For example, measuring the inside of a small hole, the probe must be thin enough to be inserted into the hole, and the prove must has projections to the transverse direction.

Fig. 2 shows the procedure to fabricate a probe by electric discharge machining. First, the conical tool electrode used for creating the die is made (step 1). Then, a conical hole is made in the block material, by rotating this conical tool electrode (step 2). Now, using the block die made in step 2 as the tool electrode, the probe is pressed against the machined conical hole part to transcribe the hole shape of the die and complete the probe with transverse projection (step 3). Using the conical hole machined in the same way on the top surface, and pressing the X-probe made in step 3 from the top, an X-Z probe also with a projection on the bottom surface can be created (step 4).

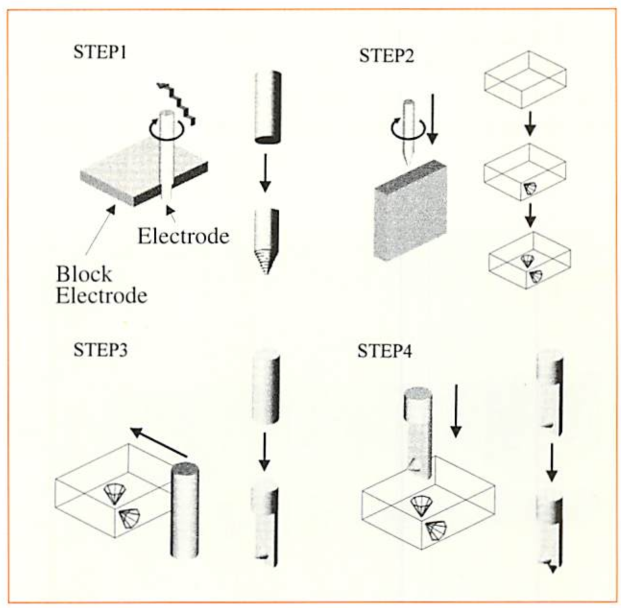


Fig. 2 Probe fabrication by electric discharge machining

Fig. 3 shows the X-Z probe experimentally made following the above four steps. We first used tungsten (the same material as the conical electrode) for the probe. However, tungsten hardly deforms elastically, the tip of the probe can easily be broken when setting the probe on the measurement device. Thus the material was changed to shape memory alloy that can withstand deformation to a considerable degree.

4. Measuring results

Fig. 4 shows the measuring result from metal surface with grooves using the X-Z probe. The sample is made of aluminum alloy engraved with 2 mm high teeth formed by electric discharge machining. Using the X-Z probe, the bottom, side, and top faces of such a sample can be continuously measured without changing the posture of the sample. Other than surface profile, the squareness between the bottom and side, and the parallelism of the bottom and top can also be evaluated.

5. Long depth of focus microscopic observation

When measuring minute parts, optical microscopes are needed to identify the measurement position or to insert the probe into thin holes. However, optical microscopes have limited depth of focus. Especially when using a high magnification objective lens to enlarge the image, the depth of focus becomes small. Thus, focusing on one point make all other parts blurred and it is impossible to view the entire image clearly. This is why an optical microscope with CCD camera is used (Fig. 1), but the insufficient focal depth requires the use of a synthesis system that composes a long focal depth microscopic image by image processing.

Fig. 5 shows an example of an observation of a small relay contact. The focused parts of the upper two and the lower left partially out-of-focus images are synthesized into the lower right clear image. Satisfactory results are obtained using long depth of focus microscopic images when inserting the probe into thin holes.

6. Conclusion

Research on micromachines in the United States and Europe is mainly focused on the silicon process, while in Japan, the research is conducted from a wider point of view, also including micromachining based of traditional mechanical machining technology. I believe the technology for compacting machines is Japan's forte. In this context, I want to struggle to develop micromeasuring technologies.

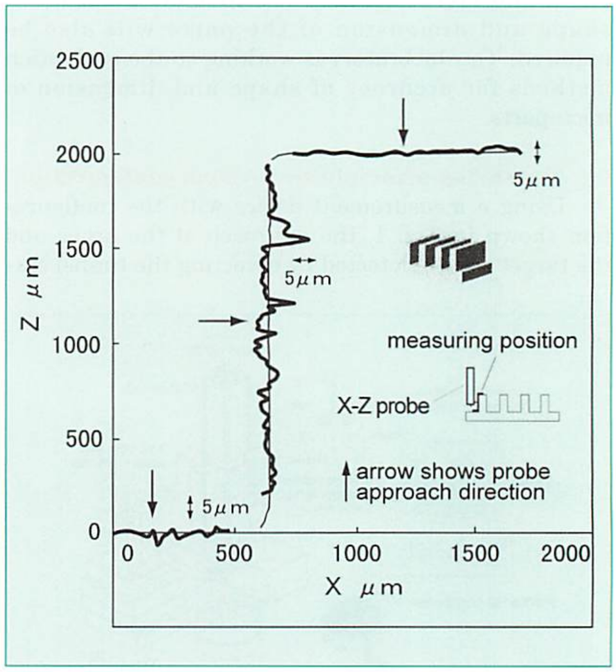


Fig. 4 Measuring result from metal surface with grooves

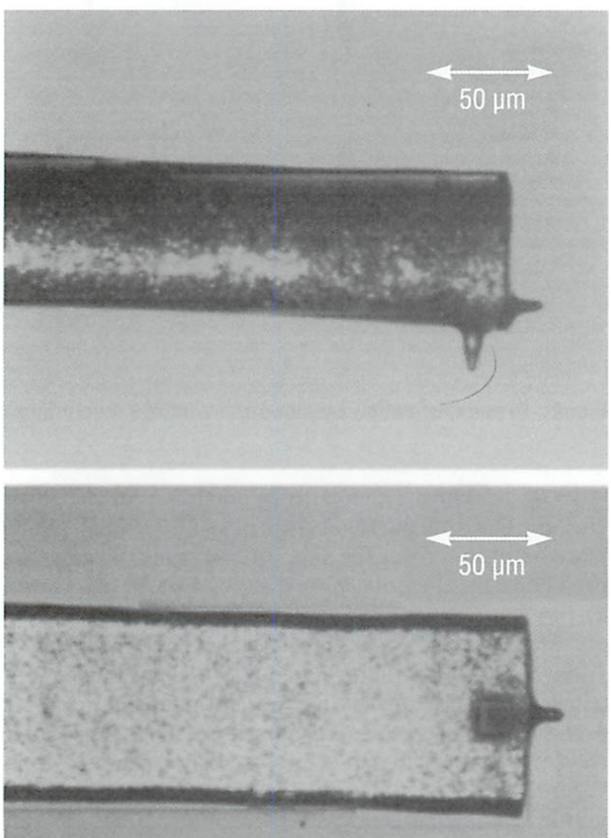


Fig. 3 Profile of prove

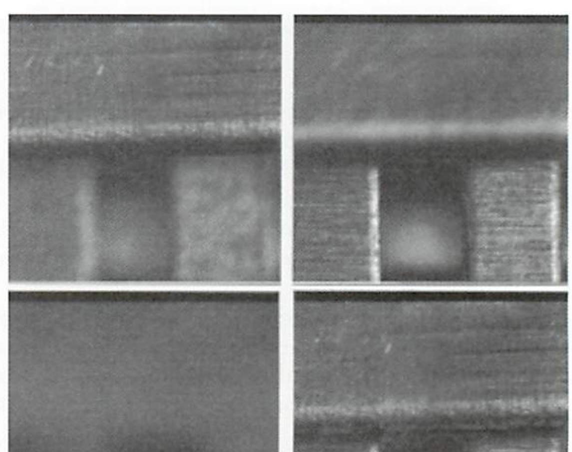


Fig. 5 Long depth of focus microscopic observation

Activities of the Micromachine Center Conducted in Fiscal 1997

I. Investigations and Research on Micromachines

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

Based on the R&D results on elemental device technology in the first phase, the ultimate objective of this project is to establish the technologies required to realize micromachine systems. Such systems include mechanical systems composed of minute functional elements that locomote within very narrow spaces within complicated equipment used at power plants and other facilities and inside the human body. Fiscal 1997 financed the following R&D themes:

(1) Research and development on advanced maintenance technologies for power plants

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

R&D of systematization technology was conducted by producing of an experimental system for a wireless micromachine. Inside a metal tube with a curved section, this micromachine will be able to move forward, backward, horizontally and vertically, stop optionally, and recognize its surroundings as well as detect defects of pipelines. R&D has also been conducted on system integration of mobile devices, energy supply and communication devices using microwave and light, micro visual devices that receive and transmit images of defects of pipelines.

② R&D of systematization technology (Chain-type micromachine for inspection on outer surfaces of tubes)

R&D of systematization technology was conducted by producing an experimental micromachine system composed of a group of single micromachines capable of combining or separating according to the form of the object to be inspected. R&D was conducted on system integration of a driving device to propel the machine, reduction and traveling devices and microconnectors for combining multiple machines.

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

R&D of systematization technology was conducted by producing of an experimental micromachine system capable of entering the equipment with complex and variable structures, and measuring or repairing minute internal flaws. R&D was conducted on system integration of flexible pipe structures with multi-degrees of freedom, manipulators for repair, attitude detection device using a small gyroscope, and optical scanner monitoring devices.

④ R&D of technologies to improve functional devices

R&D was conducted on advanced technologies including micronization of high performance, multi-functional devices that form the components necessary and have the potential to realize future micromachine systems.

R&D focused on creating artificial muscles, microjoint, low-friction suspension devices, rechargeable micro-batteries, optically driven free joint devices, etc.

⑤ R&D of common basic technologies

R&D was conducted on common basic technologies, those for the control, measurement, design, and evaluation necessary for realizing micromachine systems. R&D focused on achieving pattern-forming technology for groups of distributed micromachines, hierarchical group control technology, measuring technology for micromachines, etc.

⑥ Comprehensive investigation and research

Comprehensive investigation and research on micromachine technology was conducted including the basic design of maintenance micromachines required for maintaining future power plants, and leading investigations and research on micromachine systems expected to be used for maintenance. Joint research was also conducted with the Mechanical Engineering Laboratory of AIST on analyzing the micro-device characteristics.

(2) Development of microfactory technology

① R&D on processing and assembly technology

R&D was conducted on systematization technology by producing an experimental system for processing and assembly capable of manufacturing models of small parts by integrating processing, assembly, conveyance, and inspection machines in a limited narrow space.

R&D focused on micro processing technology, micro assembling technology, micro fluid technology, micro optical driving technology, micro electric driving technology, micro conveyance technology, and micro inspection technology.

② Comprehensive investigation and research

Comprehensive investigation and research was conducted on the influence of microfactories including problems such as electromagnetic interference caused when various devices are integrated or concentrated in a confined space, as well as on micromachine systems that will be applied in the manufacturing sector. MMC has also jointly investigated with the AIST's Mechanical Engineering Laboratory on microfactory technology, including the downsizing of production systems, the analysis of the economic efficiency of microfactories, and the structure of the future microfactory system concept.

(3) R&D on Micromachine Technology

① Research on micromachine systems

R&D was conducted on miniaturization and multi-functionality of micro-laser catheters and micro-tactile sensor catheters for the medical field. These catheters are the major functional components of micro-catheters for diagnosis and treatment of cerebral blood vessels, and intraluminal diagnostics, and therapeutic systems. Research was also conducted on creating an ultra-small liquid synthesis system that allows preparation of an extremely small amount of medication and various liquids with accuracy.

② Comprehensive investigation and research

Comprehensive investigation and research was conducted on effectively using of micromachine systems for future medical applications. Joint research was also conducted with the AIST Mechanical Engineering Laboratory on the basic design and manufacturing technologies of micromachines. International joint research was also conducted (NEDO's international joint research on bio and new materials) on production of electrode for micro electric discharge machining using LIGA by dispatching a researcher to the University of Wisconsin.

2. R&D of Materials for Micromachine (Joint research with the Mechanical Engineering Laboratory of AIST)

MMC has conducted joint research with the AIST's Mechanical Engineering Laboratory on ① operating environments for micro functional elements, ② materials for micromachine, and ③ a feasibility study on materials for micromachine.

3. Investigation and Research on Fundamental Micromachine Technology (aid activities from the Japan Motorcycle Racing Organization: Promotion of research

with industry and academia)

MMC has conducted joint research with industry and academia, exploring technology seeds of eight themes concerning micro science and technology as well as the design technology necessary to construct various micromachine systems.

4. Investigation and Research on Creating New industries with Micromachine Technologies (delegated activities by The Japan Machinery Federation)

Investigation and research were conducted to identify the main application fields for micromachine technology, while mindful of the change on the existing industrial and social structure, as well as the impact on creating of new industries.

5. Investigation and Research on Potential Applications for Micromachines in 21st Century Society (delegated activities by Mechanical Social Systems Foundation)

Investigation and research was conducted on application for the micromachine technology in society of the 21st century (25 years from now).

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

MMC has identified universities, research institutes, private enterprises that are working on micromachine-related research and investigated the researchers, research themes, research contents, research results, and research structure, to analyze and organize R&D trends.

7. Examination of Long-Term Technological Concepts

With a view to studying how MMC should promote micromachines in the 21st century, MMC has identified research and development subjects necessary for the micromachine technology to be core for creating new industries.

