Micromachine
マイクロマシン

Sept. 1996

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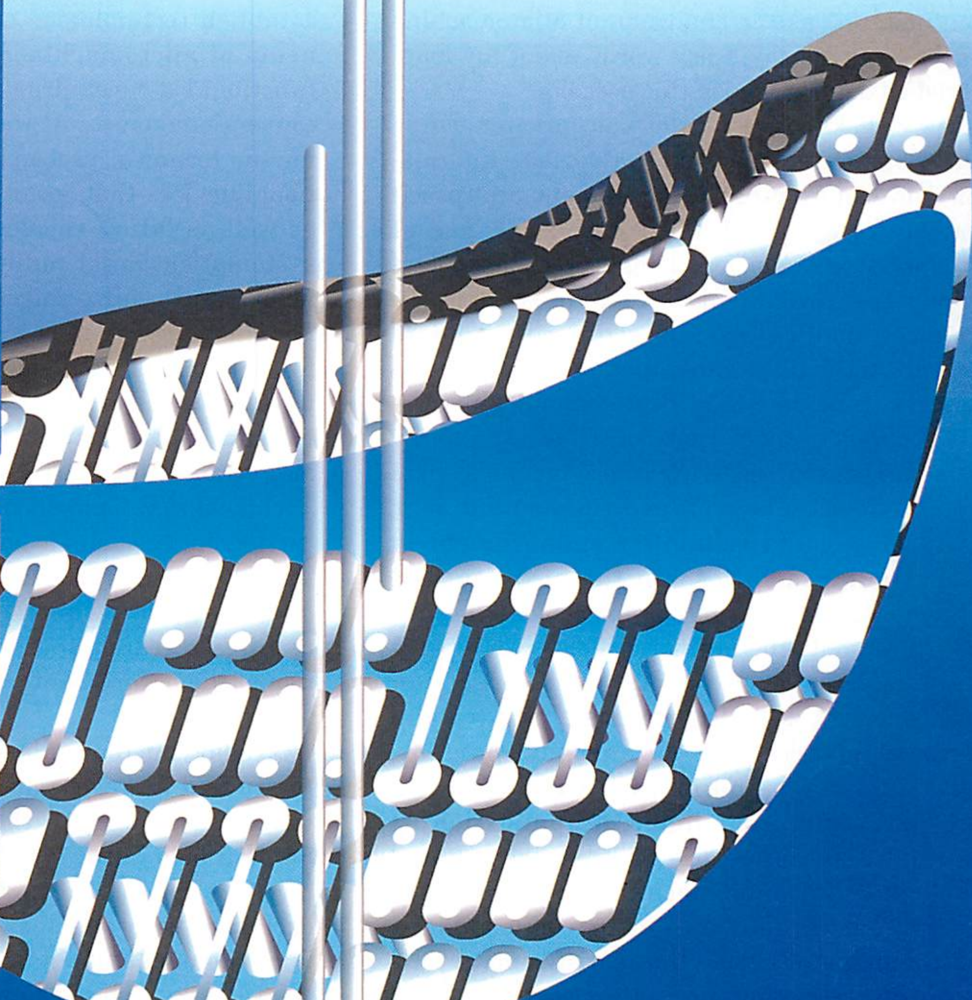

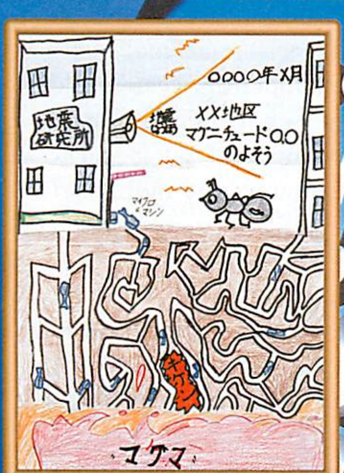

No. 16

MICROMACHINE CENTER

Inaugural Address

Tsuneo Ishimaru
Chairman, Micromachine Center

In succession to Dr. Seiuemon Inaba, I have been installed as the chairman of Micromachine Center. Let me say a few words about my long-cherished aspirations on this occasion.

As well known to all of you, micromachine technology is indispensable to various information and communication equipment and precision equipment, which are the essence of foundation technologies of high-precision micro-processing and electronics, as well as to advanced medical system required for micro surgery, artificial organs, diagnosis, and treatment. I think micromachine technology is the only technology field that contribute to energy saving and resource saving in production system of small devices, as well as to promote drastic advancement and reliability enhancement in mechatronics facilities. In the next century, micromachine technology is expected to be utilized in not only the industrial fields where various facilities and plants need precision maintenance, but also medical, welfare and hygiene, leisure, housing and environment, house appliances and information equipment, aerospace, and other fields of application. I think micromachines, the fruit of research and development of micromachine technology, will contribute much to realize industrial foundation and the living of people that satisfy energy saving, resource saving, and other social requirements through size reduction and functionality improvement of mechanical systems.

However, micromechanics is a new branch of technology and its scope of application is so vast that many technical developments are necessary in diverse fields. In the first phase of the "Micromachine Technology" project of the Industrial Science and Technology Frontier Program of Agency of Industrial Science and Technology started in fiscal 1991, a variety of research and development was carried out to establish technologies related to basic components of micromachines. One result was the functional devices drastically progressed from conventional ones. At the same time, it clarified unique technical problems with individual functional devices that occur only to micromachines, as well as future themes for advancement and systematization of individual component technologies to realize micromachines as systems. For this purpose, in the second phase started in fiscal 1996, research and development is going to have three major themes; advancement of individual component technologies, systematization, and establishment of fundamental technologies. Technical development of this nature cannot be carried out by a single enterprise, national institute, or university. Establishment of systematic micromachine technology is necessary, and it requires research and development by cooperation of the government, academic, and industrial sectors.

Today, micromachines are being energetically studied at research institutes all over the world. As it went in the second Micromachine Summit held in the late April in Switzerland, we have to promote technical and personal exchange with overseas organizations and act upon common understandings among countries.

To make rich of the industrial structure and society in the future, Micromachine Center is willing to play the core role in promoting establishment of micromachine fundamental technologies and disseminating them in the world.

I, myself, will do my best with your assistance.

