1999 8

MMC

MICROMACHINE

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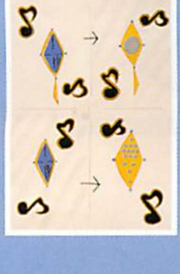

MICROMACHINE CENTER

No.28

Preface

Naotake Ooyama
Director-General, Mechanical Engineering Laboratory
Agency of Industrial Science and Technology
Ministry of International Trade and Industry

As we approach the end of the century, Japan's manufacturing industry is facing its first technological revolution since the industrial revolution. We have entered an era in which the conventional consumer goods industry based evaluation criteria have moved to the one which is human-friendly, and places emphasis on the environment, such as energy conservation, resource conservation and zero waste. The production of food to accommodate the increase in world population and the new mechanization to support this production calls not for an expansion of existing technology, but instead requires totally new ideas. It is no longer acceptable to consume large quantities of energy, and the utilization of resources is limited. It is within this context that we have stipulated priority sectors and directions. The three priority sectors we have stipulated in addition to conventional basic technologies, are currently regarded as state-of-the-art technologies: the energy and environment sector; the manufacturing technology sector; and the robotics/medical and welfare sector. To these we have added three directions for research: concurrentization, microminiaturization, autonomization. And we are currently realizing the "The Creation of Human- and Environment-Friendly Advanced Mechanical Technology" (Fig. 1) as the embodiment of these directions.

With regard to concurrentization, we must attempt to move from the concurrentization of the past in which the design and production fields were fused to develop in parallel simultaneously, to global concurrentization. This will result in manufacturing technology systems being optimized and integrated, becoming environment-friendly, and the evolution of a totally different social structure from the disposable structures that have existed in the past. That is to say, the concepts of "inverse" and "ecofactories" will become key technologies. This means changing to a technological system that optimizes all processes, from design and production to dismantling and recycling. In other words, up until now society had been one in which products were designed and manufactured, and ended when they were consumed. The global environment can no longer exist unless we create technological systems that dismantle and recycle products that have been consumed. Microminiaturization is extremely important as the manufacturing technology involved here. This encompasses microminiaturization, ultra-precision and functional integration. There is also a demand for automation, sophistication and human- and machine-harmonized autonomy in the robotics/medical and welfare sectors. Japan is experiencing the rapid aging of its society, and it is vital to make machines easier for the elderly to use. There is a need to create a human-friendly relationship, i.e. advanced welfare support systems using human-friendly robots. We are developing the "The Creation of Human- and Environment-Friendly Advanced Mechanical Technology" while concentrating on these three directions.

As can be seen in Fig. 1, microminiaturization is the central research issue for the future, and Japan, the US and Europe are fighting an evenly matched major battle against one another in this area. The Micromachine Center stands at the forefront of Japan's micromachine research, and its research findings have an impressive track record. Wide-ranging interaction including joint research on micromachine materials, design/manufacture and microfactories continues to take place between the Micromachine Center and our laboratory. In this background, one of the research results achieved is the world's first microlathe, on August 8, 1996. This is one example of the extremes to which factories and their component machine tools, conveyors and production lines can be miniaturized. This microminiaturization consumes power of 1.5 W, equivalent to 1/1000th of that of conventional machine tools, with a weight of 100 g, or 1/10,000th, and dimensions of 3 cm, or 1/50th. The point which should be noted is that the microlathe probably operates on new principles. While the microlathe shakes, it produces the same surface roughness and roundness as general-purpose machine tools, with a processing accuracy of 1 μm. It is quite possible to be able to realize a microfactory with a revolutionary type of machine processing. If this technology is applied, it should be able to make a great contribution to energy conservation, resource conservation and global warming. I am sure we will soon see the day when Japan will become home to the first microfactory.

Cooperating with industry, academia and public authorities, centering on the Micromachine Center, we hope to devote our utmost efforts to creating new microminiaturization technology sourced from Japan, and realize "Human- and Environment-Friendly Advanced Mechanical Technology." We look forward to your cooperation in the future.

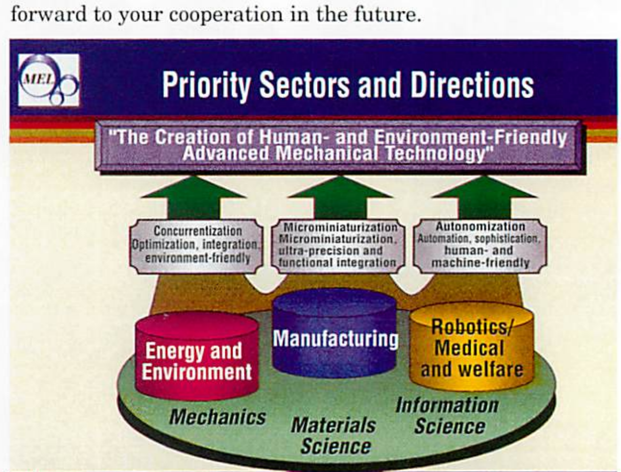

Fig. 1

Investigation into Environmental Information Processing and the Mechanisms of Intelligent Behavior Released by Micro-Brain Systems

Associate Professor Ryohei Kanzaki
Kanzaki Laboratory, Institute of Biological Sciences, University of Tsukuba

1. Introduction

Insects have evolved adapting themselves to various environments to diverse more than 18 million species known to date. Their diversity is also seen in different movement patterns such as flying by beating wings, walking on six feet, and swimming. The behavior of an insect is produced by acquiring environmental information via sensors, through information processing and integration in the brain, and by instructing the motor system by the brain. Examples of the resulting movements can be found with an ant going around or passing over obstacles, or a fly in an acrobatic flight. What is amazing is that such behavior is displayed by functions of a motor system and a micro-brain consisting of as few as $10^{4\text{-}6}$ neurons contained in the tiny body of the insects (Figs. 1A-1D). Insects probably have acquired their brain structures, functionality, and intelligence fit for their size through natural selection.

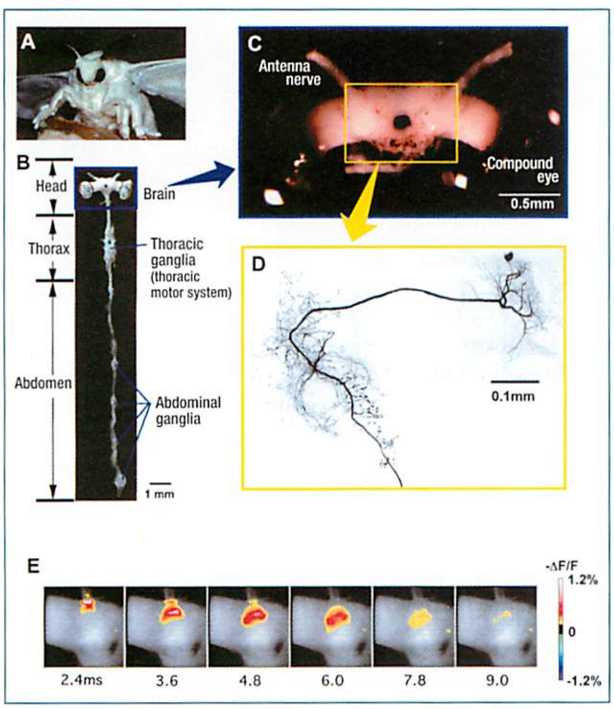

Fig. 1 Analytical study on micro-brain of insects
A. Silk moth (*Bombyx mori*)
B. Brain, thoracic ganglia, and abdominal ganglia of silk moth
C. Micro-brain
D. Brain neuron showing flip-flop response
E. Image of neural activity transfer produced by electric stimulus to antenna nerve to primary olfactory center (antennal lobe)

2. Study Objectives

Environmental information is changing moment by moment. Insects acquire and process this information, and display appropriate behavior. For instance, pheromone molecules released from the source float in the air and continually change their distribution status in space in complex patterns. Under such conditions, insects can trace the pheromone molecules to orient toward a mate over several kilometers away. The aims of our research are to clarify the design principle of the micro-brains of insects and resolve the mystery of the intelligence there, through understanding how insects sense, process, and integrate environmental information and display appropriate behavior, using the orientation of insects toward a pheromone source as a model of primitive intelligent behavior.

3. Current Status

We have been studying the behavioral strategies of pheromone source orientation, pheromone information processing mechanisms in the sensory system, and information exchange processes from sensory system to motor system to clarify the principle of releasing mechanisms of adaptive behavior. Our analytical results are being shared to create small mobile robots with another team led by Professor Isao Shimoyama at the Department of Mechano-Informatics, Graduate School of Engineering, University of Tokyo. We are also fabricating compact and lightweight remote transmitters (telemetry) to record realtime information from living insects freely walking and flying, to evaluate and confirm the analytical results of their behavior and neural functions. Study themes are explained more specifically below.

(1) Behavior analysis

We are studying algorithms of insects' pheromone source orientation with a 3-dimensional behavior analyzer system using a wind tunnel and high-speed video camera. Insects have rather a small number of neurons in the brain, so they can basically show programmed, fixed patterns of behavior. Nevertheless, our recent study shows insects modify their fixed behavioral patterns flexibly through interaction with their surroundings.

(2) Analysis on single brain neuron level and neural network level (Fig. 1)

We are trying to clarify the brain neural networks in the brain that command insects' pheromone locating behavior by recording the single brain neuron activities and the neuron's 3-dimensional structure by using a confocal laser scanning microscope (Fig. 1D). An interesting point is that the neural circuits elicite a response similar to the operating characteristics of the flip-flop used as a memory device in an electronic circuit. We demonstrated that insects search repeatedly for pheromone sources turning from left to right, then right to left, according to the signals from the neural circuits.

(3) Analysis on neuron system level (Fig. 1)

We succeeded for the first time in the world in the display of graphic images, at good signal-noise ratio, of spatio-temporal activity patterns of a brain in the antennal lobe, the primary olfactory. (Fig. 1E). Now we have proceeded to analyze the pheromone information coding in the brain from the spatio-temporal pattern changes produced by the interaction of multiple cells as well, not only the response patterns of a single neuron. Recent electrophysiological studies suggested that odors are coded as an oscillation evoked by interaction of multiple cells in the antennal lobe of honeybees and grasshoppers. We also succeeded in capturing the oscillation as graphic images. There may be common neural mechanisms shared by insects and vertebrates.