II. Collection and Provision of Micromachine Information

① MMC has collected and sorted periodical literature, documents, and other materials on micromachines. ② Major materials were provided to those concerned, in our periodic "Micromachine Index." ③ MMC has also provided English documents and micromachine-related event information on the Internet.

III. Exchange and Cooperation with Worldwide Organizations Involved with Micromachines

1. Research Grants for Micromachine Technology

MMC has solicited applicants for Micromachine Technology Research Grant in fiscal 1997 (5th) and has provided Research Grants for 12 themes, including eight new themes and four carried over at universities for R&D on basic micromachine technology. This was also meant as a contribution to the development of micromachine technology as well as promotion of exchange between industry and academia.

2. Participation in the 3rd Micromachine Summit

MMC participated in the "3rd Micromachine Summit" held in Vancouver, Canada, in April 1997. The conference started with the introduction of the micromachine activities in each participating country and region, followed by discussions on standardization, health care, environments, new prospects and new materials, transportation, and information technology.

3. European Seminar and Japan-Switzerland Seminar

In June 1997, MMC held the "European Seminar" in Finland, Denmark and France, jointly with local research institutions, aiming at technological exchange with industry. The "Japan-Switzerland Seminar" was held with the assistance of JETRO (Japan External Trade Organization), in February, 1998 at Interlaken, Switzerland, for technological exchange between the two countries.

4. Sino-Japanese Joint Micromachine Workshop with Tsuinghua University, China

The "Sino-Japanese Joint Micromachine Workshop" was held in September 1997 at Tsuinghua University in Beijing, China, under joint sponsorship of the MMC and Tsuinghua University.

5. The 3rd International Micromachine Symposium

The 3rd International Micromachine Symposium was held in October 1997 at Tokyo Science Hall, under the theme of "The basis of science and technology in the primary era of micromachines," jointly sponsored by the MMC and Japan Industrial Technology Association. This symposium presented the results of micromachine research and development as well as applications in each participating country, followed by discussions by Japanese and overseas academics and experts related to the Industrial Science and Technology Frontier Program of the Agency of Industrial Science and Technology, which is in the second year of phase II.

6. MEMS 98 Participation

MMC participated in the MEMS 98 held in Heidelberg, Germany, in January 1998. MMC's investigation mission was also dispatched to Europe.

IV. Standardization of Micromachines (Commissioned in part by The Japan Machinery Federation)

As carried over from fiscal 1996, MMC has collected 220 technical terms necessary to standardize micromachine technology, translated 117 terms into English, and made a Japanese-English dictionary. With regard to measurement and evaluation issues, MMC has restudied the existing data up to fiscal 1996, and conducted further investigations. The method for measuring and evaluating material characteristics was also investigated in comparison with the current JIS standard. The first "Micromachine Standardization International Workshop Tokyo '97" was also held, and a common consensus for future development was reached among the participants.

V. Dissemination of Information on and Education about Micromachines

1. Public Relations Magazines

MMC published four public relations magazines, respectively in English and Japanese.

2. Micromachine drawing contest

MMC held the "4th Micromachine Drawing Contest" with the assistance of MMC's supporting members. Five elementary schools and junior high schools in Chiyoda-cho (Ibaraki Prefecture), Akashi City (Hyogo Prefecture), and Iimori-cho (Nagasaki Prefecture) sent us 411 pictures. MMC selected 14 pictures for awards.

3. Portable Exhibits

MMC created "Micromachine Portable Exhibits" with the cooperation of MMC's supporting members, to promote wide understanding of our result in the Industrial Science and Technology Program of AIST. Five exhibits were made, compared to four in the previous fiscal year.

4. Introductory and Promotional Video

MMC created a video that summarized the latest results of the Industrial Science and Technology Program of AIST.

5. Domestic Micromachine Seminars

MMC held "Domestic Micromachine Seminars" for people interested in R&D on micromachine technology, in September 1997 (Toyama), and January 1998 (Naha).

6. 8th Micromachine Exhibition

MMC held the "8th Micromachine Exhibition" in October 1997 at the Science Museum in Tokyo. There were 70 enterprises, universities, and organization participating, with 3300 visitors attending over the three days of the exhibition.

Summary of the Research Supported by the Fourth Micromachine Technology Research Grant

Micromachine Center (MMC) is promoting the research and development of national project "Micromachine Technologies," one of the Industrial Science and Technology Frontier Program of Agency of Industrial Science and Technology, Ministry of International Trade and Industry (MITI), entrusted by New Energy and Industrial Technology Development Organization (NEDO). At the same time, MMC is conducting an independent activities to promote R&D and its diffusion of micromachine technology.

The titled research grant program started invitation in 1993 as a part of the independent activities of MMC, intended to assist college and university staff engaged in basic research on micromachines, as well as to promote further development of micromachine technology and communication between academics and people in the industrial world.

Among themes selected for the fourth (1996) research grant, one 1-year research and five 2-year researches carried over from fiscal 1995 have completed. Turn the pages for the summary of the research results.

• Carried-Over Projects Selected for Fiscal 1995

Leader & Co-Worker	Affiliation	Subjects	Period
Naoe Hosoda	Research Associate, Research Center for Advanced Science and Technology, The University of Tokyo	Reversible micro bonding	2 Years
Koji Ikuta	Professor, School of Engineering, Nagoya University	Micro integrated fluid system using micro photoforming process	2 Years
Haruma Kawaguchi	Professor, Faculty of Science and Engineering, Keio University	Development of functions in polymer microsphere having on-off function	2 Years
Susumu Sugiyama	Professor, Faculty of Science and Engineering, Ritsumeikan University	Distributed microactuator using high aspect X-ray lithography	2 Years
Kahoru Torii Koichi Nishino	Professor Associate Professor Faculty of Engineering, Yokohama National University	Development of three-dimensional measurement technology for micro flow	2 Years
Takeshi Nakada	Professor, College of Engineering, Tokyo Denki University	Optical microactuator using ER fluid	2 Years

• Research Project Selected for Fiscal 1996

Leader & Co-Worker	Affiliation	Subjects	Period
Hisayuki Aoyama Akira Sasaki	Associate Professor, Deoartment of Mechanical & Control Engineering, University of Electro-Communications Professor, Faculty of Engineering, Shizuoka University	Development of micro devices by miniature robots	1 Year
Kazuyuki Minami	Assistant Professor, Graduate School of Engineering, Tohoku University	Fabrication of flexible tube actuator by using laser machining	1 Year
Katsushi Furutani Naotake Mohri	Associate Professor Professor Graduate School of Engineering, Toyota Technological Institute	Monitoring of piezoelectric element by using induced charge	1 Year

An Application Guidelines for the 6th (Fiscal 1998) Research Grant Theme on Micromachine Technology

1. Object of the research grant
Basic research on basic technology, functional element technology and systematization technology of micromachines.

2 Research period
Theme A: April, 1999 - March 31, 2000, or
Theme B: April, 1999 - March 31, 2001

3. Application period, theme decision and fund grant date
Application period: July 1 - October 31, 1998
Theme decision: Early in March, 1999
Fund grant date: Late in March, 1999

4. How to apply
Send a fax request for the application form to Micromachine Center, with your fax number specified.
Fax: +81-3-5294-7137

5. Qualification
College or university faculties (professors, associate professors, lecturers and research associates) who belong to the academic societies which are affiliated with Federation of Micromachine Technology

6. Others
(1) Total fund granted: about 15 million yen
(The limit for a single research is 2 million yen for theme A and 3 million yen for theme B.)
(2) We may ask the grant receivers to carry out the researches in cooperation with supporting member enterprises of the Micromachine Center after the grant is decided, since one of the objectives of this project is to encourage communication between enterprises and academies.
(3) Reference: Research Department, Micromachine Center (persons in charge: Hodono)

Reversible Micro Bonding

Naoe Hosoda
Research Associate, Research Center for Advanced Science and Technology, The University of Tokyo

The global destruction of the environment is a serious issue of our contemporary world. The earth's environment has maintained its stability by circulation in a closed system, but this balance was greatly disturbed by the large-scale industrial activities humans started, making the circulation function effective no more. The reason why we have brought about such a remarkable situation is because we lacked an awareness of circulation of matter throughout our industrial activities. Our production has drained resources, deteriorated the environment, increased waste, etc. Now, what would the environmental issue for the micro-world of micromachine technology be like? Design and development in the micro-world is mostly the same as the normal world, and done without consideration of circulation of matter. Speaking from an environmental conservation point of view, development of assembly technology incorporating recycling at the parts and material level is very important also for micromachines.

This research proposes the incorporation of reversible interconnection technology into the micromachine assembly. This is an important element technology for the design of circulation type manufacturing.

The method I propose here, is technology to bond dissimilar materials at low temperature, and separate them at the boundary face using hydrogen. Separation is done by inserting a hydrogen storage alloy that expands by absorbing hydrogen and micronizes, at the insertion layer in advance (Fig. 1).

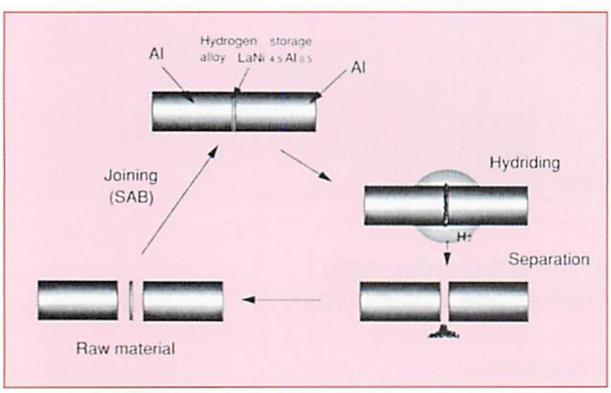
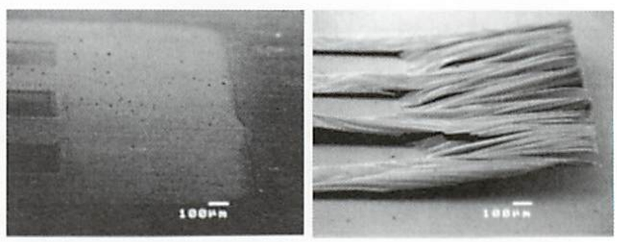


Fig. 1 Reversible micro-bonding using hydrogen storage alloy

The bonded body will separate when the inserted hydrogen absorption alloy micronizes, so the hydrogen storage alloy and the bonded materials can be reused without repeating the smelting process. The hydrogen used for separation can also be collected and reused. I used the $LaNi_{4.5}Al_{0.5}$ hydrogen storage alloy for the experiment. As formation of the reaction layer is undesirable for reversible microbonding at the bonding face, bonding is best done at low temperature to allow separation at the bonding face, I tried the room temperature bonding method (SAB) that uses surface activating.

I irradiated an argon fast atomic beam onto the surface of the bonding material in vacuum, observed the change of elements in impurities on the surface by Auger electron spectroscopy, and investigated the relationship between the bonding strength and the surface elements. The result showed that the adhesion increased, as the surface impurity elements decreased. The $LaNi_{4.5}Al_{0.5}$ can be bonded with Al and solder at room temperature, and has satisfactory strength.

The separation experiment was done by exposing the bonded sample to 3 MPa hydrogen gas. The alloy micronized at about 1 μm, and spalled from the boundary face. When Cu and a 1 μm-thick $LaNi_{4.5}Al_{0.5}$ alloy thin film multi-layer was used, exposure to hydrogen caused the thin film to expand and peel off the substrate in the original form of thin film (Fig. 2). The minimum micronization size and the



Before hydrogen exposure　　After hydrogen exposure

Fig. 2 Separation of $Cu/LaNi_{4.5}Al_{0.5}$ film from Cu substrate using hydrogen

internal distortion caused by hydrogen absorption is considered to have a correlation; the thin film seemingly did not micronize because enough stress could not be accumulated with a thickness of 1 μm, and that the hydrogen absorption of the thin film is normally small compared to the substrate. Thus, bonding using hydrogen storage alloy can be separated at the boundary face, though the thickness of the alloy determines the form of peeling. Separation experiments were repeated with alloy thin film areas of 0.16 to 25 mm^2, and hydrogen peeling was observed even on very small areas.

This research was conducted to reconsider the design of micromachines which have high potential for recycling, and to propose a whole new bonding technology designed with consideration of separation at the bonding surface of composite materials. Using hydrogen as the micromachine separation agent entertains expectations for separating composite fine bonding sections all over the micromachine with a single action. Reversible microbonding has definite expectations for becoming new method that contributes to circulative micromachine manufacturing technology.

Micro Integrated Fluid System Using Micro Photoforming Process

Koji Ikuta
Professor, Department of Micro System Engineering,
School of Engineering, Nagoya University

1. Chemical IC chip

There are great demand for the micronization of chemical devices for analyzing and synthesizing in the medical, biotechnology and biochemistry fields.

We have been proposing and conducting the development of the micro integrated fluid system (MIFS) since 1993.

The basic concept of MIFS is its use of a micro stereo lithography process (IH process) that allows sequential curing of the photopolymerizing polymer on the substrate including sensors and arithmetic circuits created by silicon processing to fabricate micron-scale structure of arbitrary form, and to form a monolithic three-dimensional fluid circuit.

This process has the potential to go beyond the limits of fluid systems created by conventional silicon processes. The recently developed chemical IC that expands the MIFS concept to a more general chemical reaction system as biochemistry is a prime example.