We hope you will understand the aim of Micromachine Center and will give us suggestions and support more than ever.

Research on Micromachine at Ritsumeikan University

Susumu Sugiyama (Professor, Dept. of Robotics)
Hiroo Ukita (Professor, Dept. of Photonics)
Osamu Tabata (Associate Professor, Dept. of Mechanical Engineering)
Satoshi Konishi (Assistant Professor, Dept. of Mechanical Engineering)
Faculty of Science and Engineering, Ritsumeikan University

1. Profile of Faculty of Science and Engineering

In April 1994, the Faculty of Science and Engineering of Ritsumeikan University transferred to the new and wide Biwako Kusatsu Campus (BKC) to the southeast of Lake Biwa. At present the faculty consists of ten departments organized in six courses and embraces about 5,000 undergraduates, about 700 graduates, and about 170 teaching staff. In this April, with the opening of the SR center equipped with compact SR system "AURORA" (Fig. 1), Ritsumeikan University started positive research on micromachines.

2. Outline of Research Facilities

To promote advanced research on micromachines that integrates bulk micromachining, surface micromachining, and lithographie-galvanoformung-abformung (LIGA) process, an exclusive beam line for LIGA process and the Micro Process Laboratory consisting of clean rooms of a total floor area of 300 m^2 have been equipped in BKC.

Fig. 2, a scanning electron microscopic (SEM) photo obtained by preparatory experiment, shows the image of lattice pattern of a line width of 20 μm formed by 30 minutes of exposure on a 200 μm-thick polymethyl methacrylate (PMMA).

The Micro Process Laboratory (Fig. 3) is equipped with the following facilities: (1) lithographic system including the electron beam pattern writing system and the single and double face aligners, (2) deposition system including the resistance heating evaporation equipment, the electron beam evaporation equipment, the high-frequency ternary sputter equipment, plasma CVD equipment, and electroplating equipment, (3) etching system including the reactive ion etching (RIE) equipment and the wet etching stations, and (4) heat treatment system including the diffusion furnaces and the annealing furnaces. Apart from these, assembly system including dicing and wire bonding machines are prepared.

3. Introduction of Laboratories

Main laboratories conducting research on micromachines using these facilities are introduced below.

3.1 Sugiyama Laboratory (Department of Robotics)

Aiming at implementation and industrial application of micro electromechanical systems (MEMS) that integrate sensors, actuators, and processing circuits, this laboratory has set three themes of research: (1) device design technology, (2) microprocess technology, and (3) processing circuit technology. The research plans are as follows.

(1) Device design technology: Using physical sensors measuring mechanical quantities such as pressure, force, and acceleration and readily miniaturized actuators such as electrostatic, piezoelectric, and electric heating types new devices will be developed by profound study on the principles of sensing. Implementation of MEMS devices that integrate sensors, actuators, and processing circuits on the same substrate will be studied. The research will not be confined to simulation and theoretical study, but actual devices and systems will be fabricated and their performance be evaluated.

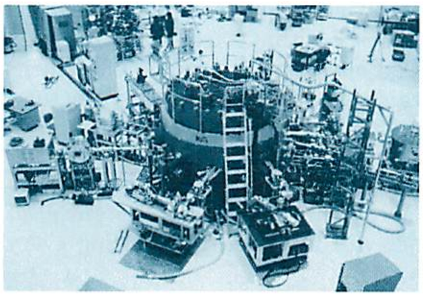

Fig. 1 Compact SR system "AURORA"

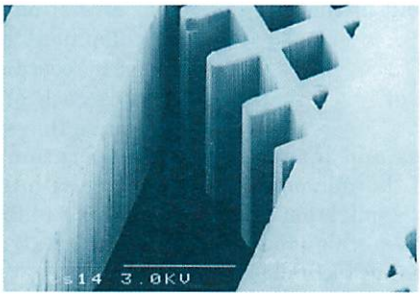

Fig. 2 PMMA structure with width of 20 μm and height of 200 μm

Fig. 3 Microprocess Laboratory

(2) Microprocess technology: Application and integration of three advanced process technologies, namely, bulk micromachining, surface micromachining, and LIGA process to develop a new 3D microstructure process technology as well as to apply the new technology to MEMS. The aim of the research is to establish not only the individual process technologies but the total technology to fabricate devices and systems.

(3) To achieve top performance of micro sensors and actuators for the most efficient operations, peripheral processing circuitry will be studied. Research on compensation of thermal characteristics and nonlinearity, design and evaluation of interface between sensor/actuator and instrumentation/control systems, and standardization are conducted.

Through these researches, application of micromachines to a spectrum of industries including robotics, mechanics, precision instruments, electronics, optics, medicine, and so on will be aimed.

3.2 Ukita Laboratory (Department of Photonics)

This laboratory started in April 1995 and pursuits total technology of optics integrated with mechanics and electronics. The present members are five graduates (master course) and six undergraduates.

This laboratory studies on optomechatronics including optical recording technology, optical micromachining technology, and optical tweezers technology, covering from the basic mechanisms to devices. The order of objective dimensions ranges from meters to nanometers. Therefore, diverse physical and chemical laws are used as the principles of the research.

Currently ongoing studies are:

- High density optical recording
- Application of complex resonance type semiconductor lasers
- Micro vibrations caused by light
- Assembly of micro structures using optical tweezers
- Drive and control of micro objects by light pressure

To carry out these studies, the laboratory designs and fabricates micromachine element components, micro vibrators, micro optical rotors, and other structures are at the Micro Process Laboratory, as well as collaborate with related organizations out of the university.

3.3 Tabata Laboratory (Department of Mechanical Engineering)

Aiming at establishment of process and instrumentation technologies in the region of the micrometer and nanometer scales, together with application to micrometer and nanometer scale machines, this laboratory is going to study (1) micromachining technology, (2) instrumentation and evaluation technology, and (3) application to MEMS. Each research theme are briefly explained below.

(1) Micromachining technology: Research on super precision machining technologies that utilize physico-chemical phenomena and production system based on such new processing technologies. Process where ultraviolet energy beams such as laser or synchrotron radiation is used to assist removal, addition, or modification will also be studied.