(4) Verification of analytical data using robots (Fig. 2)

The analytical data obtained from themes (1) and (2) was integrated and used to build small mobile robots, to reproduce the behavior for testing and evaluation (Fig. 2C). We used the real antennae of a silk moth as the pheromone sensor for the robots (Figs. 2A, 2B). Insects sense odors using their antennae. If the robots display pheromone source oriented behavior similar to that of silk moths, it indirectly underpins our theory derived from the analysis. If the robot fails to imitate the moth, and if we can find the factors that would make the robot properly imitate, then we can conjecture the existence of unknown circuits equivalent to the factors in the moth brain. Changing the programs for instructing the behavior of the robot and testing the resulting behavior probably helps to study the role of each neuron. We think that clarifying problems in the analytical results will help further detailed study on the brain function.

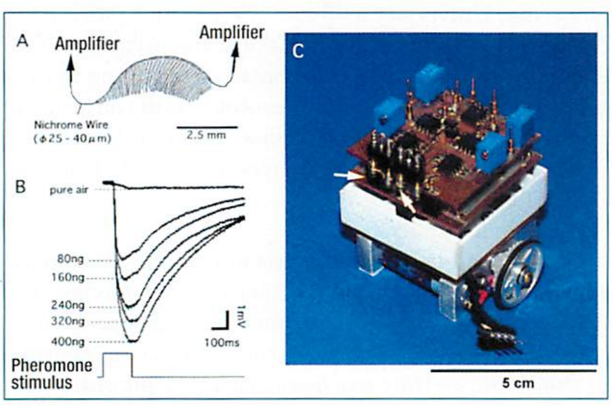

Fig. 2 Synthetic study on micro-brain of insects
A,B. Dose dependent responses to odor (pheromone) elicited between the tip and base of a silk moth's antenna
C. Small mobile robot with moth antennae (arrows) used as pheromone sensors

(5) Analysis of live information by telemetry (Fig. 3)

We fabricated small and lightweight (0.4 grams including the battery) remote transmitters with 2 FM channels to record by the telemetry realtime information of nerve activities and muscle activities of freely flying or walking insects (Fig. 3). We have already succeeded in recording flight muscle activities of a flying insect. At present we are trying to record neural activities with an advanced telemeter. If we succeed, the records of the brain neural activities of freely moving insects will verify on analytical results in (1) and (2).

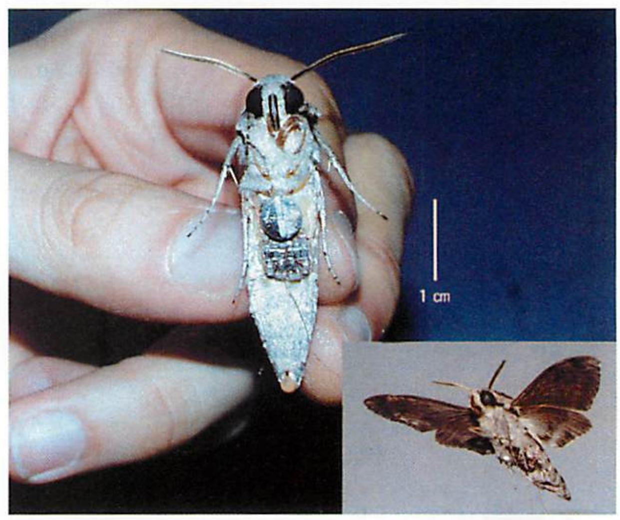

Fig. 3 A hawkmoth (*Agrius convoluvli*) with telemeter

4. Conclusion

As explained above, our team is trying to clarify the principles of adaptive behavior of insects instructed by a micro-brain. We are proceeding by analysis of insect behavior, electrophysiological and optophysiological analysis on the levels of a single neuron, neural network, and system, verification with robots, and telemetry technology.

We hope to understand the unique neural design contained in the micro-brains of insects which has been acquired through environmental changes over 300 million years, as well as to find common information processing principles between the brains of insects and vertebrates. We firmly believe these results will contribute to the creation of next-generation micromachines.

Activities of the Micromachine Center Conducted in Fiscal 1998

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 1998 financed the following R&D themes:

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

① R&D of systematization technology (Experimental wireless micromachine system 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 experimental in-tube automatic environment monitoring system comprising mobile device (main unit), micro-wave energy supply and communication devices; micro visual system that takes picture of defects, etc., and transmit the image signals using little electricity; and optical energy transmitting system to supply energy and handle communications.

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 experimental chain-type micromachine for inspection on outer surfaces of tubes via the development of the driving device that drives the main unit, reduction and travelling devices that convert the driving power of the driving device to running function, 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 experimental system to perform work within equipment, via the development of flexible structure (main unit) with multi-degrees of freedom and manipulators for repair; system integration of attitude detection device composed of small gyroscopes and optical scanner-applied monitoring device; and so on.

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 muscle, an actuator with high capability to change position and generate power to use for driving and performing work; micro joint that can joint devices with different contact surfaces and receive and transmit signals and energies; low-friction suspension devices, such as magnetic bearings that reduces friction of micro-driving unit; rechargeable micro batteries used as emergency voltage-regulated power supply in case a micromachine fails to receive energy from outside; optically driven free joint devices driven by electricity generated by converting laser light for positioning work tools precisely; and so on.

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 pattern-forming technology for groups of distributed micromachines to form patterns suitable for particular work, such as simultaneous inspection; hierachical group controlling technology to materialize holonic mechanism to facilitate ultra-free movement within narrow and complicated environment; technology to measure minute shapes of micromachines, moving behavior, and weak power or torque of actuators, etc.; and measuring technology for micromachines that use micro optical analysis to detect defects, etc., in tubes.

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.

(2) Development of microfactory technology

① R&D on experimental system for processing and assembly

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 analysis of the economic efficiency of microfactories and technology to control micro-vibration of platform in microfactories, and with the AIST's Electrotechnical Laboratory on improving the function of micro electronic guns used for beam processing.

(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. In the field of micromachine systems for rescue operations, researches for elemental technologies for monitoring-use small high-performance optical device to attach to flexible catheters and micro dosing devices. In addition, as part of the researches of elemental technologies for micromachine systems for microanalysis and reaction of liquid for screening substances that may be used for drugs, detailed review was made as to the mechanism for sampling, mixing and analyzing small amount of liquid, and basic structure of micro multi-reactor that facilitates simultaneous multi reactions.

② Comprehensive investigation and research

Comprehensive investigation and research was conducted on effectively using of micromachine systems for future medical applications. MMC has also jointly investigated with the AIST's Mechanical Engineering Laboratory on basic technologies for designing and manufacturing micromachines.

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 working environments for micro functional elements, ② materials for micromachine, and ② a feasibility study on materials for micromachine.

3. Investigation and Research on Fundamental Micromachine Technology (aid activities from the Japan Motorcycle Racing Organization)

MMC has conducted joint research with industry and academia, exploring technology seeds of nine 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)

With an aim of forecasting the effects on industrial and social activities of the use of micromachines in the 21st century, investigation and research were conducted on its economic effect assuming scenarios of industrialization of micromachine technologies.

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 from the viewpoint of life environment 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.

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 1998 (6th) and has provided Research Grants for 12 themes, including seven new themes and five 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 4th Micromachine Summit

MMC participated in the "4th Micromachine Summit" held in Melbourne, Australia, in April 1998. The conference started with the introduction of the micromachine activities in each participating country and region, followed by discussions focused on the application of micromachine technologies.

3. European Seminar

In June 1998, MMC held the "European Seminar" in France, Norway and Sweden, jointly with local research institutions.

4. The 4th International Micromachine Symposium

The 4th International Micromachine Symposium was held in October 1998 at Tokyo Science Hall, jointly sponsored by the MMC and Japan Industrial Technology Association.

5. Participation in international symposiums and missions dispatched

(1) In April 1998, a research mission was sent to universities and research institutes in Australia and New Zealand.

(2) In October 1998, MMC took part in "IARP International Workshop on Micro Robotics and System" held in Beijing, China.

(3) In November 1998, MMC took part in "É FLUIDS98" held in Anaheim, California, U.S.

(4) In November 1998, MMC sent a mission to U.S. to research into the possibility of applying micromachines to living environment in 21st century.

(5) In December 1998, MMC took part in "MST98" held in Potsdam, Germany.

(6) In January 1999, MMC took part in "MEMS99" held in Orlando, Florida, U.S. and sent a research mission to universities in U.S.

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

① MMC published "MMC Technical Report on Micromachine Technical Terms," defining 220 terms related to micromachine technology in Japanese and English.

② With regard to measurement and evaluation methods, specific, detailed researches were made into the shape, size, power/torque, hydromechanical properties, and material properties to identify technical problems for standardization.

③ As agreed upon at the 4th Micromachine Summit in Melbourne, MMC launched the "Micromachine International Standardization Forum" for 12 countries/regions on November 5, 1998 on Internet Website for global exchange of opinions, using the mailing list and "MMC Technical Report on Micromachine Technical Terms" as the basis.

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 "5th Micromachine Drawing Contest" with the assistance of MMC's supporting members. 21 elementary schools and junior high schools in Takasago and Kobe (both in Hyogo Prefecture), Gifu (Gifu Prefecture) and Omiya (Saitama Prefecture) sent us 1,464 pictures. MMC selected 25 pictures for awards.

3. Representations of the research results on Fundamental Micromachine Technology in fiscal 1997

Representations of the researche results on Fundamental Micromachine Technology in fiscal 1997 as activities to help promote machine industry, were held on two occasions, July 1998 and January 1999, in Tokyo.

4. Domestic Micromachine Seminars

MMC held "Domestic Micromachine Seminars" for people interested in R&D on micromachine technology, in September 1998 in Okayama (Okayama Prefecture), and February 1999 in Kanazawa (Ishikawa Prefecture).

5. 9th Micromachine Exhibition

MMC held the "9th Micromachine Exhibition" in October 1998 at the Science Museum in Tokyo.

6. Introductory and Promotional Video

MMC renewed the video introducing its activities, and produced memoir videos for the 4th International Micromachine Symposium and the 9th Micromachine Exhibition.

Summary of the Research Supported by the Fifth 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 fifth (1997) research grant, three 1-year researches and four 2-year researches carried over from fiscal 1996 have completed. Turn the pages for the summary of the research results.