In this research, we have created an optical sensor type microreactor and reaction control system aiming at real-time detection and control of protein synthesis reactions, and verified the chemical activities of photoprotein in fireflies.

2. Optical sensor type microreactor

Fig. 1 is the prototype of optical sensor microreactor. We created a polymer reactor and flow channel on the silicon substrate, including reaction detection optical sensor and amplification circuit, using a micro stereo lithography process. The reactor size is 1.8 × 2.2 mm, with 3.5 μl volume. The reactor has three inlets and a single outlet. The sample fluid, reaction reagent, washing solution can be supplied through the inlet micro flow channels, and the product synthesized within the reactor can be removed from the outlet.

The connection of the micro flow channels and reactor has a "valveless structure" that prevents counterflow. In this microreactor, the chemical reaction that occurs within the reactor can be detected by the luminous intensity and change of absorbance.

This prototype of chemical IC chip has the following features:

1) Non-contact sensing ..... Long-term stability
2) Optical detection based ...... High responsiveness
3) Valveless structure ...... Simple fabrication
4) Transparent device ...... Easy to observe the inside

3. Biochemical reaction control validation experiment

Fig. 2 shows the feedback control system that controls the biochemical reaction. The optical sensor microreactor also has a microcomputer and micro impact injector that allows injection of micro fluid.

The micro impact injector was developed in our laboratory, because μl resolution flow control cannot be done by commercial injectors.

Fig. 3 shows luminous reaction within the microreactor. The transparent reactor allows observation of emission inside the reactor. The luminous intensity in the luminous reaction of the reactor is detected by the optical sensor, and sent to the microcomputer as a change in electric signal, so that the amount of fluid injected by the micro impact injector can be controlled to follow the target luminous intensity. As result, the reaction of an arbitrary pattern was controllable.

Using this reaction control system, we tried detection and control of biochemical reactions. We used luciferase which is the luminous enzyme of fireflies in our detection experiment. We succeeded in detecting traces of biochemical reaction as well as good mixture of biochemical solution in an extremely small space. Thus, we verified that this system is effective for controlling biochemical reactions such as the synthesis of protein.

4. Conclusion

We have experimentally created an optical sensor microreactor, which is a basic component of chemical IC chips. Then, we built a special control system to control the chemical and biochemical reactions, to identify the effectiveness of the system through verification experiment. Though we currently do not have active elements such as micropumps within the chemical IC, we would like to continue our research on the development of micro chemical control devices for medical and biotechnology use.

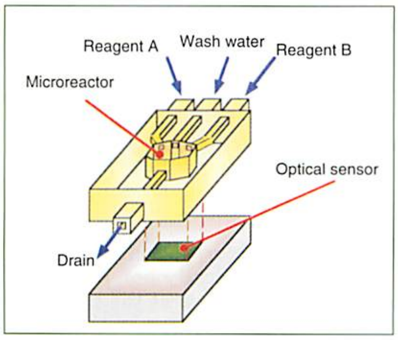


Fig. 1 Prototype of optical sensor microreactor

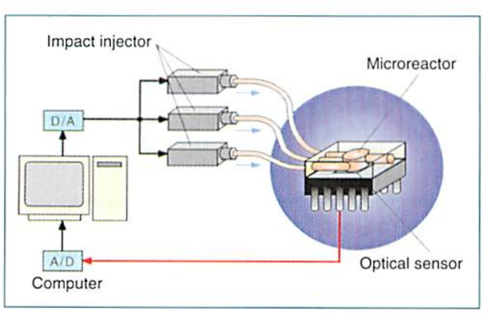


Fig. 2 Biochemical reaction feedback control system

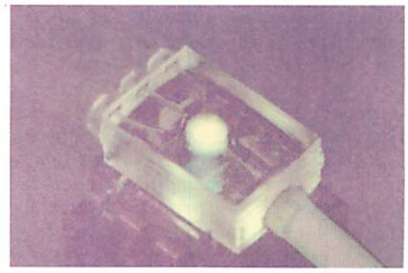


Fig. 3 Luminous reaction within the microreactor

Development of ON-OFF Functions in Polymer Microsphere

Haruma Kawaguchi
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Keio University

1. Foreword

This research considers submicron thermo-responsive polymer particle as micromachines. For example, when the shell layer is made of polymer with transition temperature, the core-shell particle (Fig. 1) that carries ubiquinone in the hydrophobic core is a thermo-responsive microreactor that performs an oxidation-reduction reaction with reducers and oxidizers in the media if the temperature is lower than the transition temperature, but stops the reaction when the temperature is high. Particles with a thermo-responsive shell layer are elements that can also control the on/off of electrophoresis or protein adsorption/desorption by temperature.

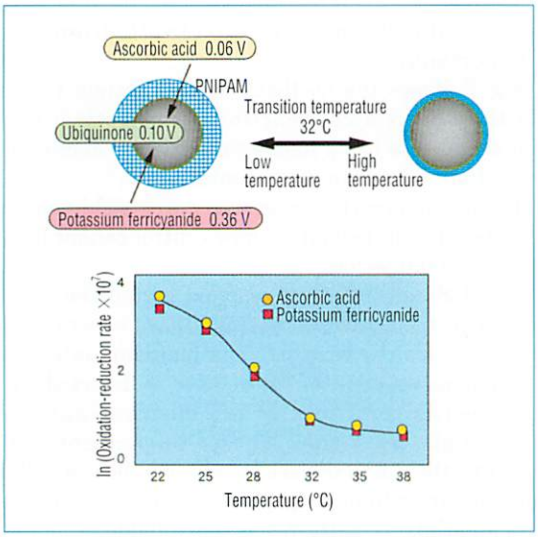

Fig. 1 Temperature control of oxidation/reduction reaction rate via thermo-responsive polymer shell layer (The figures following the compound names are oxidation-reduction potentials)

However, such on/off characteristics are not sharp at transition temperature of the polymer. This research aims to create fine polymer particles that have a sharp on/off characteristic to the change of temperature. N-isopropyl acrylamide (NIPAM) polymer (PANIPAM, transition temperature : 32°C) is used as the thermo-responsive polymer, and evaluation of the responsiveness at the transition temperature was done by the change of the hydrodynamic size (hydrodynamic diameter) of the particle.

2. Result of research

2.1 Preparation and characteristics of particles with gel shells

The thermo-responsive polymer particles that we have been handling are created by 2-stage soap-free emulsion polymerization as shown in Fig. 2A, or by precipitation polymerization of the thermo-responsive elements on the core particles. When the cross-linking density of the shells of these particles is decreased, the thermo-responsivity of the particle (the change of the hydrodynamic size) increases. However, it still does not show discontinued change at the transition temperature. So, we tried polymerization of the second stage without adding the cross-linking agent, but the shell layer of the produced particle was not fixed, and showed low thermo-responsivity. We expected repulsion of the molecule chain and sharp response by the ionic group in gel shell, but they were absent.

2.2 Preparation and characteristics of particle with hair layer shell

Next, we assumed that particles which have hair-like thermo-responsive polymer chain extending from the core particle into the aqueous phase might show sharp temperature characteristics. The hair shell particle was created as shown in Fig. 2B, by graft copolymerization to the core particle.

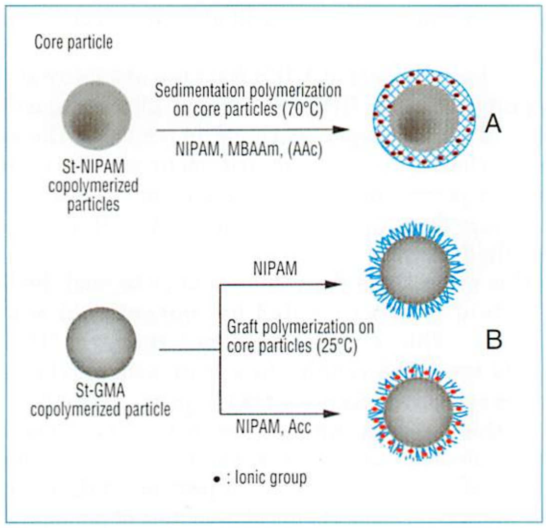

Fig. 2 Creation of thermo reactive particles

The ionic group was introduced by copolymerization of NIPAM and the acrylic acid. Particles without the ionic group and those with the large ionic group both showed slow thermo-responsivity. However, particles with hair layer including an appropriate amount of acrylic acid dissociate group showed very sharp thermo-responsivity. To be precise, the PNIPAM chain including 1%, 0.1%, and 0.02% AAc showed the most notable discontinuity at pH 4.0, 5.0, 7.4 respectively (Fig. 3). Such discontinuity was also confirmed with electrophoretic mobility.

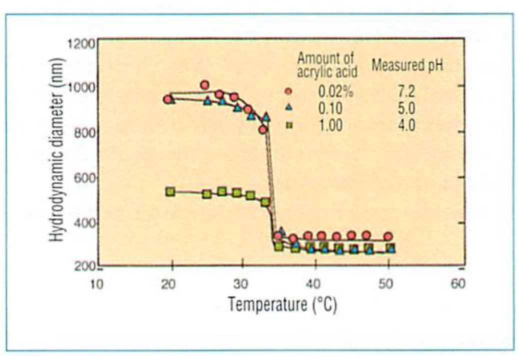

Fig. 3 Temperature dependency of particle size with thermo-responsive hair layer including ionic group

3. Summary

Particles with a hairy shell layer, in which thermo-responsive polymer is neither chemically nor physically cross-linked, showed sharp on/off response at the transition temperature of the thermo-responsive polymer. 0.02% of ionic group in the gel is enough to meet the conditions. This is very much different from the case of bulk gel.

Distributed Microactuator Using High Aspect X-ray Lithography

Susumu Sugiyama
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1. Introduction

The LIGA (Lithogaphie, Galvanoformung, Abformung) process is a transferable process, where high aspect ratio (the ratio of the depth against the width is large) grooving is performed by X-ray lithography on a thick polymer resist (100 μm or more), using this as a mold to deposit metal by electroplating (electroforming). As the synchrotron radiation (SR) light which has good rectilinear progressivity is used as the X-ray source, a highly precise three-dimensional structure can be formed, with high expectations for the machining of ultra-precision microparts or high function microsensors and actuators.

This study is the LIGA process development and application research on the microactuator, using the compact superconducting SR light source “AURORA” which started operation at Ritsumeikan University in April, 1996.

2. Results

Formation of the thick PMMA (polymetyl methacrylate) resist is done by two processes; the casting where unpolymerized resist composed of a mixture of polymer, monomer, starter and hardener are dripped in a spacer frame and polymerized, and the bonding where a polymerized and thickness-adjusted PMMA sheet is adhered to the substrate with monomer. Using the two processes, 50 μm to 2 mm thick PMMA resist layers were formed on metallic or Si substrates.

Exposed under the 575 MeV energy of the SR light source, 3 meters from the light source, 1.7 to 8 keV X-ray energy range (wavelength 0.15 to 0.73 nm), approx. 300 mA electron beam current, and using GG developer (60% 2-(2-butoxy-ethoxy) ethanol, 20% tetra-hydro-1,4-oxazine, 5% 2-amino-ethanol-1, and 15% water), a PMMA resist of up to 1 mm can be processed.

X-ray masks using 5 to 7 μm thick Au as X-ray absorbent and 2 μm thick SiC or polycrystalline Si membrane were also developed, for pattern transfer and machining on PMMA resists of 200 μm or thicker.

Using the transferred/machined 200 μm thick PMMA resist as a mold, electroforming was done using an electroplating bath with a mixture of 350 g/l nickel sulfonate and 30 g/l boric acid, to form a Ni structure of 200 μm high, 2 μm minimal line width, and 100 maximum aspect ratio. Figure 1 shows the processing example.

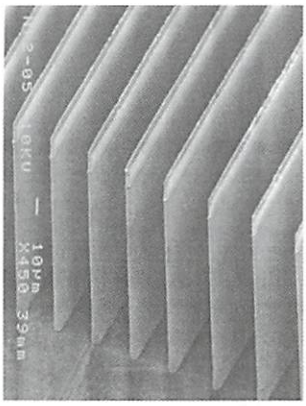

Fig. 1 An example of Ni micro structure with minimum width of 2 μm, height of 200 μm and aspect ratio of 100, using LIGA process.

By combining the above element processes, we fabricated the basic structure of the microactuator. Figure 2 is the trial fabrication example of the linear actuator having comb-shaped electrodes 100 μm high and 2 μm minimum gap between electrodes. Resonant frequency of 3.2 kHz, mobile range ±1 μm can be expected when the load is 1 mg and the applied voltage is 70 V. Figure 3 is the trial fabrication example of the wobble motor with a 1 mm diameter, 100 μm high, and 2 μm minimum gap between electrodes. 2.8 nNcm static torque can be expected with an 80 V applied voltage.

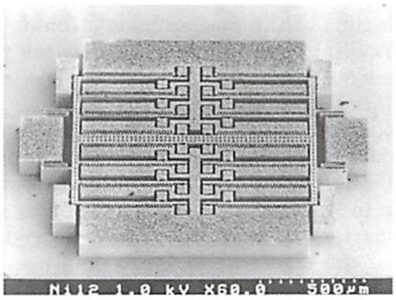

Fig. 2 A fabricated comb drive micro linear actuator with size of 1.6 × 1.2 mm², height of 100 μm and minimum gap of 2 μm.