(2) Instrumentation and evaluation technology: Research on instrumentation and evaluation technologies for various process parameters required in basic analysis and process control of micromachining process. Research on instrumentation and evaluation technologies for geometry and characteristics of components fabricated by the micromachining technologies. From micro instrumentation and evaluation technologies for atomic level analysis on processed surfaces to macro instrumentation and evaluation technologies for testing strength of processed components will be studied to understand new micromachining technologies in every aspects from the basis of the mechanism to application.

(3) Application to micro electromechanical systems (MEMS): Concept of mechanical system or electromechanical system implemented by new micromachining technologies will be proposed, to prove usefulness of and discover unknown needs of micromachining technologies. These researches are intended to develop new needs from the seed of micromachining technologies.

3.4 Konishi Laboratory (Department of Mechanical Engineering)

This laboratory is aiming to propose useful items through construction of systems that utilize features of micro mechatronics. The semiconductor micromachining technology, currently drawing attention as a mechanical element miniaturizing technology, has many unique features not found in conventional process technologies. Integration of mechanical and electric elements is an ideal form of utilization of micro mechatronics.

This laboratory is going to take up themes of how to utilize features of micro mechatronics, not only about (1) development of micro devices (design, fabrication, and evaluation) but (2) systematization (configuration and control methods, assembly technologies) as well. The focus of current research is configuration of distributed micro mechatronics system consisting of multiple intelligent micromachines. Development of a system that carries out complex tasks by coordinated operation of a group of element devices each of which has a rather simple structure. Of course this system can retain functionality of precision operations of the individual element devices. Starting with the research on positioning of objects by a microactuator array that is ongoing, potential of micro mechatronics will be studied exploiting every possibilities.

Policy of this laboratory is to advance studies by mutual stimulation between the researchers' inspiration and needs on the society.

Research and Development Basic Plan of Industrial Science and Technology Frontier Program "Micromachine Technology" (Phase II)

Based on the successful results of Phase I of "Micromachine Technology," an Industrial Science and Technology Frontier Programs, the Agency of Industrial Science and Technology decided on the basic plan for R&D for Phase II of "Micromachine Technology."

1. Research and Development Goal

(1) Based on the Phase I results of research and development into basic element technology for machine systems (micromachine systems) composed of small functional elements, the R&D goal of Phase II is to establish technology to realize micromachine systems that conduct the following operations.

1) Autonomous locomotive operations in very narrow spaces in complex equipment such as power plants
2) Autonomous locomotive operations in very narrow spaces in living organisms
3) Manufacture of minute components of small industrial products

(2) To achieve these goals, research and development will be conducted into "systematization technology," "functional device technology," and "common basic technologies," all described in the separate table.

(3) Together with this research and development, comprehensive investigations and research will be conducted to identify a total system of micromachine technology and clarify its future development.

2. Method of Research and Development

(1) The following intensively controlled joint research system will be used to implement integrated R&D.

1) To develop "systematization technology," a prototype system integrating functional devices, which precede micromachine systems, will be manufactured, and research and development will be carried out to establish systematization technology. For each prototype system, intensive research will be conducted at a base organization that coordinates the R&D activities.
2) To develop "systematization technology," "functional device technology," and "common basic technologies," a research group will be formed for each key micromachine technology, and systematic research and development will be conducted by exchanging information among these groups and working closely together.

(2) To promote the above research and development effectively and efficiently, the groups mentioned above will cooperate in their mutual researches and promote their activities in parallel with overall cooperation.

3. Period of R&D

Five years from fiscal 1996 (Total period: 10 years)

4. Total R&D Costs

Expected to be around ¥15 billion (Total amount: Approx. ¥25 billion)

5. Evaluation

In the final year of the Program, after due consideration of the developments in industrial science technologies and the social changes that occurred during the period of the R&D activities, research results will be comprehensively evaluated and guided toward practical application.

Systematization Technology

• Technology to systematize energy supply technologies and design and manufacturing technologies for 1) application in very narrow spaces in complex equipment through the manufacture of experimental systems for wireless micromachine for inspection on inner surface of tubes, systems for chain-type micromachine for inspection on outer surface of tubes, and systems for snake-type micromachine for repair in narrow complex area, and for 2) application in the production of small industrial components through the manufacture of experimental systems for microprocessing and assembling.

• Mounting technologies for experimental systems are based on the integration, miniaturization, and performance upgrading of various functional devices.

Functional Device Technology

• Technology to miniaturize and improve the performance of advanced functional devices such as artificial muscles, which represent actuator technology, micro joints and extremely low friction suspension, which represent coupling technology, and micro batteries, which represent energy supply technology

• Technology for micro laser catheters, which combine a sensor with a laser

• Technology for micro sensor catheters, which combine a sensor with an active flexing function

Common Basic Technologies

• Group control technologies for micromachines

• Instrumentation technologies for power, torque, etc.

• Evaluation technologies for small functional elements, etc.

Activities of the Micromachine Center in Fiscal 1995

Micromachines are composed of functional elements only a few millimeters in size and are capable of performing complex microscopic tasks. During fiscal 1995, the Micromachine Center (MMC) conducted the following activities. The MMC sought to establish basic micromachine technologies and disseminate micromachines in society with the aim of contributing to the development of domestic industry and the international community. The means employed were investigation and research, the collection and provision of information on micromachines, and exchanges and cooperation with related organizations in Japan and other parts of the world. In fiscal 1995, the MMC worked even harder to expand international communication, providing considerable information from Japan through such means as international symposia.

1. Investigation and Research on Micromachines

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

The ultimate purpose of this project is to establish technologies applicable to the realization of micromachine systems. These systems are composed of small functional elements able to locomote in very narrow spaces in complex equipment such as power plants and in living organs, and to autonomously perform intricate tasks or manufacture minute components of industrial products.

Fiscal 1995, the fifth year of this project, was the final year of its first phase. According to the interim evaluation, the initial goal was achieved, and research and development tasks for the second phase were identified.

[Development of advanced maintenance technology for power plants]

Research and development was carried out into microcapsules, mother ships, inspection module without wire and operation module with wire, and total systems.

To clarify future micromachine design guidelines, the "Resulting Issues" of the first phase of the project were identified.