Subjects for the Micromachine Technology Research Grant

Research Project Selected for Fiscal 1997

Leader & Co-Worker	Affiliation	Subjects	Period
Yoshinori Matsumoto	Assistant Professor, Faculty of Science and Technology, Dept. of Applied Physics and Physico-Informatics, Keio University	Study of Teflon-like Films for Eliminating Stiction of Micromachine	1 Year
Atsushi Suzuki	Associate Professor, Dept. of Materials Science, Yokohama National University	Development of Mesoscopic Memory of Photo-Responsive Polymer Gels	1 Year
Shojiro Miyake	Professor, Faculty of Engineering, Nippon Institute of Technology	Mechanical Nano Machining of Standard Rulers	1 Year

Carried-Over Projects Selected for Fiscal 1996

Leader & Co-Worker	Affiliation	Subjects	Period
Takashi Miyoshi Yasuhiro Takaya	Professor, Lecturer, Dept. of Mechanical Engineering and Systems, Graduate School of Engineering, Osaka University	Fundamental Study on Micro-machining Using the Optical Radiation Pressure Controlled Diamond Grain	2 Years
Masaharu Kameda	Associate Professor, Dept. of Mechanical Systems Engineering, Tokyo University of Agriculture and Technology	Development of a Micropump based on the Acoustic Cavitation Phenomena	2 Years
Takeo Shinmura	Professor, Graduate School of Engineering, Utsunomiya University	A New Precision Finishing Process for Micro-machine Elements by Magnetic Field Assisted Machining	2 Years
Masahiro Ohka Yasunaga Mitsuya	Associate Professor, Faculty of Science and Engineering, Shizuoka Institute of Science and Technology Professor, School of Engineering, Nagoya University	A Study on Micro Three-axle Tactile Sensor	2 Years

An Application Guidelines for the 7th (Fiscal 1999) 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, 2000 - March 31, 2001, or
   Theme B: April, 2000 - March 31, 2002

3. **Application period, theme decision and fund grant date**
   Application period: July 12 - October 31, 1999
   Theme decision: Early in March, 2000
   Fund grant date: Late in March, 2000

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)

Study of Teflon-like Films for Eliminating Stiction of Micromachine

Yoshinori Matsumoto
Assistant Professor, Faculty of Science and Technology,
Dept. of Applied Physics and Physico-Informatics, Keio University

1. Introduction

In micromachines, hydrogen bonding or van der Waals forces cannot be ignored during the fabrication and usage. The micromachine parts are easily drawn to each other by surface tension of water and then attached. This phenomenon is called stiction and is serious problem because it can degrade micromachine fabrication yields and reliability. The objective of this research is to reduce adhesion and friction on micromachine by depositing a Teflon-like film, which material has the smallest surface energy.

2. Plasma polymerization method

In this research, the plasma polymerization method was adopted to form the Teflon-like film, as it can be deposited in a dry process and has superior film quality. A structure of the plasma polymerization equipment is shown in Fig. 1. This equipment has an anode, mesh cathode, and wafer stage, which can heat the substrate, in a vacuum chamber. The monomer gas and additive gas of the Teflon-like film are supplied respectively from a ring-shaped pipe and a hole in the anode. When plasma discharge is generated between the anode and mesh cathode by a high-frequency power source, the monomer radical gas is diffused from the mesh cathode to the wafer stage and reaches the surface of the wafer to cause the polymerization reaction and form the Teflon-like film. As the cathode and the wafer stage is at the same potential in this equipment, high-quality film can be formed without plasma attack damaging the wafer surface.

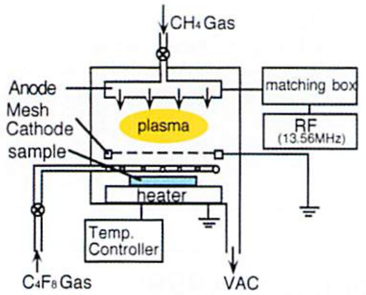

Fig. 1 Structure of plasma polymerization equipment

Teflon-like film is formed by the plasma process of CHF_3 gas, C_4F_{10} gas and Fluorinert (C_5F_{12}, C_6F_{14}, C_7F_{16}) etc. It is known that the deposition rate is improved when the ratio of C and F (F/C ratio) is smaller. In this research, C_4F_8 gas is used as the monomer gas, as it has the smallest F/C ratio, and high deposition rate.

To improve the thermal stability of the Teflon-like film, the substrate is heated and methane CH_4 is added as the additive gas. CH_4 decreases the F/C ratio of the monomer gas and can improve the deposition rate. The deposition rate of the Teflon-like film and its relationship to the CH_4/C_4F_8 ratio and the substrate temperature is shown in Fig. 2. When the substrate temperature is at either 50°C and 200°C, the deposition rate is improved by the addition of CH_4. It is confirmed that the deposition rate was improved approx. ten-fold especially at 200°C.

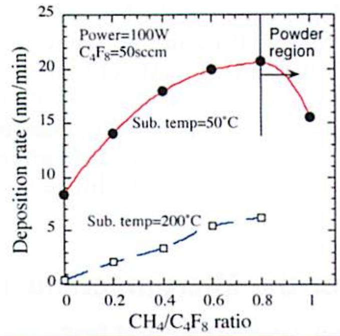

Fig. 2 Deposition rate of Teflon-like film and relationship of CH_4/C_4F_8 ratio and substrate temperature

The Teflon-like film formed in the condition of substrate temperature 200°C, CH_4/C_4F_8 ratio = 0.2, has full thermal stability through annealing at 350°C for 20 minutes in atmosphere. It also has good water repellency after the heat processing, with a contact angle of 110° as shown in Fig. 3, up to an annealing temperature of 350°C. From this result and from the stiction theory reported by Mastrangelo et.al., it was proved that this film is effective for preventing stiction. Then, this film was deposited on an acceleration sensor manufactured by micromachining technology for stiction evaluation, there was no stiction after the specimen contacted the substrate 100 times with an electrostatic attraction force equivalent to 2000G. It was confirmed that this method is effective for preventing stiction in micromachines.

Fig. 3 Water contact angle on deposited Teflon-like film

3. Conclusion

In this research, Teflon-like film was formed using the plasma polymerization method to decrease adhesion and friction of micromachines and it was evaluated. Practical thermal stability and deposition rate were realized by heating the substrate and adding CH_4 gas. The evaluation of the eliminating effect friction was not performed in this work, but a research group in the Sandia National Laboratory in the USA has already reported that Teflon-like film was also effective in decreasing friction. It has also already been confirmed that it is effective for improving the reliability of micromachines and lengthening their service life. We hope that this report will be of value for the practical application of micromachines.

Development of Mesoscopic Memory of Photo-Responsive Polymer Gels

Atsushi Suzuki
Associate professor, Department of Materials Science,
Yokohama National University

1. Foreword

Designing and developing the excellent functions of materials for micromachines depend on how to use the unique structure in the nano-meter size of the material and its unique accompanying phenomena. With the recent progress of polymer physics and chemistry, trials are being proposed to simulate the excellent functions of organisms. This requires development of nano-composites, having various types of flexible structure. In this research, polymer gel is in focus as a soft material that is a dilute multi-degree-of-freedom system with a complex structure. Its structure was studied at the mesoscopic level using technology controlled by illumination of visible light. The objective of this research is to formulate design guidelines for mesoscopic memory controlling micro domain structures by light, using the volume phase transition seen in the light-sensitive polymer gel.

2. Results of the research

2.1 Phase transition of gel and principle of mesoscopic memory

The following three phenomena were found (Fig. 1) from a basic study of the gel, a complicated dilute solid, and its fundamental was constructed.

(1) Shrinking phase transition by illumination of visible light using the hysteresis of phase transition temperature.
(2) Stress-induced phase transition of gel
(3) Direct observation of surface structure of gel in water using an atomic force microscope (AFM)

Based on these phenomena, the memory function can be operated by illumination of visible light as a principle, using the domain of the mesoscopic size of polymer network of gel. The principle of the function is established: writing by the shrinking phase transition due to local heating of polymer network using the hysteresis phenomenon of the domain conformation by external environmental change and erasing by the swollen phase transition due to external environmental change by maintaining the contracted condition even when the light is off.

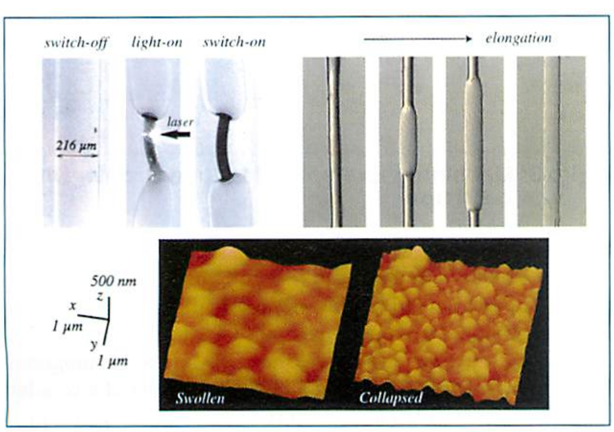

Fig. 1

2.2 Phase transition of domain structure introduced artificially

(1) Poly N-isopropylacrylamide (NIPA) gel, a representative thermo-responsive gel is synthesized in film shape and the inhomogeneity on its surface is observed by AFM and a roughness analysis is made.

(2) NIPA gel is prepared in bead shape, at a diameter of submicron order and its stimuli responsive property is investigated. Gel beads are immobilized in the acrylic amid (AAm) gel, which is thermally stable, and the light responsive property of the hybrid gel is studied. This gel is slightly impregnated with thermo-responsive gel beads and its transparency changes with temperature change. This controls the light transmission as the local shape changing of the gel beads respond to temperature changes without changing the density of the entire gel. The response speed when temperature is quickly changed is measured.

(3) To observe the coagulating condition of the gel beads, NIPA gel beads are immobilized inside the NIPA gel with a homogeneous network structure and a fractured surface of the shrinking phase is observed by AFM (Fig. 2).

(4) Optimal conditions are studied for the function to shrink (write) domain by illumination of visible light and maintain its contracted condition even when the light is off, and to make the swollen phase transition (erase) by an external environmental change. The hierarchical structure of the surface structure of the gel and the dynamic stability of the local shrinking phase are examined.

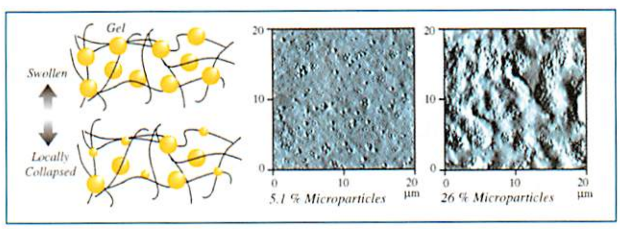

Fig. 2

3. Conclusion

Through this research, the basic principle for controlling the micro-domain structure of polymer gel using visible light was established. The results of the further research will play an important part in establishing an understanding of gel with various characteristics, which a dilute solid with a flexible and complicated structure shows, and in establishing the general principles that generate it. The unique characteristics of gel change systematically, according to a combination of the mesoscopic structure of polymer chain forming the gel, and the correlation between the molecules forming the polymer chain. This mesoscopic domain is thought to be a new micromachine research field for soft materials and this field is greatly expected to develop in the future.