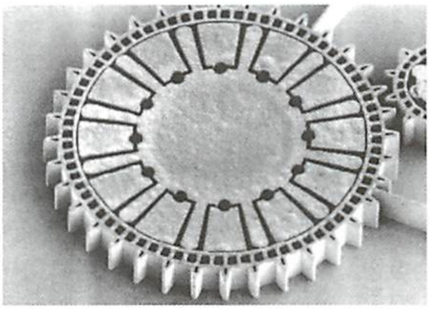

Fig. 3 A fabricated wobble motor with diameter of 1 mm, height of 100 μm and minimum gap of 2 μm.

3. Conclusion

We succeeded in proving that the compact superconducting SR light source “AURORA” can be applied to the LIGA process, and demonstrated the potential and problems of the LIGA process through the results of the X-ray lithography and the electroforming experiment. By balancing the process cost and the value added of the product, and fusing with the surface micromachining and integrated circuit, we believe that “AURORA” can be used to achieve higher precision, higher output for micro sensors and actuators, or applied in new areas such as the optics, information and communication, medical electronics and biological engineering fields.

Development of Three-Dimensional Measurement Technology for Micro Flow

Kahoru Torii, Professor and **Koichi Nishino**, Associate Professor,
Faculty of Engineering, Yokohama National University

1. Foreword

As micromachines are minute, they are subject to hydrodynamic effects by the surrounding fluid. When the surrounding fluid is a multi-phase fluid or non-Newtonian fluid, analysis and numerical evaluation of the hydrodynamic effect is difficult, but there must be some way to measure it. As the conventional sensor insertion technique cannot be applied to micro flows, a new measurement technique is desired. The target of this research is to establish a unique non-insertion, non-contact measurement technique using stereo micro-imaging method, so that the micro flows can be measured in a three-dimensional flow field. The next target is to measure the microchannel flow with water or dilute polymer solution as the working fluid, to verify the measurement technique and understand the non-Newtonian fluid effect in the micro flow.

2. Measurement principle and method

The principle of the measurement technique is PTV (Particle Tracking Velocimetry) that traces the movement of fine tracer particles in the flow. The flow velocity is calculated from the traveling distance of tracer particle images taken within a short time interval. The space resolution of measurement is determined by the diameter of the tracer particle, and can optically be enhanced up to 1 µm.

It is important to know the precise three-dimensional position of the tracer particles to measure the micro flow velocity distribution. The present technique allows three-dimensional positioning of the tracer particles with 10 µm measurement precision, by stereo micro-imaging with two CCD cameras (Fig. 1). The optical axis cross angle of the CCD cameras is 60 degrees. Double-pulse illumination, each pulse having a duration of 3 µs, is given by a strobe scope.

3. Measurement of micro channel flow

We constructed a microchannel 2 mm high and 20 mm wide, and took measurements of three velocity components. We first measured a low-speed laminar-flow at a Reynolds number = 9.5, and confirmed that the streamwise mean velocity distribution was in good agreement with the theoretical solution. Next, we measured a turburent flow, the center line velocity being 4.8 m/s and the Reynolds number = 9700, and confirmed that the streamwise mean velocity distribution was in fair agreement with the previous data, and that the rms values of three fluctuating velocity components were reasonable (Fig. 2). With the above verification experiment, we have confirmed that our measurement technique is applicable to micro flows from low to high velocity.

Sharp reduction of friction resistance, i.e., drag reduction, is known to occur in turbulent flows of solution with a very small amount of chain polymer (Toms effect). As the turbulence length scale of micro turbulent flow approaches the length scale of the chain polymer, an effect which is different from known drag reduction can be expected. The surrounding fluid where micromachines are operated includes non-Newtonian fluids, so the measurement of a dilute polymer solution is also important as a first step. In this research, we added into the water 300 ppm polyethylene glycol (product name: Alcox, molecular formula: $HO(CH_2CH_2O)_nCH_2CH_2OH$). The result of the measurement showed only about 5% of drag reduction and an extremely uniform streamwise mean velocity distribution, which is completely different from the previously reported laminarized distribution in drag-reduced turburent flows (Fig. 3). Such features are noticeable in polymers that have higher molecular weight.

4. Summary

We developed a three-dimensional measurement technique for micro flows based on stereo micro-imaging method, and verified by measuring the microchannel water flow, that this technique can be used as a velocimetry for micro-flows low to high fluid velocities. We also measured turbulent flows of a dilute polymer solution chosen as a non-Newtonian fluid, and revealed a phenomenon that is unique in comparison with previous drag reduction experiments. Though further research is required, the present result indicates that micronization of the flow can create new effects in multi-phase fluid or non-Newtonian fluid, which needs future fluid research related to micromachines.

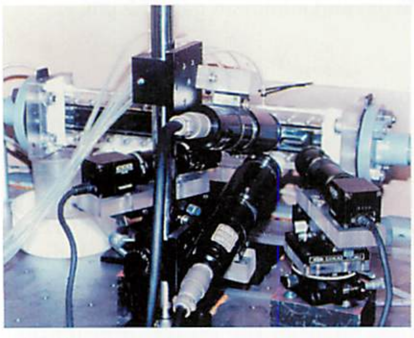

Fig. 1 Three-dimensional measurement system for micro flow

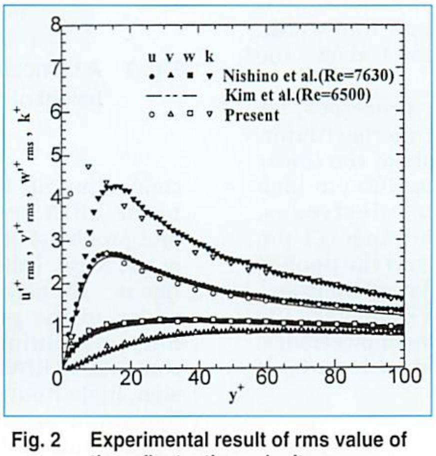

Fig. 2 Experimental result of rms value of three fluctuating velocity components in microchannel water flow

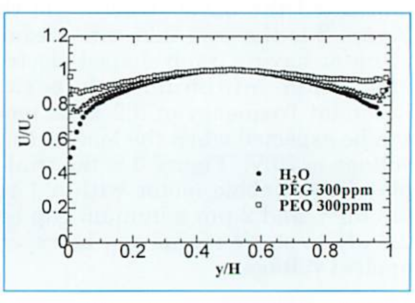

Fig. 3 Streamwise mean velocity distributions in dilute polymer solution

Optical Microactuator Using ER Fluid

Takeshi Nakada
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College of Engineering, Tokyo Denki University

1. Foreword

There has been a large demand for the establishment of diverse microactuator technology, such as the development, increased performance, and functions of microactuators based on new principles such as piezoelectric and electrostatic phenomena. The objective of this study is to clarify the possibility of creating wireless microactuator systems which could withstand electromagnetic noise interference by using PLZT elements as the photoelectric source, and ER fluid as the power transmission media.

2. Principle of optical microactuator system

ER fluid is a two-phase fluid in which fine particles are distributed as a dispersoid within insulating oil. A characteristic of ER fluid is the ER effect, namely when ER fluid is passed between parallel electrodes as shown in Fig. 1 and an electric field is applied, the apparent viscosity of the ER fluid increases with increasing field strength. It is expected that it will be possible to achieve a control valve (ER valve) without mechanical moving parts. PLZT elements (Fig. 2) are functional piezoelectric ceramics with a characteristic in which when ultraviolet light with a wavelength of approximately 365 nm is irradiated upon them they induce a high photovoltage of approximately 3 kV/cm (photovoltaic effect).

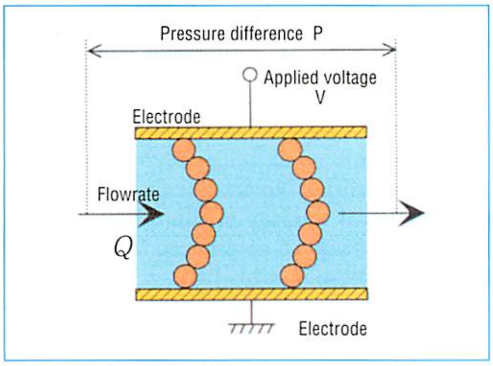

Fig. 1 Principle of ER effect and ER valve

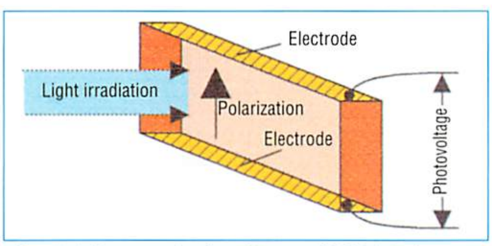

Fig. 2 Photovoltaic effect of PLZT element

It is therefore thought that if a fluid drive system utilizing the ER effect, and an energy supply system utilizing the photovoltaic effect of PLZT elements are integrated, it will be possible to create an optical microactuator system capable of withstanding electromagnetic noise, and which has a simple, wireless construction (Fig. 3).

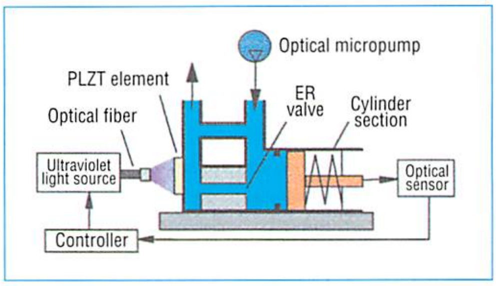

Fig. 3 Conceptual drawing of optical actuator

3. Study results

As a first step, the possibility of controlling an ER valve by a photoelectric power source using PLZT elements was investigated. The parallel electrodes shown in Fig. 1 (ER valve, distance between electrodes 0.1 mm) were connected to the PLZT elements shown in Fig. 2 as a photoelectric power source, and with ER fluid passed between the electrodes these elements were irradiated and shielded from ultraviolet light, and the photovoltage induced at the element and the pressure difference across the ER valve were measured (Fig. 4). To do so, it was necessary to optimize the impedance matching of the PLZT element and the ER valve, and steps were taken to optimize the shape of the PLZT element based on theoretical analysis. As shown in Fig. 4, a change in the pressure difference resulting from the irradiation and shielding from ultraviolet light, and the possibility of using a photoelectric power source to control an ER valve was clarified.

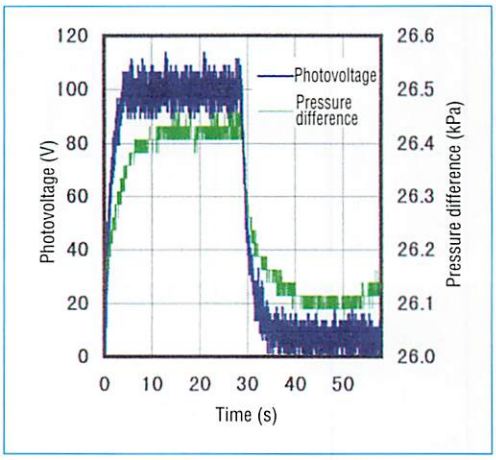

Fig. 4 Change in pressure of ER valve and photovoltage of PLZT element

4. Conclusion

Research and development on the application of a variety of different functional fluids such as ER fluid to actuators is underway, but a path to the future of optical microactuators based on a new concept that integrates optical energy supply systems, including PLZT elements has been opened.

Development of Micro Devices Using Miniature Robots

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University of Electro-Communications

1. Introduction

Recently many new approaches have been developed to make the micro parts with the help of MEMS technology. One of them is an ultra precise machining techniques based on the mechanical tooling and another is on the electro-chemical technique which is widely used in LSI process. From the view point of micro-material processing, the former can be represented as a "top-down approach" involving material removal and the later is as a "bottom-up approach" with material deposition and etching. Such an ultra precise and a micro fabrication in micro realm need the multi-disciplinary experiences of several novel processes that can create complex micro structures.

2. Research progress and results

Many miniature robots of the beetle size with micro tools and workable in a vacuum chamber for the micro device fabrication have been developed. Here the mechanical micro tooling and the local metal deposition control are to be combined. The small robot simply consists of piezoelements for source of motion and electromagnet for machine clamping so that it can provide stable locomotion with sub-micron resolution on any curved surface even in the high vacuum chamber as shown in Fig. 1. Unique small tools which can be remotely controlled are mounted on the robots so that they can collaborate in doing microscopic operation.

In the preliminary experiments, the local deposition patterning control of metals is carried out by two miniature robots. The process is shown in Fig. 2. The precise deposition pattern is obtained by both the accurate positioning action of two miniature robots in lateral and the thickness control of deposition time. Then another miniature robot with a small manipulator is also ready for supplying different material grains into the heated pot. So this simple sequence can provide a set of unique micro deposition pattern with difference materials. Furthermore another small robot with a hopping micro tool of diamond is developed for the micro indention on the specified sample. The demonstrative results such as a batch of micro devices for the humidity sensor and micro pit holes are successfully achieved by the collaboration of miniature robots.

3. Conclusions

As a future works, we are developing many miniature robots with a variety of micro processing functions in order to prepare new micro fabrication, and to establish the desktop flexible factory.