[Micro-factory technology]

R&D into element technology for micro operation and driving systems was conducted, including trial manufacturing, experiments, and evaluations. Also, the measurement of energy-saving effects and problems caused by electromagnetic noise and electrostatic influence between equipment in conjunction with microsizing was investigated.

[Medical application technology]

To develop medical application technology, basic studies, including experiments and evaluation, were conducted into research on complete micromachine systems, research on technologies for micro-tactile sensing, research on laser-applied diagnosis and treatment, and research on blood pressure and flow sensing.

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

Joint research on materials for micromachines included: 1) Research on the operating environment of micro functional elements, 2) research on materials for micromachines, and 3) a feasibility study of materials for micromachines.

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

Joint research on basic technology for the design and manufacture of micromachine systems was conducted.

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

Joint research to explore "fundamental technical seeds" was carried out between industries and universities on nine topics related to micro science and engineering, and design engineering. The research aimed to realize diversified micromachines.

(5) Investigations of the effects of micromachine technology on industrial and social structures (Commissioned by the Japan Machinery Federation)

In the investigations and research in fiscal 1995, the following were identified as four probable effects on industry and society resulting from the practical application of micromachines in the 21st century.

1) Introduction of micromachine technology into industry and society (technology-oriented)
2) Needs from industry and society (demand-oriented)
3) Case analysis of technical innovation (models of the industrialization process)
4) Scenario of industrialization (the industrialization process of micromachines)

(6) Investigations of R&D trends in micromachine technology in Japan and other countries (independent activity)

The present status of micromachine technology development and micromachine technology trends were analyzed and summarized based on questionnaires and research papers. Universities, research institutes, and private businesses in Japan, the United States, and Europe that are engaged in micromachine-related research were identified, and researchers, themes, research content, results, and research organizations were examined.

(7) Construction of micromachine database

(8) Investigations of micromachine technology applications (Commissioned by The Mechanical Social Systems Foundation and International Robotics and Factory Automation Center)

New applications of micromachine technology were investigated and studied in relation to such fields as the global environment, urban life, living and leisure, and production (construction and agriculture).

2. Collection and Provision of Micromachine Information

(1) Collection of micromachine information

Periodicals, books, and other materials containing information and data on micromachines were collected from universities, industries, and public organizations within and outside Japan. These materials were catalogued and kept with MMC's research data in the Center's documentation room (105 materials gathered in fiscal 1995, 377 materials in total).

(2) Provision of micromachine information

(3) Investigation of the construction of a micromachine technology information database

The following investigations were carried out to design a desirable database for the MMC.

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

The format of data to be collected was decided.

3. Exchange and Cooperation with Worldwide Organizations Involved with Micromachines

To promote affiliation, exchange, and cooperation with related organizations in Japan and abroad, the MMC made research grants as part of promotional activities associated with joint projects with government, industry, and academia, and invited researchers and leading authorities to international micromachine symposia and seminars.

(1) Research grants for micromachine technology

To make research grants to university staff working on basic research on micromachines and to promote further development of micromachine technology and exchange between industry and academia, the MMC solicited applications for research grants in fiscal 1995 for the third time. After strictly screening many applications, the MMC awarded research grants to 12 projects, including some continuing from the previous fiscal year.

(2) International exchange on micromachines

1) First International Micromachine Symposium

The First International Micromachine Symposium was held jointly with the Japan Industrial Technology Association on November 1 and 2, 1995 at the Science Hall of the Science Museum at Kitanomaru Koen in Tokyo. The theme of the Symposium was "Micromachine Technology: A Base of Industrial Technology for the Next Generation." The symposium, held to publicize the research results of the AIST project, combined the "Micromachine Symposium," which had been cosponsored by the MMC and Micromachine Society (Tokyo), with the "Result Presentation Meeting," which had been cosponsored by the Japan Industrial Technology Association. To promote international exchange of information, speakers were invited from the United States and Europe.

Number of participants: 465 from Japan, 40 from overseas

2) Micromachine technology seminars

In cooperation with JETRO's program, technology exchange seminars were held in Europe.

(a) Stuttgart, Germany, November 28, 1995, about 60 participants
(b) Milan, Italy, December 1, 1995, about 90 participants (Microcars and photovoltaic actuators were also exhibited.)

3) Acceptance of missions, etc.

Visitors from nine countries, including the United States, the United Kingdom and the Republic of Korea, were received and opinions were exchanged on micromachine technology and the MMC's activities.

4) Dispatch of missions

(a) '95 Micromachine Study Mission to Europe

Taking advantage of its participation in Transducer '95/Eurosensor VI held in Stockholm, Sweden, the mission visited universities and research institutes in Sweden, Norway, Denmark, and France. Opinions were exchanged and R&D trends in micromachine technology investigated.

Number of participants: 11
Organizations visited: 6
Period: June 24 - July 7, 1995

(b) '95 Micromachine Study Mission to the United States

During its participation in MEMS-96 held in San Diego, the mission visited micromachine technology-related universities and research institutes in the United States and Canada, exchanged opinions, and investigated R&D trends.

Number of participants: 9
Organizations visited: 2
Period: February 10-21, 1996

5) Workshop

Investigations and research were carried out as commissioned by the International Robotics and Factory Automation Center. One program was a workshop on the agricultural applications of micromachines with a group made up mainly of researchers from the University of Twente in the Netherlands.

Number of participants: About 10 from Europe, nine from Japan

Period: October 2-3, 1995

6) Participation in international conferences and seminars

(a) Second European Strategic Round Table on Microsystems and MEMS

Lectures were given on the present status of micromachine technology R&D in Japan and the results of the First Micromachine Summit.

Date: April 6, 1995

(b) Microelectronics '95

Research details of AIST's micromachine project and an outline of the MMC's activities were presented as a keynote speech at the conference on Microelectronics held in Australia.

Period: July 17-19, 1995

(c) Transducer '95/Eurosensor VI

This was held in Stockholm, Sweden, where investigations into the latest micromachine technology were carried out and technical exchanges implemented.

Number of participants: About 1,150 from around 20 countries

Presentations: About 260 oral and 250 posters

Period: June 10-19, 1995

(d) MEMS-96

This was held in San Diego, U.S.A.