Mechanical Nanomachining of Standard Rulers

Shojiro Miyake
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Nippon Institute of Technology

1. Introduction

This study aims to achieve nano-machining of a layed crystal material using an atomic force microscope (AFM) and a hard film coated tip as a tool. Specifically, removal processing in the order of an atom has been realized. The processing unit is controlled to be the interlayer distance by utilizing the difference between atomic bonding forces in the layed crystal material. As the processing unit of depth, one layer of the layed crystal is removed. In addition, a lattice groove and so forth having a constant depth is formed with high precision. By overlaying the produced nanomachined profile and the surface atomic image, a standard rulers of a three-dimensional length of nm order is formed.

2. Machining Using Atomic Force Microscope

If a crystal material with anisotropy and a periodically weak bond is used as the workpiece, machining with high precision and the even period can be realized. For example, mica (Muscovite mica) has a layer structure, with a cleavage plane having a low interaction at the basal plane. Moreover, the atomic image can be observed at the cleavage plane.

The machining was carried out with an optical lever type AFM. To produce a cubic boron nitride (cBN) coated tip and a diamond like carbon (DLC) coated tip, film was formed on Si tip as a substrate with a diameter of 50 nm or smaller and a vertical stiffness of about 50 N/m. The atomic force was determined from the deformation of a cantilever, with photosensors located above and below. The workpiece was machined by tip sliding at a constant load, in control of the atomic force. For the purpose of machining by the tip into a predetermined profile, the scanning path of the tip was controlled with computer.

Fig. 1 shows the crystal structure of the mica used as the workpiece and the machining model. Mica has a structure in which K, Si, O, Al, OH, and so forth are overlaid. SiO_4 can be observed at the surface. The cleavage plane is defined by the K layer sandwiched between two SiO_4, and consists of planes which distances were about 0.8 nm and 1 nm from the surface. The fracture during the machining occurs between SiO_4 and K bonded through the van der Waals force, a weak bonding force. The mica can be easily machined at every cleavage plane unit.

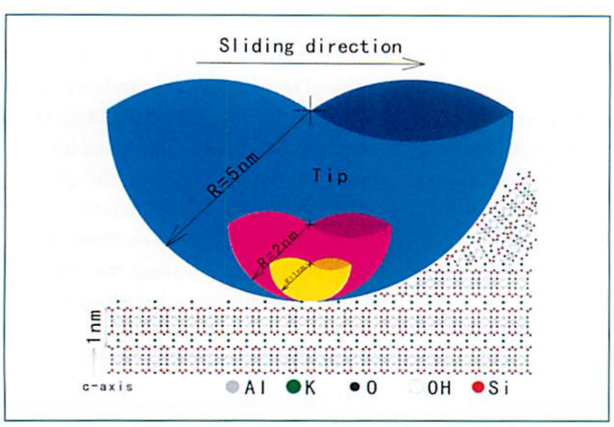
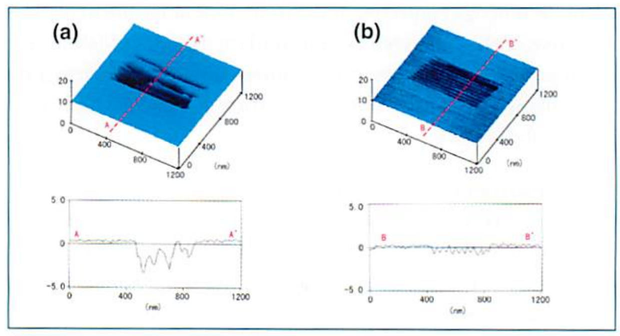


Fig. 1 Machining Model of Mica using AFM

"Line and Space" which is a basic profile for fine machining was investigated. That is, it was examined how narrow the line interval could be set in order to form a groove 1 nm deep. Fig. 2 (a) shows the profile obtained by machining with the Si tip at a line interval of 50 nm. The machined grooves partially overlapped, that is, separated grooves could not be formed. The maximum depth reached about 3 nm. Fig. 2(b) shows a groove formed with the cBN coated tip. With cBN coated tip, finer machining than with the Si tip could be performed. The adjacent machined grooves were separated, and the depth was about 1 nm. With other hard films such as the DLC film and so forth, the produced grooves partially overlapped.



(a) Machining Example with Si tip **(b) Machining Example with c-BN tip**

Fig. 2 Machining Results of Line and Scale

Fig. 3 shows a lattice groove at a pitch of 80 nm formed with the cBN tip which enabled fine machining at nm order. The standard rulers of a three-dimensional length at nm order can be realized by utilizing the above machined lattice grooves and lattice intervals in the surface atomic image.

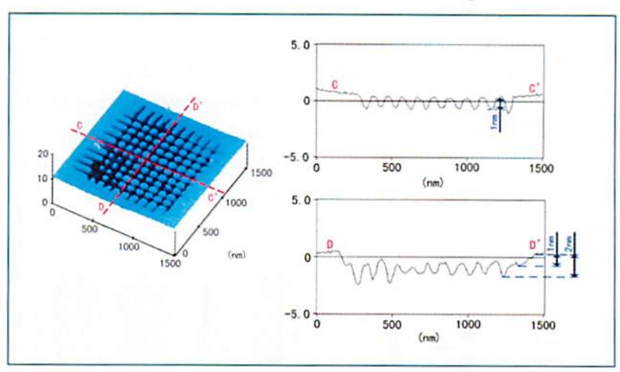


Fig. 3 Machining Example of Lattice Groove with c-BN tip

3. Conclusion

Nanomachining using super hard film coated tip can be widely applied not only to the standard rulers of a length but also the production of micromachines for which high precision is required. Further, at present, our investigation is progressing on nano-technology applied to the formation of a tera-bit AFM memory for ultra high-density recording, a nanomachine, and so forth.

Fundamental Study on Micro-machining Using the Optical Radiation Pressure Controlled Diamond Grain

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Graduate School of Engineering, Osaka University

1. Introduction

The purpose of this study is to establish a new micro-machining technology by using laser trapping technology that enables trapping and controlling grains under very low optical radiation pressure, which laser beam exercises over objects. As Fig. 1 shows, when focused laser beam strikes a grain, for example diamond grains, the momenta of photons change with the reflection and refraction of light on grain surfaces, followed by the resultant force of the optical radiation pressure working as a trapping force at the center of the gravity.

Its components in vertical and horizontal directions work as downward pressing and rotating forces, respectively. The fluctuation of the focus position results in longitudinal oscillation, with the crosswise scanning producing a cutting force. This study aims at realizing micro-machining by using and controlling a variety of properties of the above-described optical radiation pressure.

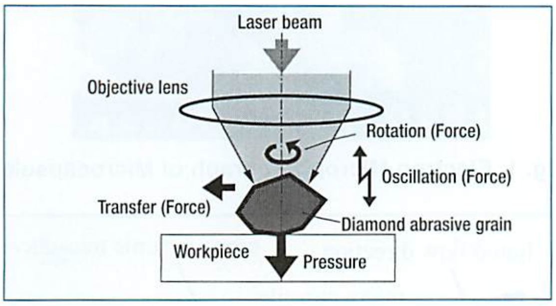

Fig. 1 Concept of Micro-machining with Optical Radiation Pressure

2. Laboratory Equipment

Fig. 2 is a schematic diagram of the prototype of the laboratory equipment, consisting of a laser-trapping optical system that traps diamond abrasive grains and a microscopic optical system for observing the behavior of diamond abrasive grains using the CCD camera. First, Ar laser beam is focused with the objective lens (NA 0.55) and applied to diamond abrasive grains. The laser output is 0.3 W with a laser spot diameter of about 4 µm. The pressing force is estimated to be in the order of 0.1 nN based on the computer simulation. Next, the diamond abrasive grains with a diameter of several µm are dispersed in an aqueous solution of KOH with its pH adjusted to 11. Then, a machining experiment is carried out in a glass container as given in the figure, with this treated solution applied onto silicon wafer chips. Transfer of the stage with samples can be computer-controlled so that an arbitrary locus can be drawn in units of several mm.

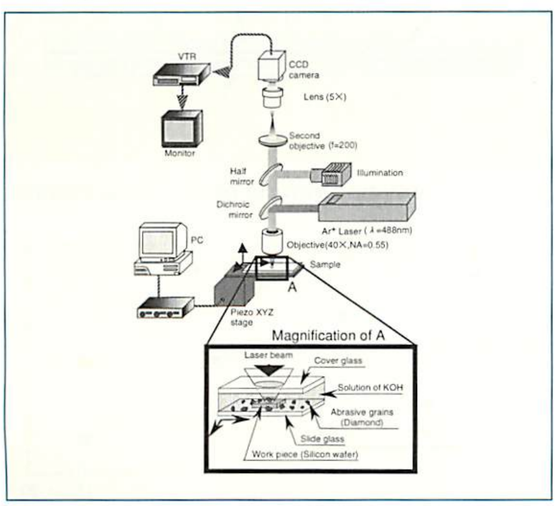

Fig. 2 Laboratory Equipment for Optical Radiation Pressure-induced Micro-machining

3. Experiment Results

Fig. 3 gives an example of the experiments: an image observed by AFM on the surfaces of silicon wafer samples scanned 50 times with diamond abrasive grains rotating at a speed of about 150 rpm. The size of the diamond abrasive grain is about 6 µm in the longer diameter and 3 µm in the shorter diameter.

The "⌈ " shaped dark part low in luminance appearing in the center of the figure may be traces of machining. This concave section profile (section A-B) has a groove, 3~4 nm in depth and about 4~5 µm in width, equivalent in size to the diamond abrasive grain used. Optical radiation pressure-induced micro-machining may be accomplished in the following manner: light irradiation lowers the bond strength between atoms so that a very small impact force from the rotating abrasive grains (optical radiation pressure) can render comparatively easy removal, with the removal further accelerated chemically with the KOH solution.