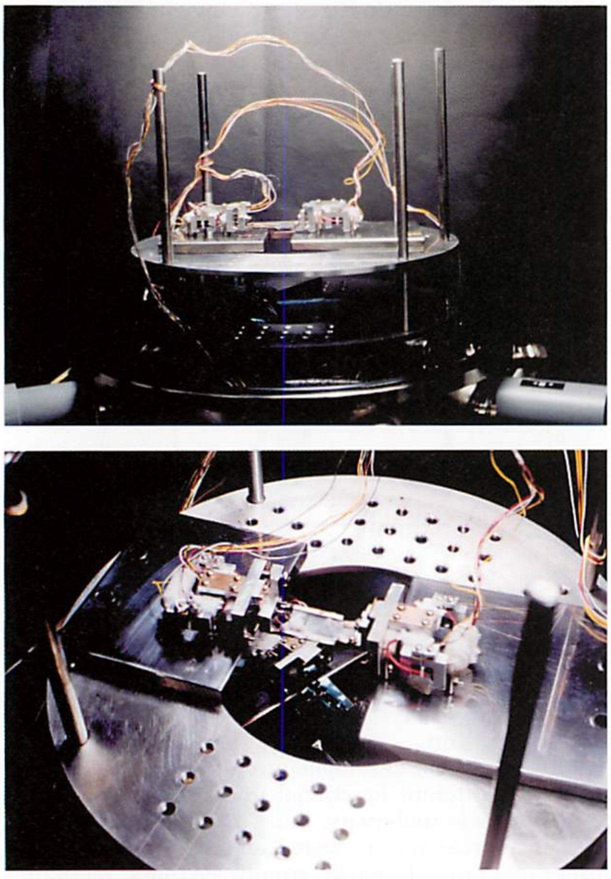

Fig. 1 Experimental set-up

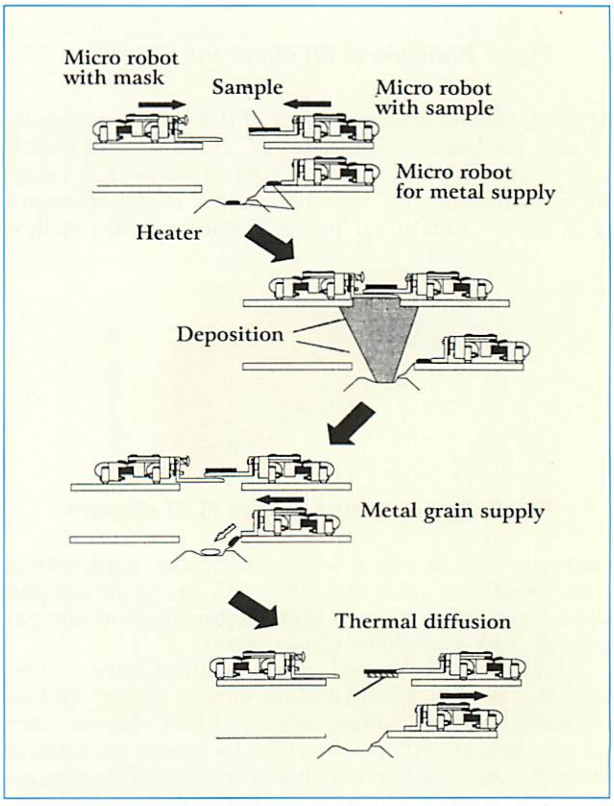

Fig. 2 Micro fabrication process performed by miniature robots

Fabrication of Flexible Tube Actuator Using Laser Machining

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1. Foreword

Microactuators are an important element in micromachines. In practical terms, micromachines are systems in which sensors, actuators and control circuits are positioned three-dimensionally. It is predicted, however, that it will be difficult to mount micro actuators fabricated on a flat board onto a three-dimensional structure.

In this study, in order to solve this problem while focusing on the creation of a tube-shaped micromachine resembling an active catheter, a flexible tube actuator (bellows-shaped electrostatic microactuator) incorporating an electrostatic actuator structure in a flexible tube-shaped structure was proposed and fabricated.

2. Actuator fabrication

Fig. 1 shows a simplified diagram of the actuator fabricated in this study. The electrostatic actuator section formed opposing electrodes to generate an electrostatic attracting force within the thin polymer bellows-shaped structure. The structure contracts when voltage is applied to opposing electrodes, and when the voltage is removed it returns to its original shape due to the elasticity of the structure. Because the electrodes are connected in a helical-shape, only wiring from outside needs to be connected to the edge of the actuator, which makes wiring work simple.

Fabrication was carried out as follows. Initially brass pipe with an external diameter of 1 mm was coated with a 100 μm polyimide film, then a helical-groove is formed on the surface using an excimer laser. Using the processing characteristics of laser ablasion, it is possible to create a V-shaped groove for an electrostatic actuator with an opening 20 μm wide and a 5 μm bottom. On top of this, a polymer called parylene and gold electrode were evaporated, and finally the brass pipe and polyimide are removed by etching and lead wires attached.

Fig. 2 shows the fabricated actuator section. The length of the actuator section is approximately 1 mm, and bellows with approximately 44 rises are formed.

3. Operational evaluation

It was confirmed that the contraction was performed by applying voltage. At 100 V it deformed 30 μm, and the time taken for the deformation was within 0.5 msec. In addition, hysteresis properties were observed in the voltage-deformation properties. When driven by a feedback circuit that controlled the driving voltage by comparing the capacitance between electrodes with the reference value, driving without hysteresis became possible, as shown in Fig. 3.

4. Conclusion

An actuator incorporating an electrostatic microactuator structure in a tube-shaped structure was fabricated, and its operation was confirmed. It was shown that by the use of a laser for three-dimensional micro processing it was possible to fabricate a micro actuator structure in a three-dimensional structure.

Future issues to be addressed are innovations to further reduce the driving voltage, and achieving a structure capable not only of contraction but also of carrying out operations such as bending.

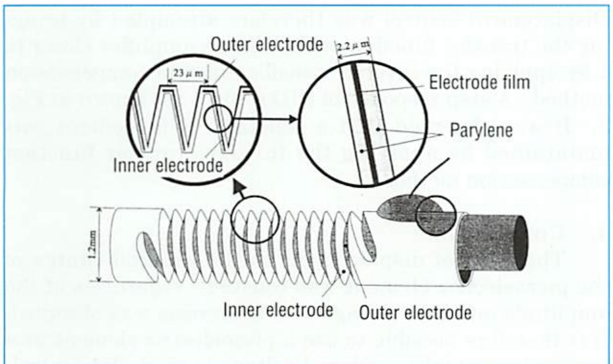

Fig. 1 Conceptual drawing of flexible tube actuator

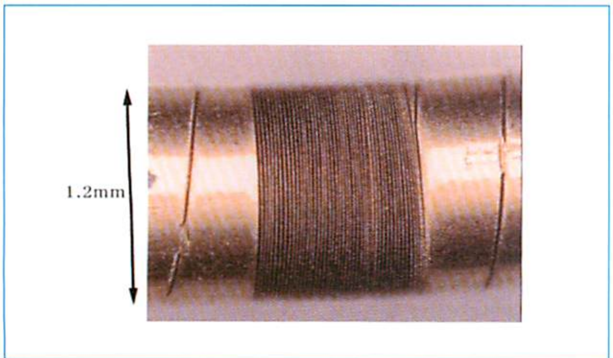

Fig. 2 Fabricated flexible tube actuator

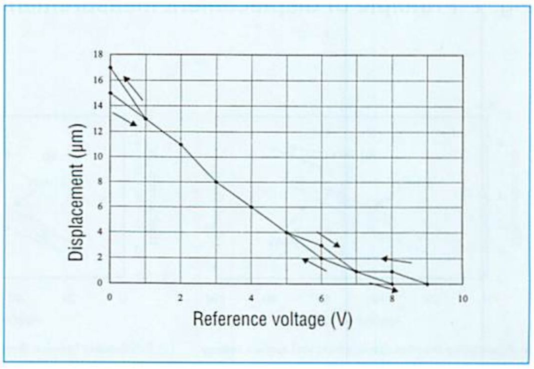

Fig. 3 Driving by a control circuit

Monitoring of Piezoelectric Element Using Induced Charge

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Naotake Mohri
Professor, Graduate School of Engineering, Toyota Technological Institute

1. Foreword

Piezoelectric elements are small actuators capable of micro displacement and are highly responsive. They are therefore suitable for various positioning devices. Generally, the displacement of piezoelectric elements is controlled by varying the applied voltage. However, hysteresis exists between the applied voltage and the displacement, so a lot of methods have been proposed to reduce this hysteresis.

On the other hand, stacked piezoelectric elements have a structure similar to that of parallel-plate capacitors. When voltage is applied, charges are induced on the outer faces of the piezoelectric element parallel to the internal electrodes. Because these induced charges vary with the internal charges, the state of the piezoelectric element can be measured by measuring these charges. As the circuits added to detect the induced charge are connected in parallel with the piezoelectric element, it is possible to design the drive circuit independently without restrictions.

2. Principles of displacement measurement

The principle of the proposed measurement method for a stacked piezoelectric element is shown in Fig. 1. Stacked piezoelectric elements have a structure in which the thin plate which is the piezoelectric material and the internal electrodes are stacked on each another alternately. At both ends of the piezoelectric element, detection electrodes are set parallel to the internal electrodes. When voltage is applied to the piezoelectric element, the internal electrodes are charged. Because detection electrodes are set on the inner electrodes which are on the very outside, charges are induced on the detection electrodes. This induced charge is generated by electrostatic induction, so it is in proportion to the internal charge. The induced charge is measured with a charge amplifier. If the relationships between the induced charge and the displacement in the piezoelectric element, the force generated and the external force applied are calibrated beforehand, it is possible to measure them by using the induced charge.

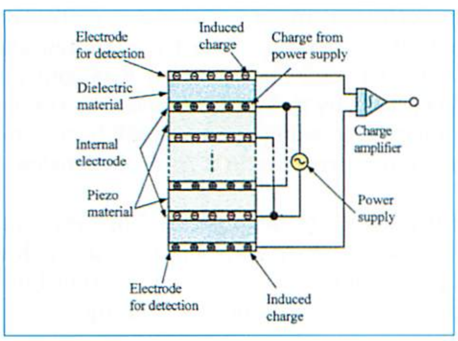

Fig. 1 Principle of displacement measurement

3. Response to induced charge and application to positioning

We observed the relationship between the displacement of the piezoelectric element and the output voltage of the charge amplifier caused by the induced charge. The relationship in a steady state is shown in Fig. 2. Fig. 2 (a) shows the relationship between the applied voltage and displacement, while Fig. 2 (b) shows the relationship between the displacement and the output voltage of the charge amplifier that measured the induced charge. Comparing the transient response of induced charge with the displacement when steplike voltage was applied to the piezoelectric element, they nearly corresponded.

Because the charge amplifier has the same frequency characteristics as a high-pass filter, it is difficult to use it for displacement control over periods of time much longer than the time determined by the cut-off frequency. Displacement control was therefore attempted by bringing the transfer function of the charge amplifier closer to 1 by applying the inverse transfer function compensation method. A step response of PID control are shown in Fig. 3. It was observed that a constant displacement was maintained by applying the inverse transfer function compensation method.

4. Conclusion

The ratio of displacement to the induced charge of the piezoelectric element was constant, regardless of the amplitude and bias voltage. No hysteresis was observed. It is therefore possible to use a piezoelectric element as a linear element when induced voltage is used. By controlling the displacement of the piezoelectric element by feeding back the induced charge, similar results to displacement feedback were achieved.

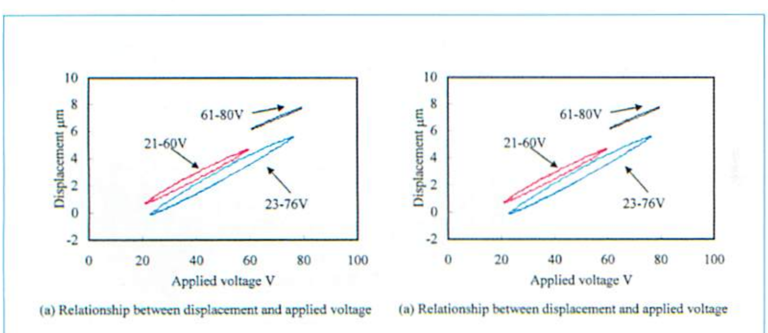

Fig. 2 Hysteresis loop of displacement of piezo

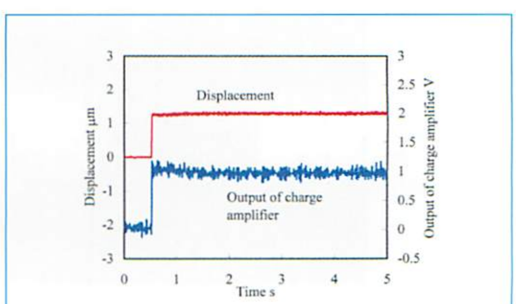

Fig. 3 Displacement control by feedback of induced charge with inverse transfer compensation

Toshiba Corporation

Setsuo Yamamoto
General Manager, Mechanical Systems Research Laboratories, Research and Development Center

1. Micromachine Technology Initiatives

The national R&D project "Micromachine Technology" which started from 1991 has proceeded its technological phase from developing the micro-sized elements to the system integration of using them. In order to achieve our goal of "CCD Micro Camera", which is to be the subsystem of "Experimental Wireless Micromachine for Inspection on Inner Surface of Tube", Toshiba has been developing the following technologies of micro machining, three dimensional packaging, electrostatic micro actuators, and micro camera designing. Together with those fundamental technologies we have been also studying the systematization technologies both of assembling micro parts and of operating the CCD image under low transmitting capacity.