Number of Participants: 401 from 19 countries

Presentations: 41 oral and 50 posters

Period: February 11-15, 1996

Presentations relating to AIST's Project: 3 oral and 7 posters

(e) International Conference on Precision Engineering

This conference was cosponsored by the Precision Engineering Society and Gintic Institute of Manufacturing Technology, Manyang Technological University in Singapore. A representative of the MMC made a keynote speech entitled "R&D and Future Prospects for Micromachine Technology in Japan."

Period: November 21-24, 1995

Place: Singapore

(f) PHOTONICS-WEST'96

A joint general meeting of three academic societies concerned with Biomedical Optics, Optoelectronics Lasers & Applications, and Electronic Imaging, this was a large academic conference with more than 2,500 presentations. The MMC presented the AIST Project and its latest results in relation to optical application technology.

Period: January 27 - February 2, 1996

Place: San Jose, California, U.S.A.

4. Promotion of Micromachine Standardization (Commissioned by the Japan Machinery Federation)

The MMC carried out classification (including hierarchical structuring) of 221 terms essential to micromachine technology. The MMC also accumulated basic materials on measurement technology in the area of micromachines, clarified technical tasks to promote standardization, and simplified data access. Investigation began into methods of measuring and evaluating material characteristics. Cooperation with overseas standardization activities was also promoted.

5. Dissemination and Education on Micromachines

(1) Publication and distribution of public relations magazine

During fiscal 1995, Japanese and English editions (Nos. 11-14) of ***MICROMACHINE*** were issued.

(2) '95 Micromachine technology R&D presentation

The results of Phase I of the "Micromachine Technology" Program assigned to MMC by NEDO were presented on the second day of the First International Micromachine Symposium (November 16, 1994) at the Science Museum in Kitanomaru Koen, Tokyo. Twenty-one lectures were presented to 505 registered participants, including 40 from abroad.

(3) Sixth Exhibition on Microsystem Technologies

Concurrent with the First International Micromachine Symposium, the Sixth Exhibition on Microsystem Technologies (MST Japan '95) was held at the Science Museum at Kitanomaru Koen in Tokyo under the theme "Micromachines — A Dream Fostering Technology." Focusing on the results of Phase I of the AIST Project, the Exhibition attracted 69 exhibitors and about 3,500 visitors.

(4) Micromachine Drawing Contest

To have children understand and be familiar with micromachines, as one of the micromachine dissemination and education aims, the MMC held the Second Micromachine Drawing Contest for primary and junior high school pupils. With the cooperation of MMC's supporting members, the contest targeted 19 primary and junior high schools in Tsukuba City in Ibaraki Prefecture, Kariya City in Aichi Prefecture, and Kitakyushu City in Fukuoka Prefecture. Twenty-six drawings were selected from a total of 1,373 entries.

(5) Evening Seminars

During fiscal 1995, a total of nine evening seminars were held (on the third Wednesday of each month) for the dissemination and exchange of research results, etc.

6. Participation in the Federation of Micromachine Technology

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

The Second Micromachine Summit

Financially supported by the Swiss government, the Second Micromachine Summit was held over three days, from April 24 through 26, 1996 in Montreux, Switzerland. Like the first Summit sponsored by the MMC, the second Summit was also a great success.

Under the organizing committee composed of the chief delegates of the six European countries that participated in the first Summit, preparations continued, centered around Prof. de Rooij of the University of Neuchâtel. Prof. de Rooij was the Summit chairman.

At the reception on the first day, Prof. H. Ursprung, the State Secretary for Science and Research made a guest speech, indicating that the Swiss government placed great importance on the Summit and on micromachine technology. The keynote speech at the beginning of the meeting was delivered by Dr. Heinrich Rohrer, Nobel prize winner for physics in 1984. Dr. Rohrer emphasized the importance of micromachine technology in the 21st century. The presence of such important guests indicated the Swiss government's strong desire to promote micromachine technology. The major areas of agreement reached at the Summit were:

(1) The importance of standards and the need to take concrete action to advance the standardization of micromachines by cooperation among all countries.

(2) For further promotion of micromachines, education is extremely important, and therefore efforts should be made to implement detailed education programs.

(3) The third Summit will be held in British Columbia, Canada, in late April, 1997, and Australia is among the countries proposed for the fourth Summit in 1998.

(4) The Summit will be sponsored by the host country. However the Micromachine Center was appointed the permanent secretariat for recording all Summits and reviewing future schedules.

From Japan, a total of 20 people, including the five-member delegation and observers (supporting members) attended the Summit.

The Japanese delegation was made up as follows:

Chief Delegate:

Naomasa Nakajima, Professor, Division of Engineering, Graduate School, The University of Tokyo

Delegates:

Toshiro Shimoyama, Chairman of Olympus Optical Co., Ltd.

Tsuneo Ishimaru, Chairman of Nippondenso Co., Ltd.

Sadao Moritomo, Vice-President of Seiko Instruments Inc.

Takayuki Hirano, Executive Director of the Micromachine Center

The presenters of country reviews and the topics are shown in Tables 1 and 2 respectively.

Table 1 Country Review Presenters

(Chief delegates of participating countries)

Country	Chief Delegate	Institution
Japan	Naomasa Nakajima	Professor, Division of Engineering, Graduate School, The University of Tokyo
U.S.A.	Richard Muller	Director, University of California Berkeley
Canada	Gordon Guild	President, Simon Fraser University
Australia	Ian Bates	Professor, Royal Melbourne Institute of Technology
France	Daniel Hauden	Director, LPMO
U.K.	Howard Dorey	Professor, Imperial College of Science
Italy	Arnaldo D'Amico	Professor, University of Roma Tor Vergata
The Netherlands	Jan H. Fluitman	Director, University of Twente
Germany	Wolfgang Menz	Director, Albert-Ludwigs Universität Freiburg
Switzerland	Nicolaas F. de Rooij	Director, University of Neuchâtel