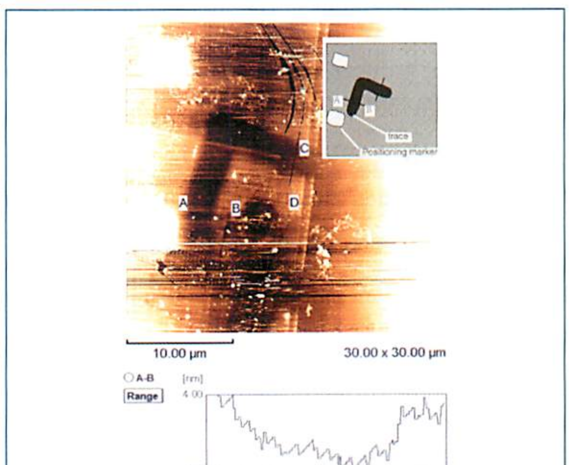

Fig. 3 AFM-Image of Machining Traces and Sectional Profile

4. Conclusion

Optical radiation pressure to the extent of 0.1 nN can stably hold diamond abrasive grains about 4 µm in average diameter. In addition, some of the abrasive grains rotate at a speed of about 150 rpm with the rotating abrasive grains transfer-controlled freely. Traces of machining, observed in the order of several nanometers in depth, were brought about by the light emission pressure-induced pressing and rotating forces upon the diamond abrasive grains in the KOH solution. This in turn suggests the possibility of micro-machining.

Development of a Micropump based on the Acoustic Cavitation Phenomena

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Tokyo University of Agriculture and Technology

1. Introduction

We have developed miniature pumps by utilizing bubble expansion and contraction due to pressure change. Bubbles expand and contract to a large extent under specific conditions in the sound field, a phenomenon called accoustic cavitation. Positively taking advantage of this movement, we aimed at achieving a pump system through which a large flow can be expected despite its small size.

2. Hollow and Elastic Microcapsules

It is difficult to keep bubbles stably in liquid which led to the development of a hollow microcapsule with an elastic wall to perform the function of the bubbles. A composite of polystyrene-vinyl based polymers (PS-nBA) and synthetic rubber (styrene-butadien rubber: SBR) was used for the walls. The capsule was prepared using the submerged drying method.

Fig. 1 shows an electron microphotograph of the prepared microcapsules. They are spherical with a diameter of about 0.2 mm, most of them having pinholed walls. Those with pinholes are unacceptable, because they allow the sealed in air to leak from the pinholes. Because of the poor yield of hermetically-sealed capsules at present, improvement of the method of preparation needs to be made. We also checked the behavior of the capsules under reduced pressure to confirm the expansion of those capsules without pinholed walls.

3. Valveless Pumps

Next, we designed a pump shown in Fig. 2. Because of the difficulty involved in manufacturing a valve that moves in compliance with high-frequency bubble expansion and contraction, we decided to adopt a valveless system.

The valveless pump we designed has a paired nozzle/diffuser. The flow through the nozzle differs from that through the diffuser under the same conditions. Fig. 3 gives the findings calculated on the differences in flow under several conditions. The findings clearly show that the volume flow rate through the diffuser is larger than that through the nozzle, irrespective of the conditions. Accordingly, this valveless mechanism enables the creation of a unidirectional flow.

4. Conclusion

As important components of the pump, we manufactured hollow, elastic capsules, and designed a valveless pump to evaluate its performance. The results were as we had expected. Now, we are making the prototype of a pump system into which all the above factors are incorporated and will carry out performance tests in the near future.

We would like to express our sincere thanks to Prof. S. Omi at Tokyo University of Agriculture and Technology for his valuable advice on microcapsules, and Dr. O. Nakabeppu at Tokyo Institute of Technology for his assistance in developing the valveless pumps.

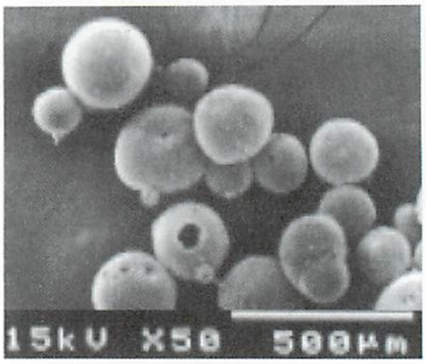

Fig. 1 Electron Microphotograph of Microcapsules

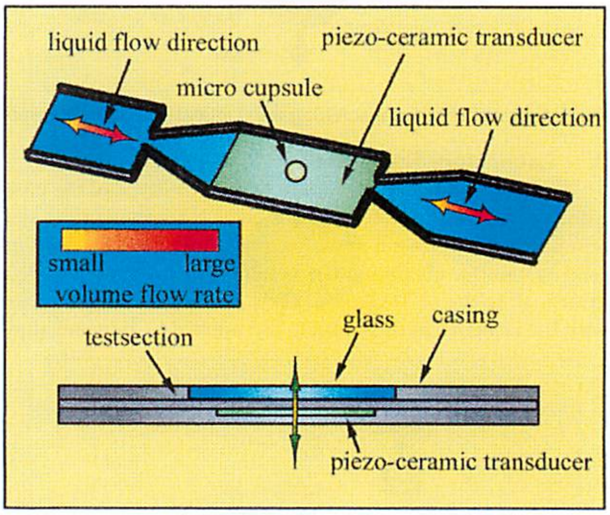

Fig. 2 Schematic Drawing of Valveless Pumps

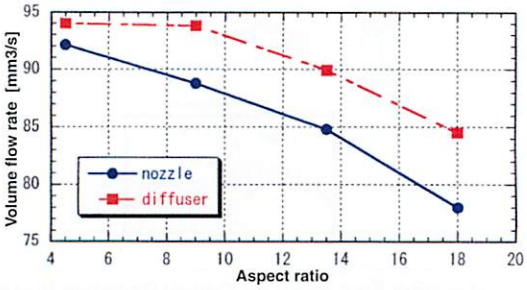

Fig. 3 Flow Characteristic of Nozzle/Diffuser

A New Precision Finishing Process for Micro-machine Elements by Magnetic Field Assisted Machining

Takeo Shinmura
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Utsunomiya University

1. Introduction

Recently the trend is particularly noteworthy in miniaturization, lighter weight, and higher performance of computers, medical equipment, and various precision machines, to say nothing of fine parts for micro-machines. Therefore the development of a new high-precision finish technology to meet the demand for fine, intricately-shaped parts as the components of the above equipment is earnestly desired. In this study we investigated whether the magnetic polishing method we developed can be applied to answer the above social needs.

2. Processing Principle and Problems Encountered

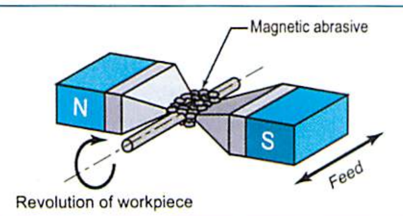

Fig. 1 Processing Principle of Magnetic Abrasive Finishing

Fig. 1 gives the principle of processing. When the processing zone is filled with magnetic abrasive grains between N-S magnetic poles, the grains are lined up along the line of magnetic force to produce a magnetic force (processing force). When workpieces are inserted into the processing zone and rotated, their surfaces are precisely finished.

The magnetic polishing method can be applied to miniaturized, intricately-shaped workpieces by miniaturizing the processing device and by rendering the magnetic abrasive grains finer.However, finer abrasive grains lead to a decrease in the processing efficiency due to a decrease in the processing force.On the other hand, it is necessary to enlarge the grain diameter to create a higher magnetic force. In this case, however, workpieces may enter between the larger abrasive grains resulting in a decrease in the contact point between the two to lower the processing efficiency. It therefore appears to be difficult to process miniaturized, intricately-shaped workpieces only by simply reducing the scale of the magnetic polishing method. We therefore carried out experiments to check the limit of the diameter for optimum processing.

3. Processing Experiments and Results

Fig. 2 shows a photograph of the appearance of laboratory equipment. The carriage of the small bench lathe is provided with a magnetic pole, a yoke, and a permanent magnet to generate the magnetic field. The direction and the rate of feed can be automatically controlled by motor. The workpiece is a SUS304 round bar, 1.5 mm in diameter and 75 mm in length. The processing experiment was carried out by varying the number of rotations of the workpiece, magnetic pole feed rate, and the diameter of iron powder to be mixed with the magnetic abrasive grains, to investigate the realizability of the magnetic polishing method and the influence on processing properties.

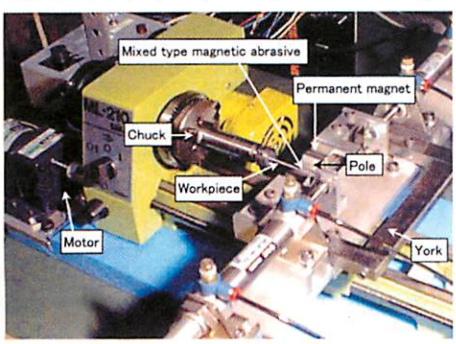

Fig. 2 Photograph of Processing Device Appearance

Fig. 3 gives the influence of the number of rotations of the workpiece. An increase in the number of rotations of the workpiece increases the processing distance per unit time, resulting in an increase in throughput.

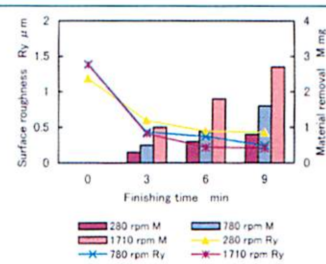

Fig. 3 Changes over Time of Surface Roughness and Material Removal (Influence of Number of Revolutions)

Fig. 4 shows the influences of the diameter of iron powder and the feed rate. The throughput will not be significantly influenced by the feed rate of the magnetic pole, because the effect of the intersection of the processing loci is not evidenced due to an extremely large number of rotations, as compared to the rate of feed in the direction of the magnetic pole axis. Furthermore, an increase in iron powder diameter increases the throughput. This may be accounted for by an increase in cutting depth due to an increase in the processing force of the roughened iron powder.

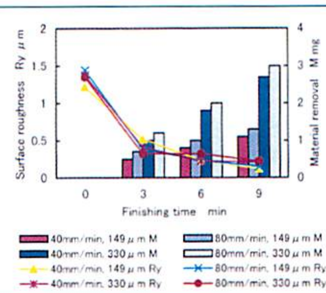

Fig. 4 Changes over Time of Surface Roughness and Material Removal (Influences of Iron Powder Diameter and Feed Rate)

It can also be seen that any surface, when finished for a sufficient time, becomes almost the same in terms of smoothness under any processing conditions. Surface finish is considered to be dependent on the size of the magnetic abrasive grains used. In any case, it has been proven that polishing can be achieved.

4. Conclusion

It has been clarified that a workpiece with a diameter of over 1.5 mm can be polished by simply miniaturizing the scale of the conventional magnetic polishing method.