2. Development of Micromachine Technology

CCD Micro Camera device (Fig. 1) is a CCD micro camera capable of changing its inspecting direction, mounted on the Experimental Wireless Micromachine for Inspection on Inner Surface of Tube. In addition to detecting 20 μm scratches on the inner walls of 10 mm diameter piping in power plants, it performs forward direction surveillance when moving while changing its inspecting area. The lens is a 2 mm dia. × 1 mm cata-dioptric system (Fig. 2), which achieves its ultra-thin construction by reflecting light between the inner surfaces of the lens with a concave-convex shape. To improve the high density of the lens, the lens barrel is integrated with an electrostatic linear motor for focus adjustment, and these are surrounded by two electrostatic rotating motors fitted with reflectors, which allows monitoring to be performed freely at any direction within the pipes when the reflected images are captured with a CCD. The key feature is the technology that allows the construction of the system, namely for the lens and lens barrel to be simultaneously formed by thermal pressing with micron level accuracy for the electrostatic electrode.

High-density three-dimensional packaging technology is important for integrating the elemental parts of the CCD Micro Camera. For example, the multiple ICs with different shapes necessary for CCD control are stacked in bare chip, and the electrical connections are made on the cut surface of the IC. This resembles the writing of index letters on the edge of a dictionary. When this is shared with a flexible board for the CCD, all of the components including the CCD are constructed three-dimensionally in a close-packed structure, enabling image pickup elements to be integrated in a module.

To integrate the CCD Micro Camera into the systems of other devices such as mobile mechanisms, mechanical and electrical connections must be carefully constructed. There are approximately 50 wires for the electrostatic motor and the CCD. Voltage also ranges from -7 V to 80 V. It is impossible to wire these inside such a small housing. To overcome this problem we have developed the technology to consist the housing of an electrically insulating material with metal wiring patterns on it.

3. Future Initiatives

Shortly the CCD Micro Camera is to be mounted on the Experimental Wireless Micromachine for Inspection on Inner Surface of Tube, then the operating method is expected to become the next problem. The characteristic of micromachines that they are able to enter extremely confined environments conversely turns out both to be the limitation of its activity area, and to be the difficulty of energy supply and communications. In addition to working to overcome these problems, Toshiba hopes to improve the potential of micromachines, and to achieve the implementation of truely practical micromachines for the 21st century.

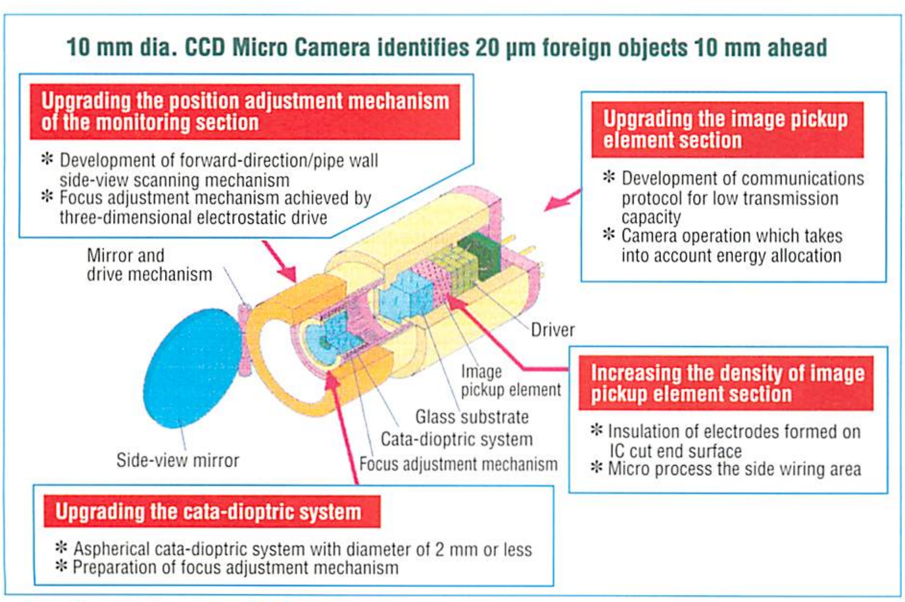

Fig. 1 Structure of CCD Micro Camera

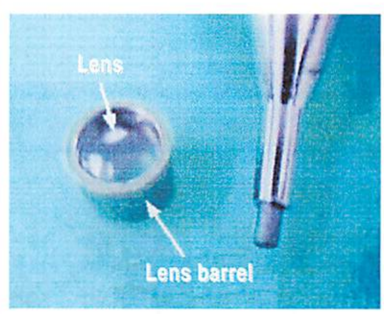

Fig. 2 Cata-dioptric system

Japan Power Engineering and Inspection Corporation

Katsuomi Kodama
President

1. Basic Approach to Micromachine Technology

Thermal and nuclear power plants together account for roughly 90% the total generated electric energy essential for daily living and industrial activity in Japan. The advanced age of some of the existing power plants facilities makes inspection even more important for improving the availability factor and safety, thus creating the need for more advanced, high-precision inspection technology. In the field of nuclear energy, now seen as a means of reducing CO_2 output in order to prevent global warming, age deterioration countermeasures are being considered, and advanced inspection technologies for power plants facilities are now more important than ever. At the thermal and nuclear power plants, where plant operations are periodically stopped to perform inspections and maintenance, micromachines are expected to play an important role in inspection, particularly in narrow, confined spaces. It is in response to such micromachine needs at power plants that the Japan Power Engineering and Inspection Corporation (JAPEIC) has undertaken investigation on maintenance micromachines with the objective of promoting the efficient and effective development of the required micromachine technology.

2. Investigation on Micromachine Technology

In phase I of the investigation on maintenance micromachines, which focused on the thermal and nuclear power plants, we developed a concept for an ideal micromachine to satisfy the needs of electric power companies. In phase II, in which our examination focuses on future implementation at power plants, we are developing a highly feasible maintenance micromachine system from the perspective of the relative difficulty of the functions required for maintenance micromachines.

The most feasible type of micromachine for power plant maintenance would be one that, rather than functioning alone, would access the equipment or area in question by operating in combination with conventional automated machine and robots. One example of this is the set manipulator (a micromachine paired with a flexible manipulator) shown in Fig. 1, which could be used for steam turbines and other types of equipment with a relatively wide inlet but a narrow interior. This year we will also investigate other types of micromachine systems with the potential for application in power plants.

To survey future trends in power plant maintenance technology (one topic of this survey research), the state of automatic machine and robot use, and actual circumstances regarding equipment diagnostic devices, we are hosting the "Power Plant Maintenance System Technology Meeting" with the guidance of participating electric power companies and power plant equipment manufacturers. We also plan to solicit these members' advice regarding issues relating to the appropriateness of the proposed maintenance micromachines to existing and planned power plants. By incorporating the opinions and needs of electric power companies and power plant equipment manufacturers, we intend to develop even more feasible maintenance micromachine systems.

3. Plan for the Future

Based on the results of the previous investigation, the concepts for maintenance micromachine systems for tomorrow's power plants are beginning to take shape. Because power plants require the highest degree of reliability and safety in their equipment and technologies, micromachine technology must be introduced through a procedure that assures overall reliability by gradually expanding the coverage of each device in question. With this in focus, we intend to consider the various scenarios of and issues related to the practical future implementation of micromachines in power plants.

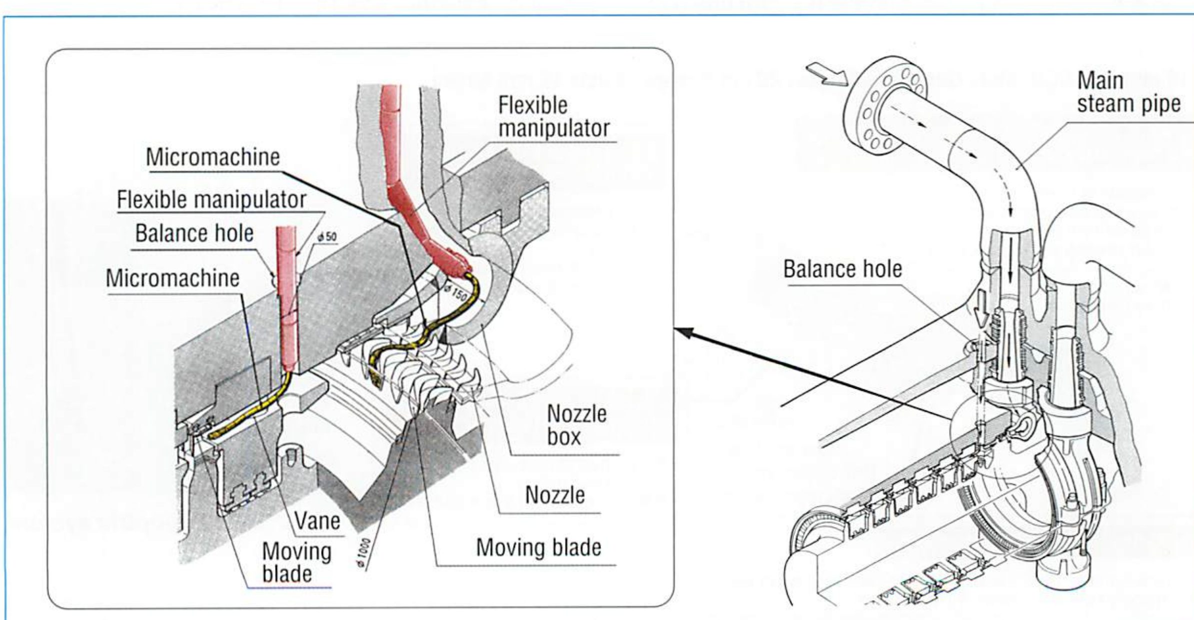

Fig. 1 Concept of a micromachine for inspecting inside of a steam turbine

'98 Micromachine Australia/New Zealand Mission

Using the opportunity of the Center's participation as an observer in the 4th Micromachine Summit, held in Melbourne, Australia, a survey mission was sent to Australia and New Zealand from April 25 to May 6 to visit universities and research institutes in those countries. Led by Prof. Naomasa Nakajima, dean of School of Engineering, The University of Tokyo, this mission comprised a total of 14 persons from the Center along with supporting members. The mission visited six institutions in Australia and New Zealand, surveyed R&D conditions, exchanged information with other researchers, and provided information about the status of Japanese R&D (primarily in the Industrial Science and Technology Frontier Program).

An overview of each university and research institute visited follows.

(1) University of South Australia

The mission visited the Levels campus's Microelectronics Centre, situated north of Adelaide. Although first established in 1970, as a microelectronics research center for undergraduates, with corporate support it subsequently began research on silicon technology-based sensors and expanded its R&D into the field of microengineering research. The center receives no government funding to support its annual administrative expenses of ¥140 million and R&D expenses totaling approximately ¥40 million per year, but instead concentrates on joint research with industry. R&D topics include bio-sensors, mechanical fuses, diaphragm-type micropumps, and eddy current sensors for non-destructive testing, all of which were applications of silicon-based micromachining.

(2) Royal Melbourne Institute of Technology

One of Australia's largest engineering colleges. The mission visited the laboratory of Dr. R. Zmood, who is the liaison for Industrial Science and Technology Frontier Program in Japan. This laboratory is conducting R&D on micro magnetic bearings and suspension mechanisms to reduce axial friction in micro gear train.

Of the research facilities observed, the micromachine facility was the most substantial. This facility is one of Australia's most advanced facilities in micromachine research and accepts talented foreign researchers.

(3) Bionic Ear Institute

This research institute is situated adjacent to and is affiliated with the Department of Otolaryngology, the University of Melbourne. With research and support staff comprising roughly 20 persons each, the institute is run with an annual budget of roughly ¥180 million (the majority of which is provided by the University of Melbourne). In addition to research on the causes of hearing impairments, the institute is also involved in research on hearing restoration and developing hearing aids and other devices.

A bionic ear is a 22-channel electrode cell implanted into acoustic cells which transmits the sensation of hearing to the brain by stimulating those cells' electrodes. A microphone and transmitting antenna are worn outside the ear, and a receiving antenna inside the ear. Acoustic information is converted to 22 channels of electric signals which are sent to the electrodes. Mission members were told that confirmed results have been achieved with children. Thus, Australian medicine has already advanced to the point of using electrode cells implanted inside acoustic cells within the ear to restore hearing.

(4) CSIRO (Commonwealth Scientific and Industrial Research Organization)

This national research institute was founded in 1926 and currently has a staff of over 7,000 — including approximately 3,000 scientists — working in 32 offices, research centers and other divisions located throughout Australia. Although it is a national research institute, CSIRO receives only 30% of its funding from the Australian government, with the remainder acquired through contract research for the military and private sector.

The manufacturing science and technology division, which the mission visited, employs 340 researchers and has an annual research budget of ¥4.1 billion, of which contract research revenues account for approximately ¥1.5 billion. The fields of research are forging and casting, joining and heat treatment processes, production systems and automation, materials processing, and photonic micromachining, with particularly robust research on microengineering systems employing electron beam lithographic devices. Here, research is being conducted on mask applications, new printing techniques and other areas of microprocessing and microelectronics.

The mission was told that research on photoresist-based fine lithography and microchip analyzers (chemical analysis devices) is also under way.