Table 2 Presenters at the Second Micromachine Summit

Topics	Presenter	Institution
Scope of Micro-machine	Peter Pfluger Naomasa Nakajima	Chief Executive Officer, CSEM S.A., Switzerland Professor, Division of Engineering, Graduate School, The University of Tokyo, Japan
Standardization	Wolfgang Menz	Director, Institut für Mikrosystemtechnik, Albert-Ludvig Universität Freiburg, Germany
Research and Education	Koji Ikuta Khalil Najafi Jan H. Fluitman	Professor, Faculty of Engineering, Nagoya University, Japan Professor, EECS, University of Michigan, U.S.A. Director, MESA Institute, University of Twente, The Netherlands
R&D Programmes and Role of Governments	Deborah Crawford Kaigham Gabriel Gaetan Menozzi Jean-Jacques Gagnepain Takayuki Hirano	Program Director, National Science Foundation, U.S.A. Deputy Director, Electronics Technology Office, DARPA, U.S.A. Chairman, NEXUS, EU Director, Department Science pour l'Ingenier, C.N.R.S., France Executive Director, MMC, Japan
Social & Industrial Impacts of Micro-machines	Howard Dorey Toshiro Shimoyama	Professor, Imperial College of Science, U.K. Chairman, Olympus Optical Co., Ltd., Japan
Needs Expressed by the Industries	Tsuneo Ishimaru Felix Rudolf	Chairman, Nippondenso Co., Ltd., Japan Section Head, CSEM S.A., Switzerland
Markets	Constant Axelrad Chang-Tze Hu Sadao Moritomo Joseph M. Giachino G. Benjamin Hocker	Marketing Manager, CEA-DTA, France Director, German Office, National Science Council, Taiwan Vice-President, Seiko Instruments Inc., Japan Program Manager, Electronic Division, Ford Motor Company, U.S.A. Principal Research Fellow, Honeywell Technology Center, U.S.A.

Keynote speech by Dr. H. Rohrer, Nobel prize winner

Banquet of the Second Micromachine Summit

Summary of the Research Supported by the Second 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 second (1994) research grant, three 1-year researches and three 2-year researches carried-over from fiscal 1993 have completed. Turn the page for the summary of the research results. Detailed results will be presented at the MMC meeting hall in late September. We hope many listeners.

•Carried-over research project selected for fiscal 1993

Leader & Co-Worker	Positions	Subjects	Period
Shuichi Miyazaki	Associate Professor Institute of Material Science, University of Tsukuba	The Development of Shape-Memory Alloy Thin Films for Microactuators	2 years
Eric Yeatman Richard Syms	Lecturer Head of Section Imperial College of Science, Technology and Medicine	Surface Tension Micromolding and Microactuation	2 years
Kunihiko Mabuchi Iwao Fujimasa	Associate Professor Professor Research Center for Advanced Science and Technology, The University of Tokyo	Application of Micromachining Techniques for the Development of Micro-Telesurgery Systems — A Basic Study	2 years

•Research projects selected for 1994

Leader & Co-Worker	Positions	Subjects	Period
Kazunori Kataoka	Professor, Department of Materials Science and Technology, Science University of Tokyo	Development of Superior Biocompatible Surfaces for Micromachine Engineering	1 year
Yasunori Saotome Akihisa Inoue	Associate Professor, Faculty of Engineering, Gunma University Professor, Institute of Materials Research, Tohoku University	Microforming and Fabrication of Micromachines with Amorphous Alloys	1 year
Ken Suzuki	Assistant, Institute of Biomedical Engineering, Tokyo Women's Medical College	The Stable Coating of Biocompatible Materials on Micromachine Surfaces	1 year

An Application Guidelines for the 4th (Fiscal 1996) Research Grant Theme on Micromachine Technology

1. Object of the research grant

Basic research on basic technology, functional element technology and systematization technology of micromachine.

2. Research period

Theme A: End of March, 1997 - March 31st, 1998, or
Theme B: End of March, 1997 - March 31st, 1999

3. Application period, theme decision and fund grant date

Application period: July 1st - October 31st, 1996
Theme decision: Beginning of March, 1997
Fund grant date: Late of March, 1997

4. How to apply

Request the application form to the following Micromachine Center with your Fax number
(Fax: +81-3-5294-7137)

5. Qualification

Teaching staff (professors, associate professors, lecturers and research associates) of universities belonging to the academic societies which are affiliated with Federation of Micromachine Technology

6. Others

(1) Total fund granted: about 15 million yen.
(The limit is 2 million yen for theme A and 3 million yen for theme B per unit)

(2) We may ask the joint research with the supporting member enterprises of the Micromachine center after the grant is decided, since the purpose of this work is to promote the exchange between enterprises and academies.

(3) Reference: Research Department, Micromachine Center (persons in charge: Ueda/Namise)

Basic Research on the Development of Shape-Memory Alloy Thin Film for Microactuators

Shuichi Miyazaki, Institute of Materials Science, University of Tsukuba

1. Introduction

To drive a micromachine, high-performance super mini driver (microactuator) must be developed. Some materials and mechanisms have been proposed for microactuators. Among these, shape-memory alloy produces large displacement and force, both of which are about 10 times of piezoelectric materials. Besides, shape-memory alloy can be heated and driven by only a several volts of electricity. Therefore, development of shape-memory alloy thin film has been strongly expected.

In this research, aiming to develop tough microactuator materials to drive micromachines, by sputtering method we formed and evaluated characteristics of thin films of Ti-Ni binary alloy, which has the most excellent actuator characteristics among shape-memory alloy, and of Ti-Ni-Cu ternary alloy containing Cu as the third element.

2. Research Results

In the first year of this research, through development of Ti-Ni binary alloy thin film, we established sputtering method to form thin films having equivalent actuator characteristics to bulk materials. A maximum displacement of 5.5% and a maximum recovery force of 500 MPa or greater were confirmed. It was also verified that it is possible to prepare samples in which martensite transformation and its reverse transformation take place at high 60°C and 87°C, respectively. Since the both transformation points are considerably higher than room temperatures, the samples can readily be driven without special cooling system.

Fig. 1(a) shows the change of the shape-memory characteristics of a Ti-Ni alloy thin film by repeated deformation caused by the martensite transformation. Since the sample contained excess Ni and had been aged, the transformation temperatures were low. However, regardless of repeated deformation by cooling and heating under a high stress of 250 MPa, the shape-memory characteristics was quite stable except the little variations in the early stage. This sample showed two stage deformation. The first stage deformation is induced by R-phase transformation. Fig. 1(b) shows the behavior of the sample deformed by the R-phase transformation alone. Deformation in this phase is subtle compared to that caused by the martensite transformation, appeared on the second stage. Shape-memory characteristics associated with this R-phase transformation phase is very stable and is free from changes.