A Study on Micro Three-axle Tactile Sensor

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Shizuoka Institute of Science and Technology
Yasunaga Mitsuya
Professor, School of Engineering, Nagoya University

When a micro-machine inspects and remedies the inside of the blood vessels or digestive organs or when it inspects and maintains the internal piping of a plant, it inevitably contacts the walls of the blood vessels or the piping respectively. It is also programmed to discover the affected or defective parts, such as tumors or cracks formed on the walls.

When the micro-machine works as described above, a feeler is effective. In addition, the machine is required to remove any object attached to the inside wall of the blood vessel or the piping. It therefore becomes necessary to measure its shear force. Accordingly, a feeler sensor to be mounted on a micro-machine should be capable of conducting triaxial-force measurements.

This study therefore aims at developing a triaxial feeler sensor for mounting on a microscope-shaped micro-robot. For ease of microminiaturization, the sensor is structured as simply as possible, with its triaxial force rendered measurable by the effective application of an alogorithm.

Fig. 1 gives the principle of the feeler sensor in question diagrammatically. As Fig. 1 shows, the feeler sensor consists of a rubber sheet, an acrylic board, a CCD camera, and a light source. Beams of light, emitted from the light source to the edge of the acrylic board, are enclosed totally and reflected inside the acrylic board. When an object like rubber adheres onto this acrylic board, the adhered part causes the light to scatter, enabling the observation of the contact part from the rear side. Since conical projections (conical feelers) are arrayed on the rubber surface, the distribution of the vertical force working on the rubber can be measured in terms of light intensity distribution. Furthermore, the range of displacement of the conical feelers in the horizontal direction becomes larger in proportion to an increase in the shear component of the working force. As described above, in this feeler sensor vertical and horizontal forces can be identified, respectively, by light intensity and the feeler displacement range. Fig. 2 shows the structure of the sensor made on the above basis.

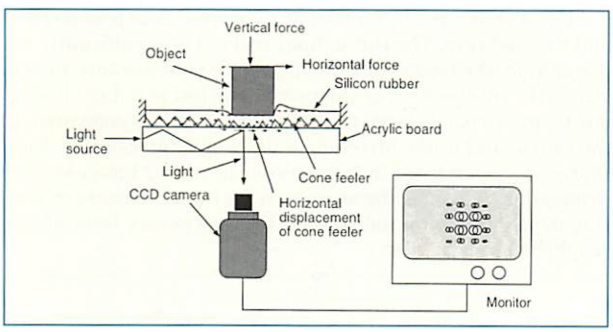

Fig. 1 Trixial Force Detection Method

The feeler sensor being highly sensitive, we developed a new biaxial force sensor for calibration tests, consisting of an electronic balance and a self-made load cell. This device has proven that linear relations exist between the brightness value and the vertical force.

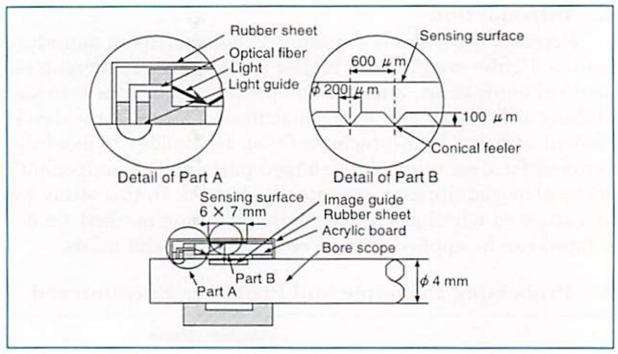

Fig. 2 Structure of the Feeler Sensor in Question

Next, Fig. 3 gives the sensitivity characteristic in the horizontal direction. The low and high load areas have different sensitivity coefficients. It can also be seen that the inflection point moves in a horizontal direction as the vertical force becomes larger. However, an experiment conducted separately reveals that the magnitude of the horizontal force has no influence on the sensitivity characteristic in the vertical direction, so the horizontal force can be measured from the range of movement of the feeler after the relation between the horizontal force that causes inflection and the vertical force has been clarified.

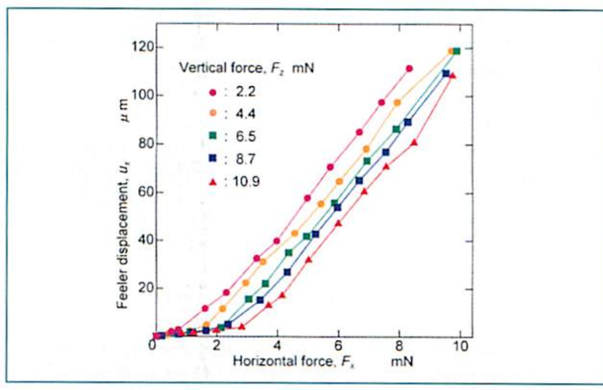

Fig. 3 Sensitivity Characteristic of Horizontal Force

We proposed a principle of the triaxial feeler sensor intended for mounting on the microscope-shaped micro-machine, and confirmed the adequacy of the principle by a trial model. We are planning to incorporate this sensor into a master manipulator system with which to carry out an identification experiment of the state of the surface of micro objects which no ordinary-sized feeler sensor can measure.

Mitsubishi Electric Corp.

Goro Yamanaka
General Manager, Advanced Technology R&D Center

1. Our Work on Micromachine Technology

Wisdom and technological progress begins with the small dreams of humans. By adding a new function or new concept to the technology and knowledge that people have acquired, and by integrating them, the original dream can be expanded and further developed. The Advanced Technology R&D Center of Mitsubishi Electric Corp. seeks to contribute to an even more convenient and comfortable life in the 21st century, through all of the company's business fields, and thereby create a great future, one and two steps ahead. One such technology for giving a tangible shape to our dreams of the future is micromachine technology.

2. Development of Micromachine Technology

In the Industrial Science and Technology Frontier Program, our company is conducting research and development on an experimental chain-type micromachine for inspection of outer tube surfaces. In this project, we created several machines that are $125mm^3$, with a width of less than 10mm including the connector. By having these machines close around the object tube, the system inspects for any flaw.

One of the elements that comprise the each machine is the driving device shown in Fig. 1. This is an electromagnetic motor of radial-gap type, with a diameter of 1.6mm, length of 2mm, and speed of 40,000 rotations per minute. The dimension of the stator is 1.6mm in outer diameter, 0.8mm in inner diameter, and 0.7mm in length. It has six slots inside. Built into one slot is a microscopic coil with 50 turns, which is made using high-aspect ratio and multi-layer micromachining technology. For the coil insulation material, SiO_2 with excellent heat conductivity is used. For the rotor, a permanent magnet (NdFeB) of 0.74mm in outer diameter, 0.55mm in inner diameter, and 1.0mm in length, on a stainless steel shaft are used.

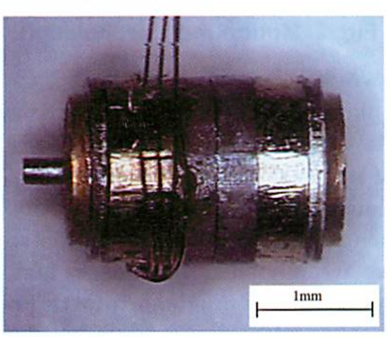

Fig. 1 Outer view of the driving device

The basic machine with this driving device built in is shown in Fig. 2. Two driving devices are each connected to a pair of traveling devices on the left and right. Each traveling device has a drive wheel and two driven wheels, all constructed of a permanently magnetic material. This running mechanism is a $125mm^3$. A flaw inspection device with a pair of micro-connectors mounted on the left and right is placed upon this. When this basic machine was run on a flat surface, we confirmed that it could run in a straight line, and, it could run in a curved line by changing the rotation speed of the wheels on the left and right sides. Also, we found that it could run while pushing an object more than twice its own weight (1 yen coin). This is possible because a strong traction force is produced by the magnetic attraction between the wheels of the permanent magnet and the flat surface.

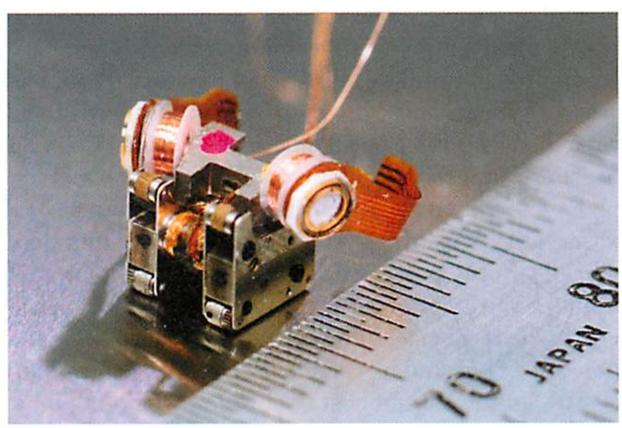

Fig. 2 Micromachine for running (Jointly developed with Sumitomo Electric Industries, Ltd. and Matsushita Research Institute Tokyo, Inc.)

3. Future Work

Mitsubishi Electric Corp. will strive to create well-balanced new system technology and element technology, and move forward to achieve the kind of dreams stated at the beginning. As we implement the Industrial Science and Technology Frontier Program, we will strive to put the technology we develop into practical applications. We will conduct our R & D as to make tangible contributions to the advanced information society.

Mitsubishi Cable Industries, Ltd.

Koichi Suzuki
Director, General Manager,
Central Research Laboratory

1. Our Work on Micromachine Technology

By applying optical fiber technology, we are developing technologies for micro-actuators and micro-sensors that uses light to transmit signals and energy. The use of light makes it possible to transmit high-density signals and energy without electromagnetic interference, and to build even more compact devices. We are working on these technologies with our sights set on the 21st century. There is much expectation that they can be used in micro-surgery and other advanced medical techniques that are more people-friendly and in various types of industrial maintenance systems that can reduce and even eliminate danger and heavy work, for example. Our company is working actively on micromachine technology as the basic technology to realize these applications.