(5) Industrial Research Ltd. (IRL)

Initially established as the industrial division of the New Zealand government's Ministry of Scientific and Industrial Research, IRL is today a public corporation that also receives private-sector funding and which operates research centers in three cities: Auckland, Wellington and Christchurch. Over the past five years research funding has averaged ¥3.3 billion per year, with government subsidies accounting for 68%.

IRS's staff currently numbers 370 (including 120 Ph.D.'s), of whom 270 are assigned to the Wellington location, which the mission visited.

The basic goals of IRL are the pursuit of national interests and the transfer of technology to the private sector, with an emphasis on the licensing of patents and other forms of intellectual property. In line with government policy, research is focused on energy conservation and the fields of agriculture, forestry and livestock and encompasses a broad range, from elemental technology to applications. Currently, R&D is under way energy technologies (geothermal, wind power and solar cells), production processes for natural products (lumber, dairy products and meat), and manufacturing technology.

(6) University of Canterbury

Begun as a state college in 1873 and upgraded to its current university status in 1957, University of Canterbury comprises seven schools: arts, science, engineering, law, economics, agriculture and music. Current enrollment exceeds 10,000. The university's distinguished school of engineering is New Zealand's oldest, established in 1887 and currently having an enrollment of approximately 900. Its largest department is the department of electrical and electronic engineering, founded in 1902 and today comprising roughly 350 undergraduates, 80 graduate students, 23 professors, and a support staff of 20.

The mission visited the department of electrical and electronic engineering's NEST (Nanostructure Engineering, Science and Technology) research group, which is conducting research on optical nanoprocessing. Having become active only in 1997, the group had only begun installing research equipments.

This university's research and development activities would seem to have as their mission the industrialization of New Zealand. Efforts to rebuild the country's lagging electronic engineering sector and obtain the micro- and nanoprocessing technologies that are an absolute prerequisite for the forefront research by the university indeed appeared to have only just begun.

Both Australia and New Zealand are at somewhat different levels than Japan, North America and Europe in terms of industrial technology, and funding for state-of-the-art science and technology is by no means abundant. Nevertheless, the researchers were enthusiastic and motivated, and R&D to contribute to each country's industries is under way.

The 4th Micromachine Summit

The 4th Micromachine Summit was held on April 30 and May 1 in Melbourne, Australia. Hosted by Prof. Ian Bates, Associate Dean, Faculty of Engineering of the Royal Melbourne Institute of Technology, and held at the institute's Storey Hall, the summit was attended by 46 participants and 28 observers from 13 countries/regions, including Japan. The Japanese delegation was led by Prof. Naomasa Nakajima (Dean, Faculty of Engineering, The University of Tokyo), and consisted of Dr. Tsuneo Ishimaru (Chairman, DENSO CORP.), Dr. Toshiro Shimoyama (Chairman, Olympus Optical Co., Ltd.), Dr. Sadao Moritomo (President, Seiko Seiki Co., Ltd.) and Mr. Takayuki Hirano (Executive Director, MMC). Also in attendance as observers were 14 MMC staff and supporting members.

The conference covered a total of seven topics, beginning with country reviews of micromachine-related activities in each country/region, and also included discussions focusing primarily on applications of micromachine technology. The discussions are summarized below.

(1) Country/Region Reviews

Chief delegates of each participating country/region discussed the status of research and development at their principal research and development institutions. The host country, Australia, has no government-funded projects, but is promoting micromachine-related research and development primarily at universities. In the other countries/regions, government-supported projects are the mainstay of the research and development under way, and new developments included the start of a new project to create a three-dimensional micromachine system last year in France. The objective of this four-year CNRS project is to develop new processing and assembly technologies to create three-dimensional structures similar to those of Japan's Industrial Science and Technology Frontier Program, and also to develop CAD tools for micro systems and micromachine systems that incorporate μTAS, biochips and other chemical technologies. In other countries, as well, the development of micromachine systems that incorporate chemical technologies is being approached as a new objective.

Representing Japan, Prof. Nakajima showed a videotape from the Micromachine Exhibition '97 to explain the status of Industrial Science and Technology Frontier Program. His report on the future research and development topics selected by MMC generated great interest in Japan's long-term research and development.

(2) Applications across Major Industries

The many example applications based on so-called silicon micromachining were, from Taiwan, an inexpensive, high-performance micro bolometer for home security systems; from the UK, micromachine applications in the field of aviation, and from the U.S., a micro-optical device fabricated with surface micromachining technology. None of these applications were particularly original technologically, but all demonstrated the efforts now under way to develop products suited to market needs.

(3) Market Predictions and Pathways of Potential Products to Commercial Production

French and German delegates gave reports on forecasts for the micromachine market. Both reports were based on the results of NEXUS market surveys, and predicted that the MST market of the world (Japan, Europe, and U.S.) in 2002 will be worth US$43 billion in Germany, and US$34 billion in France (¥5.8 and ¥4.6 trillion, respectively). However, nearly all of these markets consist of existing markets for inkjet printer heads, hard disk heads and pressure and acceleration sensors. The new micromachine system market is still estimated to be worth only several billion dollars (US$). While microanalysis systems in the fields of chemicals and biotechnology were cited as one segment of the micromachine system market where significant growth is expected, no examples of revolutionary applications for these areas were given.

(4) Global Problem Solutions

Among the examples of micromachine applications to solve global problems, such as environmental, health care and pollution problems, the Chinese delegate presented microsensors and microrecorders, Dr. Shimoyama described futuristic medical technologies employing micromachines; the Americans, a micro fluid operation device, and the Swiss, a drug delivery system (DDS) implant. Dr. Shimoyama, during his presentation, attracted particular attention with a videotape using computer graphics and showing actual photographs of futuristic medical techniques, such as minimally-invasive medical procedures and home treatment.

(5) Scenarios for Building the Micromachine Industry and New Manufacturing Technologies

Regarding the creation of a micromachine industry possible scenarios presented included the UK delegate's discussion of European industrial policy in various micromachine projects and the Australian scenario for new-industry creation using SR devices. Europe has created systems (such as EUROPRACTICE) that provide wider access to the micromachine manufacturing technologies of individual companies and research institutes. This demonstrated how micromachine industrial policy is being promoted in Europe.

As for new manufacturing technologies, the Taiwanese presented an idea for micromachined spinnerets for micro fibers. They reported that the LIGA process makes it possible to form spinnerets with complex shapes.

During this session the Mr. Hirano reported that although proposals for standardization networks were made at the international standardization workshop held in Tokyo last October. The workshop was seen as a forum for the informal exchange of information and was participated in by several countries/regions where interest is great.

(6) Micromachine Education and Research Initiatives

The Swiss explained their micromachine technology education programs for corporations and universities, while the Swedes reported on their own micromachine technology education program for universities. Both emphasized that "awareness" of the "usefulness" of micromachine technology is an important prerequisite for the advancement of micromachine technology.

(7) Applications to Improve Daily Life Style

As example applications for improving daily life style, the Mr. Hirano discussed the role of micromachines for future Japanese society; the Australians, bionic ears for persons with hearing impairments, and Dr. Ishimaru, the ideas of children who participated in a drawing contest held by MMC. The bionic ears, which are already in commercial use, were described in a videotape that showed how they have improved the speech capabilities of children with hearing impairments. This aroused a great deal of interest among the participants as an actual example of the usefulness and value of micromachine technology.

The Australian hosts had held a drawing contest for local school children similar to that held by MMC, and the winners, before presenting their own works, listened to a speech entitled "School Children's Ideas for Micromachining" by Dr. Ishimaru, who then awarded out the prizes. This wonderful event filled the auditorium with warm feelings, and was the perfect ending for the summit.

Chairman's summary

To mark the summit's closing, the chairman summarized the discussions as follows.

(1) With regard to standardization, an international network with Japan as the core will be constructed to promote standardization using the Internet, based on the results of the workshop held in Japan, and contact persons will be assigned from active countries/regions.

(2) The 1999 summit is to be held in Scotland, with the 2000 summit to be held in Japan, and it was proposed that the 2001 summit be held in the United States. The United States made clear their intent to review the matter in a positive light. Other countries which wish to hold the summit include Germany and Denmark.

(3) Due to activities in Singapore becoming quite pronounced, Singapore will be added as a member at the next summit.

(4) The home page for the summit proposed by Japan shall be started on the Micromachine Center's web site. For the time being, this home page will display pasts programs, participants, and chairman's summaries, in addition to plans for the staging of future summits.

In this, the fourth summit, a common level of awareness of micromachines among the participating countries/regions was notable, as was an awareness of the need for greater efforts to assure the development of micromachines into the 21st century.

Chief Delegates

Country/Region	Chief Delegate	Affiliation
Australia	Prof. Ian Bates	Associate Dean, Faculty of Engineering, Royal Melbourne Institute of Technology
Benelux	Dr. Albert van den Berg	MESA Research Institute, University of Twente
Canada	Mr. Gordon Guild (Proxy: Dr. P. Dawson)	President, MTC Micromachining Technology Center, Simon Fraser University
China	Prof. Zhaoying Zhou	Chairman, Dept. of Precision Instruments & Mechanology, Tsinghua University
France	Prof. Daniel Hauden	Director, LPMO-CNRS
Germany	Dr. Wolfgang Menz	Institute fuer Mikrosystemtechnik, Universitaetsgelaande Flugplatz
Italy	Prof. Paolo Dario	ARTS Laboratory, Scuola Superiore Sant'Anna
Japan	Prof. Naomasa Nakajima	Dean, Faculty of Engineering, The University of Tokyo
Scandinavia	Prof. Jan-Ake Schweitz	The Angstrom Laboratory, Uppsala University
Switzerland	Prof. Nico de Rooij	Institute of Microtechnology, University of Neuchâtel
Taiwan	Dr. Minh-Shyong Lin	Executive Vice-President, Industrial Technology Research Institute
U.K.	Prof. Howard Dorey	Dept. of Electrical & Electronics Engineering, Imperial College
U.S.A.	Prof. Richard Muller	Dept. of EECS, University of California at Berkeley

Portable Micromachine Technology Exhibits (II)

Sanyo Electric Co., Ltd.

"A Small Moving Actuator using a Photon Energy Source"

1. Development of Micromachine Technology

Sanyo is engaged in research on developing a working system for photon energy transmission in which light is used in the wireless transmission of energy and signals. A typical application would be used for a prototype mobile in-pipe wireless micro-inspection machine system in which a small wireless device transmits information, about foreign objects for instance, to the outside.

This research project, based on current photovoltaic microdevices, aims to develop advanced microphotovoltaic devices by adding new optical communication functions and systematization for photon energy transmission. Research is focusing on advanced performance of photovoltaic devices, functional system integration, and microresource management.

2. Overview of the Portable Exhibit

[Significance of creating the exhibit]

Energy supplies are a major issue in the development of independent micromachines, and Sanyo has addressed this issue since phase I and demonstrated the validity of driving a micromachine using a photon energy supply. The exhibit features part of these development efforts.

The achievements of phase I showed it was possible to drive a micromachine sensor or actuator by supplying photon energy through a flexible photovoltaic device mounted on the micromachine's surface. This use of a micromachine's surface for supplying energy is advantageous according to the scale effect in miniaturized devices (i.e., the increase in the ratio surface area/volume). Thus, the exhibit demonstrates that energy can be supplied to a device mounted to a small actuator simply by irradiating light from an outside source (Fig. 1).

[Explanation of the exhibit]

The small actuator (Fig. 2) modeled after a ladybug is the demonstration device for the exhibit. The two film-shaped objects on its back are a newly developed flexible photovoltaic microdevice capable of converting light directly into electricity. When exposed to sun light, this ladybug-shaped device will operate virtually indefinitely. The parts that look like the ladybug's eyes are photosensors which detect light so that the device stays within the spotlight beam as it moves around.

[Key points in the exhibit]

The flexible photovoltaic microdevices atop the small actuator (size: 1 × 1.5 cm, driving power: approx. 1.3 mW) feature a thin film of amorphous silicon and a structure (Fig. 3) formed using laser microfabrication technology, that is capable of generating roughly 2.5 V and which can be mounted on curved surfaces having a radius as small as 2 mm. We have also developed a high-voltage photovoltaic device capable of generating 207 V, the world's highest for a 1 cm^2 device (Fig. 4).

3. Future Applications

We plan to develop advanced energy supply technologies because of their importance in the commercialization of micromachines, and, after that, to achieve even more-advanced energy supply technologies through integration with other functions and the use of microresource management technologies. We will also conduct research and development on applying these technologies to portable devices.