To improve deformation response in case of the martensite transformation, either transformation temperature hysteresis has to be reduced or transformation temperature be raised. To do this, either Cu or Pd should be added as the third element. Hence, development of thin films of Ti-Ni-X (X for Cu or Pd) ternary alloy is important. On the second year of this research, we prepared thin films of Ti-Ni-Cu ternary alloy. Fig. 2 shows the effect of adding Cu upon transformation temperature hysteresis of a solution-treated film. The hysteresis of binary alloy (0% Cu) was 27 K, whereas adding Cu of about 8% reduced the hysteresis to 11 K, proving the effect of the additive.

Perfect shape-memory characteristics were proved for such ternary alloy thin films as were for binary alloys.

3. Future Expectations

Since there had been no shape-memory alloy thin film that has equivalent characteristics to bulk materials, shape-memory alloy is not as popular as piezoelectric materials as the material for microactuators. Ti-Ni shape memory alloy thin films developed in this research match bulk materials in transformation temperatures, displacement, force, and stability. We hope wide use of shape-memory alloy thin films will be started inspired by our research.

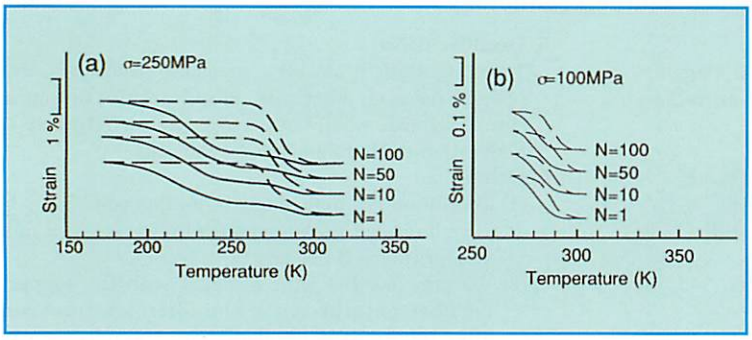

Fig. 1 Effect of cyclic deformation on shape memory characteristics of aged Ti-55.8at%Ni thin film (N: number of cycles)

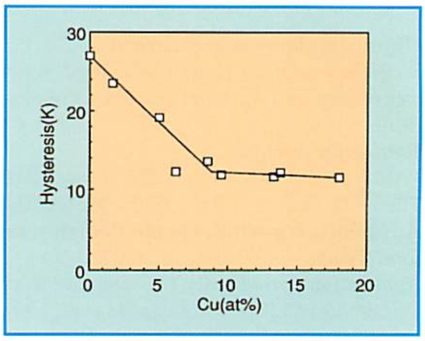

Fig. 2 Effect of copper content on the transformation temperature hysteresis of solution-treated Ti-Ni-Cu thin film

Research on Micromolding and Microactuation Using Surface Tension

Eric Yeatman, Lecturer, Richard Syms, Reader and Andrew Holmes, Lecturer
Electrical and Electronic Engineering Department, Imperial College, University of London

Micromolding

In this part we investigated the use of surface tension in reshaping meltable microstructures. Previous applications for this technique include the formation of channel waveguides and microlenses, where the requirement is for smooth cylindrical or spherical surfaces. Here, we considered the use of reflow to transform a structure with uniform height, made up of rectangular strips or discs, into portions of cylinders or spheres with height variations. The shape transformation can be analysed using minimisation of surface area and conservation of volume, from which we find that, for appropriate initial land dimensions, a uniformly etched structure can be reshaped into one in which the height of reflowed spherical droplets considerably exceeds that of cylindrical droplets. A connected structure containing both types may then be planarised by an encapsulant, which is etched back to expose the tops of the spherical droplets. Using these access points, the meltable material may be etched away to leave a network of buried cylindrical pipes suitable for microchemical analysis systems (Fig. 1). Fig. 2 shows a verification of this principle, in structures formed by reactive ion etching and melting 15 µm thick layers of borophosphosilicate glass on Si.

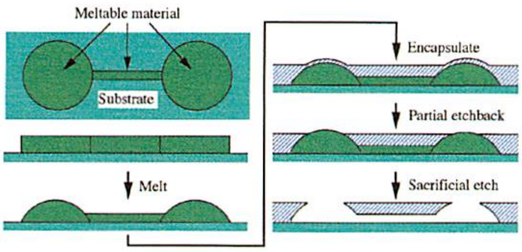

Fig. 1 Process for micro-channel fabrication

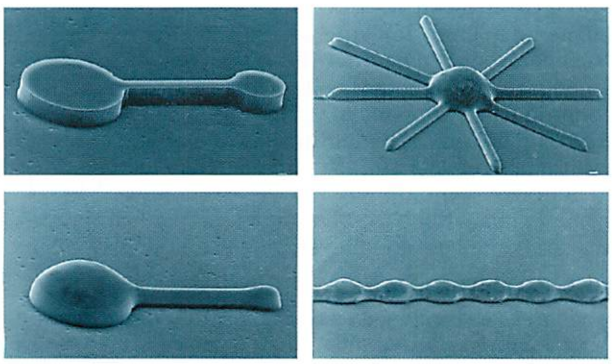

Fig. 2 Etched and reflowed glass structures

Microactuation

The effects of capillary forces in micromechanisms are well known; often the results are unwanted, such as the stick-down of structures freed by wet etching, but useful effects have been shown, such as in flip-chip bonding or in 3-D micro-assembly[1]. Here we have examined the use of surface tension to achieve reversible, electrically controlled actuation. The effect exploited is electro-wetting, in which the contact angle between a liquid electrolyte and a conducting surface is altered by an applied voltage. This results from the increase in the liquid-solid interfacial energy γ_{LS} due to the introduction of surface charges; the contact angle is dependent on γ_{LS} according to Young's equation. Surface tension actuation scales very favourably into micro-dimensions, with enormous forces being achievable. We have obtained resonant excitation of a simple beam structure using an electrolyte between Au and Pt surfaces, and have fabricated micromechanical actuators in Si for more detailed and precise investigation, as shown in Fig. 3. An advantage of the technique is that only low voltages (< 1 V) are necessary. However, there are difficulties with degradation of surfaces, and control of liquid volumes, which we are seeking to overcome. A longerterm aim is to implement the mechanism in a conductive porous medium to form an 'artificial muscle' material.