2. Development of Micromachine Technology

When a micromachine is at work inside a thin tube or in a narrow space inside a machine or device, it is indispensable to have not only a manipulator for performing various actual operations and a sensor to control the movements, but it is also imperative to have a device that acts as the "eyes" to grasp the surroundings visually. In the kind of microscopic spaces referred to above, a conventional still camera or video camera are too limited in fulfilling such visual function. Then, too, when an inspection with visual capability needs to be carried out for the overall microscopic processing and assembly stages in a microfactory, a desktop factory, plane observation alone is inadequate, and a stereoscopic observation with the sense of depth is essential. Specifically, in the processing unit of a microfactory, this requires the monitoring of the processing status of the electrochemical machining device, and inspection of the processed hole, and inspection of the setting of the substrates on the assembly stage in the assembling unit, and/or inspection of the state of insertion of gear. For this reason, we are developing a fiberscope type environmental recognition device which can simulate the actual sense of on-the-spot observation, as if a human became tiny enough to get into a small part or small space and observes the surroundings. (See Fig. 1.) To create this device, we are developing a microscopic and stereoscopic vision technology which uses a fiberscope with flexibility and workability to penetrate spaces with a thin diameter, which has a variable parallax mechanism capable of sensing and appropriately for the object of observation and task; and we are developing a tip articulation mechanism that can pass through curved spaces and select a field of vision freely. The tip articulation motion of the device produced on a trial basis is shown in Fig. 2. By building into the device, a tip articulation mechanism using a shape-memory alloy micro-actuator with an outer dimension of 3 mm, we achieved a tip articulation degree of about 60 degrees.

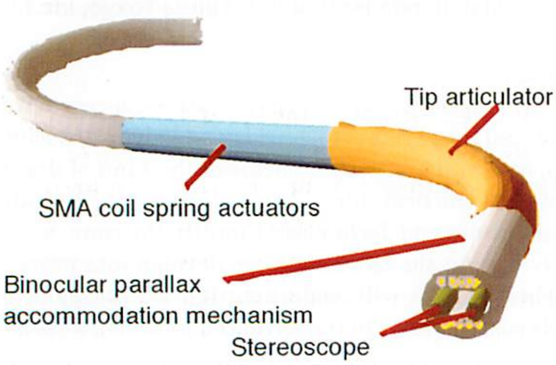

Fig. 1 Environmental recognition device

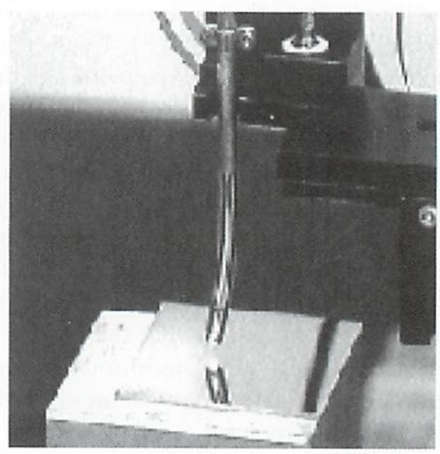

Fig. 2 Motion of tip articulation

3. Future Work

We are planning to actually mount on environmental recognition device in a microfactory, verify the performance of the mechanism for the required inspection task, and complete the development of this micro-inspection technology. And based upon the successes of ISTF project accomplished thus far, we aim to achieve practical application of micromachine technology, and to move forward with research and development on applications of this technology in a broad range of areas including industrial and medical fields.

The 5th Micromachine Summit

The 5th Micromachine Summit was held at the Glasgow Marriott Hotel in Scotland from April 28 - 30, 1999. This year's participants were from the 13 countries and regions which had participated in the past (Japan, USA, UK, Mediterranean region, Australia, Benelux, Canada, Switzerland, Germany, France, Northern Europe, China, Taiwan). Korea also joined the proceedings for the first time this year as a special participant (with regular member status from the next summit). A total of 83 participants took part in this year's activities, including 48 delegates and 35 observers. The participants from Japan (listed below) included four delegates led by Prof. Naomasa Nakajima, Dean of School of Engineering, the University of Tokyo. Other participants included 11 observers from MMC's supporting members and MMC.

	Name	Affiliation
Delegates (4)	Naomasa NAKAJIMA	Dean, School of Engineering, The University of Tokyo
	Tsuneo ISHIMARU	CEO, Denso Corp.
	Toshiro SHIMOYAMA	CEO, Olympus Optical Co., Ltd.
	Takayuki HIRANO	Executive Director, Micromachine Center
Observers (11)	Takanobu HORI	President and CEO, Aisin Cosmos R&D Co., Ltd.
	Tsukasa YAMASHITA	Director, Central R&D Laboratory, Omron Corp.
	Ryo OTA	Chief Manager, Research Group 1 ARC, Olympus Optical Co., Ltd.
	Toshihiko SAKUHARA	General Manager, Corporate R&D, Seiko Instruments Inc.
	Takashi KURAHASHI	Senior Project Manager, Research Laboratories, Denso Corp.
	Masaki MAENO	Manager, Secretarial Department, Denso Corp.
	Kiyoshi SAWADA	Honorary General Manager, Basic Research Laboratory, Fanac Ltd.
	Hideaki OKU	Manager, Basic Research Laboratory, Fanac Ltd.
	Koji NAMURA	Manager, Mechanical Systems Dept., Advanced Technology R&D Center, Mitsubishi Electric Corp.
	Kazuhiro TSURUTA	Manager, Research Department, Micromachine Center
	Yuji IWATA	Manager, Information Department, Micromachine Center

Summit session

Delegates from Japan

Prof. Beardmore of Smiths Industries (located in the host country of the UK) served as the general chairperson of the summit. A total of seven sessions were held, with sub-chairpersons assigned to each session. Throughout the summit, lively discussions were held on a variety of topics, including country reviews, new developments and hot topics, bionics, the environment, manufacturing technology and standards, wireless distributed systems, methods to reduce costs related to small-lot production, impact on large-scale industries, and expectations regarding uses for and developments in Micromachine technology in the future. Giving reports on behalf of the delegate organizations from Japan were, in order of presentation, MMC Executive Director Hirano, Prof. Nakajima (Dean, School of Engineering, The University of Tokyo), Tsuneo Ishimaru (CEO, Denso), and Toshiro Shimoyama (CEO, Olympus). The presentations, which focused on the current status and future trends in Micromachine technology in Japan and expectations for the future, were well received by participants. In particular, CEO Shimoyama's presentation featuring a video on medical applications had a particularly strong impact. At the chief delegates' meeting, it was approved that the next summit would take place on April 10 - 12, 2000, in Hiroshima, Japan. Preparations for the next summit will get underway shortly, headed by MMC. Before and after the summit, a UK research mission was organized, with participants visiting the Rutherford Appleton Laboratory in Oxford, Exitech Limited, Glasgow's University of Strathclyde, STS Limited in Newport, British Aerospace in Bristol, CRL Limited in western London, and Imperial College in London. This mission enabled participants to strengthen their relationships with researchers. At the Rutherford Appleton Laboratory, participants visited the Central Microstructure Facility and were given an overview of technical research focusing on the processing of 3-dimensional micro structures on silicon substrates, such as plasma etching technology and lithography technology utilizing electron beams, eximer lasers and SR. Then at Exitech, participants learned how this small company of just 40 employees was conducting aggressive R&D in a variety of areas, such as developing advanced laser precision processing technology and processing complex structures in three-dimensions. During the visit to University of Strathclyde in Glasgow, participants toured two optics research laboratories and one superconductive device research laboratory. At the optics research laboratories, participants enjoyed an explanation of a 3-D imaging system for detecting cavities inside teeth which utilized sensors and lasers that included micro-structures, as well as a micro-fluorescent analysis probe which utilized fiberoptics. At the superconductive device research laboratory, biomagnetism (brain magnetism, muscular magnetism) was detected utilizing a superconducting quantum interference device (SQUID). Next, at Surface Technology Systems (STS) Limited (part of the Sumitomo Precision Industries group), participants listened to an explanation of ICP (inductively coupled plasma) etching devices, of which STS holds more than 80% of the global share, and ASE (Advanced Silicon Etching - high aspect ratio silicon etching). At British Aerospace, participants enjoyed an explanation of the development of micro-devices for use in aeronautical equipment, such as an infrared image display for evaluating the capabilities of infrared sensors, micro-gyros utilizing PZT and silicon, high-frequency electromagnetic filters, and fluid control devices.

At Central Research Laboratories (CRL), participants listened to a lecture on micro-chemical reactors geared toward plutonium separation and extraction applications. At the last stop, participants visited Department of Electrical and Electronic Engineering at Imperial College, where representatives provided individual explanations of current R&D projects, including a comb-toothed electrostatic actuator/resonator, 3-dimensional micro-optic device utilizing self-assembling technology, a mass spectrometer which utilized four optical fibers, an infrared sensor created from silicon micro-machining technology, and a high-frequency inductor/switch.

Visit with CRL researchers

At Imperial College

Technical Terms in Micromachine Technology (v1.0) — Part 2

This is the second issue we publish a glossary of key terms excerpted from MMC Technical Report: Technical Terms in Micromachine Technology (MMC TR-S001(01)-1998), which was published by MMC. For more detailed explanations, please refer to the Technical Report.

Actuator [アクチュエータ]
[DEFINITION] A mechanical device that converts various types of energies such as electric energy, chemical energy into kinematic energy to perform mechanical work.
[DESCRIPTION] For a micromachine to perform mechanical work, the micro-actuator is indispensable as a basic component. Major examples are the electrostatic actuator prepared by silicon process, piezoelectric actuator that utilizes functional materials like PZT, pneumatic rubber-actuator, and so on. Many other actuators based on various energy conversion principles have been investigated and developed. However, all these actuators deteriorate their energy conversion efficiency as their size is reduced. Therefore, motion mechanisms of organisms such as deformation of protein molecules, flagellar movement of bacteria, and muscle contraction are being utilized to develop special new actuators for micromachines.
[References] (1)(2)(3)(6) **[Related terms]** Electrostatic actuator, Piezoelectric actuator, Pneumatic rubber-actuator, Actuator

Piezoelectric actuator [圧電アクチュエータ]
[DEFINITION] An actuator that uses piezoelectric material.
[DESCRIPTION] Piezoelectric actuators are classified into the single-plate, bimorph, and stacked types, and the popular material is lead zirconate titanate (PZT). The features are: 1) Quick response, 2) Great output force per volume, 3) Ease of miniaturization because of simple structure, 4) Narrow displacement range for easier micro-displacement control, and 5) High effeciency of energy conversion. Piezoelectric actuators are used for the actuators for micromachines, such as ultrasonic motor, micro-displacement stage, fan, pump, and speaker. An applied example is a piezoelectric actuator for traveling mechanism which moves by the resonance vibration of a piezoelectric bimorph, and a micro-positioner piezoelectric actuator which amplifies displacements of a stacked piezoelectric device by a lever. **[References]** (2)(4)(5)(6)(8)(14)(15)
[Related terms] Piezoelectric element, Ultrasonic motor