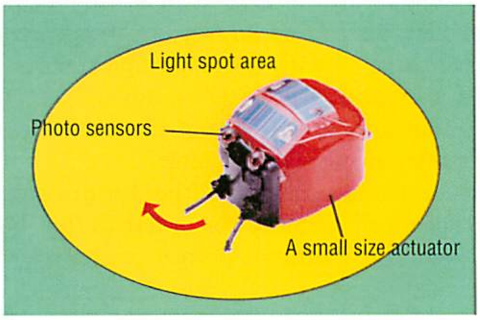

Fig. 2 Illustration of a small ladybug actuator

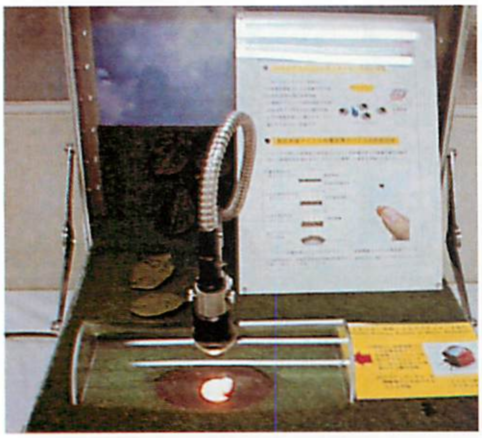

Fig. 1 Portable exhibit "A moving small actuator by photon energy supply"

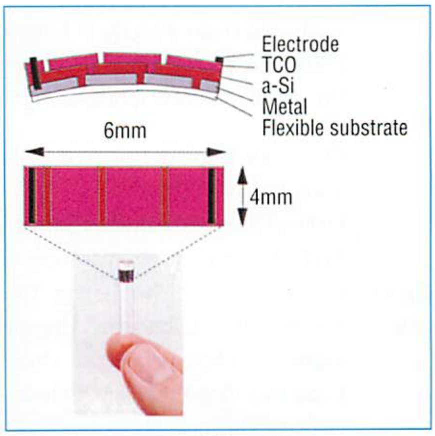

Fig. 3 Structure of flexible photovoltaic micro-device

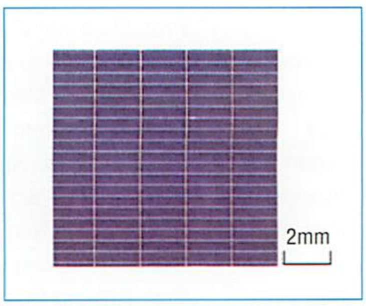

Fig. 4 High voltage photovoltaic micro-device

DENSO CORPORATION
"In-Pipe Micro Inspection Machine"

1. Development of Micromachine Technology

DENSO CORP. is engaged in research on prototype of wireless micromachine for inspection on inner sueface of tubes capable of traveling through and inspecting the inside of complex pipes at power plants and other facilities. We are focusing on research on systematization technology for configuring the overall system, including locomotion devices capable of moving through pipes, microwave energy supply and communication devices, control circuits and mounting (Fig. 1).

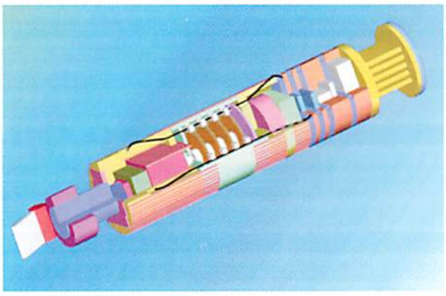

Fig. 1 Prototype of wireless micromachine for inspection on inner surface of tubes

2. Overview of the Portable Exhibit

[Significance of creating the exhibit]

A micromachine such as this prototype in-pipe environmental recognition system requires a variety of element technologies, such as a micro mechanism capable of moving in response to various environmental changes, microsensors for inspecting the surrounding area, and fabrication technologies for combining these miniature components mechanically and functionally.

The objectives of this exhibit (Fig. 2) were to demonstrate the performance of the locomotion device's in-pipe movement and the defect detection device for finding cracks in pipes, and to find the issues relating to the system integration technologies used to combine these multiple devices into a single system.

Fig. 2 Portable exhibit

[Explanation of the exhibit]

The micro inspection machine is 5.5 mm in diameter, 20 mm long, and weighs 1 g. The movement mechanism is an inertial drive system in which a sawtooth waveform with an amplitude of 100 V and a frequency of 2 kHz is applied to an internal piezoelectric actuator to repeatedly apply an impact force to an inertial body. The reactive force to which the piezoelectric actuator is subjected at this time is used to gradually change the position of a clamp held against inside of the pipe by friction. This makes it possible to move the interior of an 8 mm diameter pipe at a rate of up to 6 mm/sec (Fig. 3).

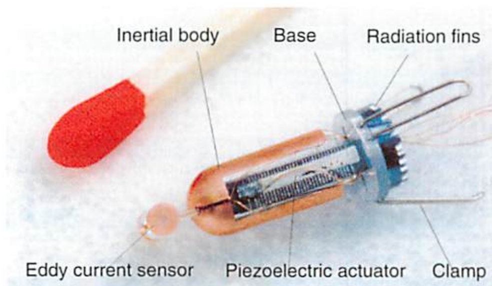

Fig. 3 Internal structure of the micro inspection machine

[Key points in the exhibit]

For the locomotion device, the pipe is partly filled with a liquid to simulate the changing friction conditions that occur when a pipe's inner surfaces are wet. Even under wet conditions, the device is capable of moving with the same parformance as when the pipe is dry.

In addition, the eddy current defect detection sensor, comprised of a 2 mm diameter coil attached to the tip, is capable of detecting flaws as small as 100 μm in metal pipe.

It is said that as such micromachine components become smaller and smaller, the distinction between structural and functional materials will disappear. This necessitates a method of system integration that will not degrade each component's functions. To attach the radiation fins that radiate the heat of the piezoelectric actuator on this micro inspection machine, a heterogeneous material bonding technology was used that does not create an adhesive layer, which would act as a thermal barrier. This allows for greater cooling efficiency than would be possible with a conventional adhesive.

3. Future applications

We plan to conduct research on applying the inertial drive system demonstrated with this micro inspection machine to prototype of wireless micromachine for inspection on inner surface of tubes, and on achieving compact, low-power-consumption actuators. Heterogeneous material bonding techniques and other fabrication technologies will also lend themselves to future high-density mounting applications.

THE FOURTH INTERNATIONAL MICROMACHINE SYMPOSIUM

Foundation of Industrial Technology in the 21st Century

Date: October 29 - 30, 1998
Venue: Science Museum, Tokyo
Organizers: Micromachine Center / Japan Industrial Technology Association
Supporters (Expected): Ministry of International Trade and Industry (MITI) / Agency of Industrial Science and Technology (AIST) / New Energy and Industrial Technology Development Organization (NEDO)
Cooperators (Expected): Federation of Micromachine Technology / Micromachine Society (Tokyo) / Research Committee on Micromachine (Nagoya) / Japan Robot Association / Japan Power Engineering and Inspection Corporation / The Japan Machinery Federation
Registration Fee: ¥15,000 (Including proceedings and reception party)
Application: Complete the symposium registration form and FAX to Micromachine Center by Oct. 15, 1998
Contact: Micromachine Center
(TEL +81-3-5294-7131, FAX +81-3-5294-7137)

PROGRAM (Tentative, as of July 27, 1998)

October 29, 1998

9:00 ~

Session 1: Opening		**Chaiman: Mr. T. HIRANO**
9:30	Opening Declaration	Mr. Takayuki HIRANO, Executive Director, Micromachine Center
9:30 ~ 9:35	Opening Remarks	Dr. Tsuneo ISHIMARU, Chairman, Micromachine Center
9:35 ~ 9:43	Guest Speech (Expected)	Director-General, Machinery and Information Industries Bureau, MITI
9:43 ~ 9:51	Guest Speech (Expected	Director-General, AIST, MITI
9:51 ~ 10:00	Guest Speech (Expected)	Chairman, NEDO
10:00 ~ 10:45	Special Guest Speech : The World of Micromechanisms	Prof. Teru HAYASHI, Dean, Faculty of Engineering, Toin University of Yokohama
Session 2: The Path to New Industries in the 21st Century		**Chairman: Prof. T. SATO**
Exploiting Applications		
10:45 ~ 11:05	Micromachine and Lifestyle in the 21st Century	Associate Prof. Tetsuo KIDOKORO, The University of Tokyo/Japan
Market Forecast		
11:05 ~ 11:25	NEXUS - Results of the Market Analysis	Mr. Gaetan MENOZZI, NEXUS, EC/France Mr. Jean-Christophe ELOY, YOLE Development/France
Application		
11:25 ~ 11:55	Application of MEMS to Cochlear Implants and other Aids to Hearing	Mr. John HUIGEN, Bionic Ear Institute/Australia
Infrastructure		
11:55 ~	Role of Microfabrication Foundry in MEMS R&D	Prof. Susumu SUGIYAMA, Ritsumeikan University/Japan
~ 12:30	Foundry and Product Development Activities in the USA	Ms. Karen W. MARKUS, MCNC/USA
12:30 ~ 13:30	Lunch	
Session 3 : Thinking of Micromachines		**Chairman : Prof. M. ESASHI**
13:30 ~ 13:50	An Encounter of Micromachine with Children (tentative)	Prof. Naomasa NAKAJIMA, The University of Tokyo/Japan
13:50 ~ 14:10	Insect and Micromachine	Assistant Prof. Ryohei KANZAKI, University of Tsukuba/Japan
14:10 ~ 14:30	Origami may reveal idea of Micromachine structure	Prof. Yoshihide MOMOTANI, Kyoto International University/Japan
Session 4 : Activities in USA and Europe		**Chairman : Prof. H. FUJITA**
14:30 ~ 15:00	MEMS Research/Development at Case Western Reserve University, USA	Prof. Wen H. KO, Case Western Reserve University/USA
15:00 ~ 15:30	Current MST Programme at CNRS	Dr. Jean-Jacques GAGNAPAIN, CNRS/France
15:30 ~ 15:50	Break	
Session 5 : Innovative R&D		**Chairman : Prof. K. IKUTA**
15:50 ~ 16:10	Reversible Micro Bonding	Dr. Naoe HOSODA, The University of Tokyo/Japan
16:10 ~ 16:30	Optical Radiation Pressure Micro-machining Using Diamond Grain	Prof. Takashi MIYOSHI, Osaka University/Japan
16:30 ~ 16:50	Micromachined Optical Bench	Prof. Hiroyuki FUJITA, The University of Tokyo/Japan
16:50 ~ 17:10	Lab-on-a-Chip Devices for Acquisition of Chemical and Biological Information	Dr. J. Michael RAMSEY, Oak Ridge National Laboratory/USA
18:00 ~ 20:00	Reception Party at Josui Kaikan	

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Session 6 : Current Status of Micromachine Technology Project in ISTF Program		**Chairman : Dr. Y. ISHIKAWA**
9:30 ~ 9:40	Overview of ISTF Program	Mr. Makoto OKAZAKI, Director for Machinery and Aerospace R&D, AIST, MITI/Japan
Researches and Future Prospects on Micromachine Technology in National Research Laboratories		
9:40 ~ 9:55	R&D on Micromachine at Mechanical Engineering Laboratory - today and tomorrow	Dr. Yuji ENOMOTO, Mechanical Engineering Laboratory, AIST, MITI/Japan
9:55 ~ 10:10	Research on Micromachine Technology at ETL	Dr. Hideo TSUKUNE, Electrotechnical Laboratory, AIST, MITI/Japan
10:10 ~ 10:25	Results of Research on Micromachine and Prospects for Future Subjects in NRLM	Dr. Akira UMEDA, National Research Laboratory of Metrology, AIST, MITI/Japan
R&D in Micromachine Center		
10:25 ~ 11:10	Overview - Present Status of 2nd Phase "Micromachine Project" -	Mr. Kazuhisa YANAGISAWA, Research Committee, MicromachineCenter/Japan
● R&D (1)		
11:10 ~ 11:30	Microwave Energy Supply for In-pipe Micromachine	Mr. Takanari SASAYA, DENSO CORPORATION/Japan
11:30 ~ 11:50	Integration of Photon Transmission System by Lasaer CVD Wiring	Dr. Hisaki TARUI, SANYO Electric Co., Ltd./Japan
11:50 ~ 12:10	Motion Performance Simulator for Micromachine	Mr. Munehisa TAKEDA, MITSUBISHI ELECTRIC CORPORATION/Japan
12:10 ~ 12:30	Mechanical Planetary Gears for a Micro-reducer	Mr. Norisato SHIMIZU, Matsushita Research Institute Tokyo, Inc./Japan
12:30 ~ 13:30	Lunch	
● R&D (2)		
13:30 ~ 13:50	Micro Welding Device for Experimental Catheter-type Micromachine	Mr. Hideto NAKADA, OLYMPUS OPTICAL CO., LTD./Japan
13:50 ~ 14:10	Microfabrication Technology using Scanning Near-field Optical Microscopy	Mr. Yasuyuki MITSUOKA, Seiko Instruments Inc./Japan
14:10 ~ 14:30	Microfluid Operation Device using a Surface Treatment Technology	Mr. Takeshi HARADA, Hitachi Ltd./Japan
14:30 ~ 14:50	Application of Micromachine Technologies for Catheters	Mr. Takeshi KUDOH, TERUMO Corporation/Japan
14:50 ~ 15:00	Break	
● Technology Trend		
15:00 ~ 15:15	The R&D Trend of Measuring Technologies for Micromachines	Mr. Hideaki YAMAGISHI, Research Committee, Micromachine Center/Japan
15:15 ~ 15:30	The R&D Trend of Design and Simulation Procedure for Micromachines	Dr. Hiroshi GOTO, Research Committee, Micromachine Center/Japan
15:30 ~ 15:45	The R&D Trend of Micro-Actuator Technology	Mr. Haruo NAKAZAWA, Research Committee, Micromachine Center/Japan
Session 7 : Closing Chairman : Mr. T. HIRANO		
15:45 ~ 15:50	Closing Address	Mr. Hikaru HAYASHI, Managing Executive Director, Japan Industrial Technology Association/Japan

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