Shape memory alloy actuator
[形状記憶合金アクチュエータ]
[DEFINITION] An actuator that uses shape memory alloy.
[DESCRIPTION] Shape memory alloy actuators are compact, light, and produce large forces. The actuators can be driven repeatedly in a heat cycle or can be controlled arbitrarily by switching the electric current through the actuator itself. Lately, attempts have been made to use the alloys to build a servo system that has an appropriate feedback mechanism and a cooling system, intended for applications where quick response is not necessary in particular. Application examples under development are microgrippers for cell manipulation, microvalves for regulating very small amounts of flow and active endoscopes for medical use. **[References]** (4)(5) **[Related terms]** Microgripper, Microvalve, Active catheter

Photostricitive actuator [光歪アクチュエータ]
[DEFINITION] An actuator that uses mechanical deformation from the irradiation energy caused by the absorption of light.
[DESCRIPTION] Irradiating light (ultraviolet rays) onto a PLZT element generates a high photovoltaic electromotive force between the element's electrodes. The PLZT element is a piezoelectric element and generates deformation by applied voltage. The combined these effects are thought to convert light irradiation to mechanical deformation. Photostricitive actuators offer the advantage of not needing a power supply cable, and their application to switches or photoacoustic devices is under consideration. They have the disadvantage, however, of a very slow response of several minutes. One example is a prototype of an optically operated switch that turns on and off by amplifying tens of times a small optical deformation of several tens of micrometers using a displacement magnifying mechanism. **[References]** (4)(8) **[Related terms]** Photostrictive effect

Electrostatic actuator [静電アクチュエータ]
[DEFINITION] An actuator that uses electrostatic force.
[DESCRIPTION] Since the electrostatic actuator has a simple structure and its output force per weight is increased as the size is reduced, many researches are ongoing to apply it to the actuator of micromachines. Application examples developed so far on an experimental basis include a wobble motor, a film electrostatic actuator, and so on. **[References]** (4)
[Related terms] Film electrostatic actuator, Wobble motor

Electromagnetic actuator [電磁アクチュエータ]
[DEFINITION] An actuator that uses electromagnetic force.
[DESCRIPTION] Magnet and coil winding are the major element for micro-electromagnetic actuators. For sub-milimeter or smaller magnetic rotors for micro-electromagnetic devices, thin film magnets fabricated by sputtering are useful. High-energy products and larger thickness are needed for the thin film magnets in order to raise the power of the devices. On the other hand, research into devices based on electromagnetic force focuses on those with plane structures such as axial gap types, because it is difficult to wind the coil around the cylindrical stator used for radial gap type microdevices. With regard to efficiency, radial gap types have an advantage, but an appropriate process for winding the coil around the cylindrical stator must be developed. **[References]** (1)(8)

Flagellar motor [鞭毛モータ]
[DEFINITION] A motor that drives flagellars of bacteria.
[DESCRIPTION] The energy source of flagellar movement of a bacterium is the electrochemical potential difference between hydrogen ion concentrations in and out of the cell. The rotary part of a flagellum is the only organ that makes a rotary motion among all living things on the earth, and is the smallest motor ever known. The structure is a chemical motor consisting of fiber, a hook, and the base. It is considered that the torque arises from the inward flow of hydrogen ions from outside the cell, but the mechanism of converting the flow of ions into rotary motion is left unknown. **[Related terms]** Polymer actuator, Chemical bearing, Mechanochemical actuator

THE FIFTH INTERNATIONAL MICROMACHINE SYMPOSIUM
Foundation of Industrial Technology in the 21st Century

Date: October 28 - 29, 1999
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): The Federation of Micromachine Technology / Micromachine Society / Research Committee on Micromechatronics / Japan Power Engineering and Inspection Corporation / Japan Robot Association / 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, 1999
Contact: Micromachine Center
(TEL +81-3-5294-7131 FAX +81-3-5294-7137)

PROGRAM (Tentative, as of July 21, 1999)

October 28, 1999		
9:00 ~	Registration	
Session 1: Opening	**Chairman: 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)	Mr. Katsusada HIROSE, Director-General, Machinery and Information Industries Bureau, MITI
9:43 ~ 9:51	Guest Speech (Expected)	Dr. Takeo SATO, Director-General, AIST, MITI
9:51 ~ 10:00	Guest Speech (Expected)	Mr. Hideyuki MATSUI, Chairman, NEDO
10:00 ~ 10:45	Special Guest Speech: What Micromachine Technologies will bring to the 21 Century	Prof. Takemochi ISHII, The University of Tokyo/Japan
Session 2: The Path to New Industries in The 21st Century		**Chairman: Prof. H. MIURA**
Market Frecast		
10:45 ~ 11:05	Market Perspectives of Micromachine in 21st Century	Prof. Fumio KODAMA, The University of Tokyo
11:05 ~ 11:25	Market study on Multimedia and Peripherals (tentative)	Dr. Franz van de WEIJER, NEXUS
Exploiting Applications		
11:25 ~ 11:45	Micromachines for Wearable Information Systems	Prof. Kiyoshi ITAO, The University of Tokyo
11:45 ~ 12:05	Pet Robot and Micromachine	Prof. Tomomasa SATO, The University of Tokyo
Standardization		
12:05 ~ 12:25	Trend on Standard	Prof. Hisayoshi SATO, Chuo University
12:25 ~ 13:30	Lunch	
Session 3: Overseas Activities		**Chairman: Prof. H. FUJITA**
13:30 ~ 13:50	Recent MEMS Activities in USA (tentative)	Dr. Karen W. MARKUS/MCNC
13:50 ~ 14:10	Nordic Collaboration in Micromachine Technologies	Dr. Francois GREY, University of Denmark
14:10 ~ 14:30	Recent Developments in Collaborative Micromachine Research in Australia	Dr. Ronald B. Zmood, Royal Melbourne Institute of Technology
14:30 ~ 14:50	Recent Activities on Micromachine Technologies in Switzerland	Prof. Nico F. de ROOIJ, University of Neuchatel
14:50 ~ 15:10	Break	
Session 4: Innovative R&D		**Chairman: Prof. K. IKUTA**
15:10 ~ 15:30	Recent Research Trends in Biochips	Prof. Eiichi TAMIYA, JAPAN ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY
15:30 ~ 15:50	Micromachine for Medical Therapy	Prof. Tsuneo CHINZEI, The University of Tokyo
15:50 ~ 16:10	Nano-Technologies in Magnetic Disk Drives	Prof. Yasunaga MITSUYA, Nagoya University
16:10 ~ 16:30	MEMS Transducers for Fluidic Control	Dr. Chih-Ming HO, University of California, Los Angeles
Session 5: Thinking of Micromachines –Message to Young Generation–		**Chairman: Mr. T. HIRANO**
16:30 ~ 16:50	Trends of Young Generation (tentative)	Prof. Atsushi KADOWAKI, Tsukuba University
16:50 ~ 17:10	Science Museum: MM for Use of an Educational Exhibition	Mr. Tatsuo HAYASHI, Japan Science Foundation
17:10 ~ 17:30	MEMS Education Program at UCLA (tentative)	Prof. Chang Jim KIM, University of California, Los Angeles
18:00 ~ 20:00	Reception Party at Josui Kaikan	
October 29, 1999		
9:00 ~	Registration	
Session 6: Current Status of Micromachine Technology Project in ISTF Program		**Chairman: Dr. Y. ISHIKAWA**
9:30 ~ 9:40	Overview of ISTF Program	Mr. YAMAGUCHI, Director for Machinery and Aerospace R&D, AIST, MITI
Researches and Future Prospects on Micromachine Technology in National Research Laboratories		**Chairman: Dr. Y. ISHIKAWA**
9:40 ~ 9:55	Research and Development on Micromachines at Mechanical Engineering Laboratory	Dr. Shigeru KOKAJI, Mechanical Engineering Laboratory, AIST, MITI
9:55 ~ 10:10	Research on Micromachine Technology at Electrotechnical Laboratory	Dr. Shigeoki HIRAI, Electrotechnical Laboratory, AIST, MITI
10:10 ~ 10:25	Research on Micromachine Technology at National Research Laboratory of Metrology (tentative)	Dr. Toshio SAKURAI, National Research Laboratory of Metrology, AIST, MITI
10:10 ~ 10:40	Break	
R&D in Micromachine Center		**Chairman: Dr. Y. ISHIKAWA**
10:40 ~ 10:55	The outline of the micromachine project	Mr. Tatsuaki ATAKA, Research Committee, Micromachine Center
● Systems		
10:55 ~ 11:25	Experimental Wireless Micromachine for Inspection on Inner Surface of Tubes	Dr. Nobuaki KAWAHARA, Micromachine Center
11:25 ~ 11:55	Experimental Chain-type Micromachine for Inspection on Outer Surface of Tubes	Mr. Hiromu NARUMIYA, Micromachine Center
11:55 ~ 13:00	Lunch	
13:00 ~ 13:30	Experimental Catheter-type Micromachine for Repair in Narrow Complex Areas	Mr. Ryo OHTA, Micromachine Center
13:30 ~ 14:00	Experimental Processing and Assembling System (Microfactory)	Mr. Kazuyoshi FURUTA, Micromachine Center
● Elements		
14:00 ~ 14:20	Advanced three-dimensional assembly technology for high density CCD micro camera system module	Mr. Hiroshi YAMADA, TOSHIBA Corp.
14:20 ~ 14:40	Development of Flexible Shaped Battery	Mr. Kensuke MURAISHI, Mitsubishi Materials Corp.
14:40 ~ 14:55	Break	
14:55 ~ 15:15	Recent Progress in Artificial Muscle Micro Actuators	Dr. Ron PELRINE, SRI International
15:15 ~ 15:35	PZT Thin-Film Actuator Driven Two Dimensional Micro Optical Scanning Sensor	Mr. Hiromi TOTANI, OMRON Corp.
15:35 ~ 15:55	Microgyroscope for Experimental Catheter-type Micromachine	Mr. Kouji TAKEMURA, Murata Manufacturing Co.,Ltd.
15:55 ~ 16:15	Environmental Recognition Devices using Fiberscopes	Mr. Osamu TOHYAMA, Mitsubishi Cable Industries, Ltd.
16:15 ~ 16:35	Development of Micro Servo Actuators for Microfactories	Dr. Hiroshi NAKAMURA, Yaskawa Electric Corp.
Session 7: Closing	**Chairman: Mr. T. HIRANO**	
16:35 ~ 16:40	Closing Address	Mr. Hikaru HAYASHI, Managing Executive Director, Japan Industrial Technology Association

Pictures on the cover: Winning artworks in the Micromachine Drawing Contests
Micro ultrasonic lure, Underwater exploration machine, Flood predictor/detector, and Sound pierce & sound controller (from top to bottom)

MICROMACHINE No. 28

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