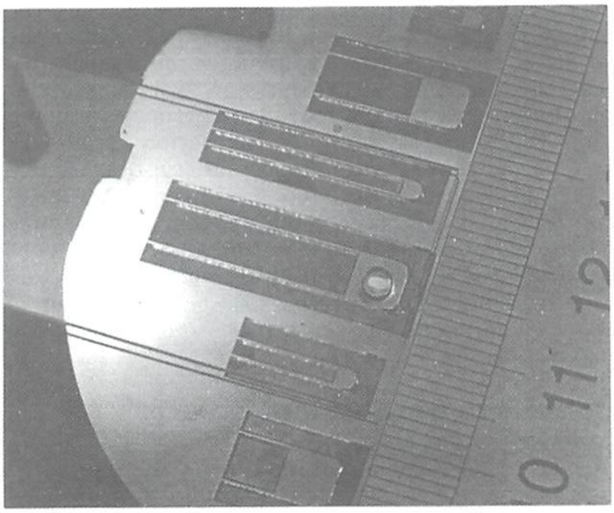

Fig. 3 Electro-wetting Si actuators with transparent counter-electrode

[1] P.W. Green, R.R.A. Syms and E.M. Yeatman, "Demonstration of three-dimensional microstructure self-assembly," IEEE J. Microelectromech. Syst. **4,** 170-176 (1995).

Basic Research on Application of Micromachine Technology in the Development of Remote-Controlled Microsurgery Systems

Kunihiko Mabuchi and Iwao Fujimasa,
Research Center for Advanced Science and Technology, The University of Tokyo

Introduction

The ultimate goal of this research is to apply the virtual reality technology to create virtual space where a surgeon can operate a remote patient as if they are in an operating room, but with a magnified field of view, thereby developing a micro telesurgery system that provides the means to perform micro surgery in a way as easy as an ordinary operation. In this research, we examined difficulties in individual technical elements from the point of micromachine technology, created a prototype of a micro telesurgery system, and conducted surgical operation from a distance of about 10 km. Summary of the process is explained below.

Application of micromachine technology to individual elements and its difficulties

Technically, "micromachines" in the field of microsurgery are categorized in miniature machines. This time, a special microsurgery microscope and the image fiber bundle (of an effective outer diameter of 0.65 mm, 6000 pixels), were used as the input device of vision, which is the most important sensory system. The image fiber bundle is advantageous in size and applicability to tubular and cavity organs. First, two image fiber bundles were used to obtain stereoscopic view. Then, to reduce size and in order to make it easy to adjust the distance between the bundles (which corresponds to the accommodation reflex), a single-bundle system was created, where a single image fiber bundle is vibrated by a piezoelectric actuator and the images corresponding to the fields of view of the left and right eyes are collected by the bundle synchronously with its vibration. As for the actuator, a micro actuator having a mechanical displacement and force transmission system is under planning and construction. This actuator is being improved to a system for the counterforce feed-back system and the pressure sensor. Micro pressure distribution detecting mechanism with pressure-sensitive rubber, and feed-back system of pressure (counterforce)/temperature as image or sound data are developed for the feed-back system to the surgeon, and the same time are researched on the creation of the artificial sense by the direct stimulation of the nerve fiber.

Construction and manipulation of telesurgery system

We put the slave manipulator of the fabricated micro telesurgery system to the Faculty of Medicine of The University of Tokyo (Hongo campus). A surgeon staying at Research Center for Advanced Science and Technology, The University of Tokyo (Komaba 2nd campus) at a distance of about 10 km did surgical operation using the master manipulator there. Image data and manipulation data are conveyed on two ISDN lines. To provide the surgeon with a magnified field of view, a special stereoscopic microscope for micro surgery was used. Image signals corresponding to the fields of view of the left and right eyes separated by the beam splitter are input to two CCD cameras, then transmitted to the surgeon side via the ISDN lines using two sets of converters (TV phones). On the surgeon side, the signals are converted into images again, and provided to the surgeon using a goggles-like head mounted display to produce a stereoscopic sensation. In this experiment, the slave manipulator that performs actual operation was a robot hand having six degrees of freedom. The hand had a gripper on its end to hold micro surgery tools and a laser radiation fiber probe to carry out surgical operation on animal tissues. The master manipulator handled by the surgeon consisted of 3D joy sticks and a trigger for laser radiation.

The image was coded into 352 by 288 pixels (for a still picture, 704×480). The image data was reduced for transmission and the number of frames per second was compressed to about five to ten. Regardless, the stereoscopic sensation was sufficient and operability was better than in case of using ordinary 2D image. A major factor in improvement of operability is considered to be the feedback of touching sensation to the operator. In the experiment system we used, there was a time lag of approx. 0.5 sec between the order of the master manipulator and response of the slave manipulator mainly because of data processing time for compression and conversion of image data. (The delay was independent from the distance between the master and the slave.)

Conclusion

There is no need to say about the usefulness of a micro telesurgery system. However, before using it in practice at bedside, many individual technical elements need to be developed or improved. Micromachines are indispensable especially for 1) stereoscopic mechanism and optical system on the manipulator end for use of fibers as the visual input system, 2) tactile and pressure sensation system, position sensing system, and actuator mechanism for the slave manipulator (that actually performs micro surgery). Time lag due to data transmission will become a big problem as the quantity of information will increase. However, it is basically a problem of communication technology. In this research, we conducted R&D on individual technical elements and fabricated a prototype total system. Much of the subject including the manipulator is yet to complete. We are going to spare time to solve the problems found in this research and continue development and improvement.

Acknowledgments

This research was supported by cooperation of Mr. Hideo Nakazawa of Aisin Cosmos R&D Co., Ltd. and the company.

Development of Superior Biocompatible Surfaces for Micromachine Engineering

Kazunori Kataoka, Department of Materials Science and Technology, Science University of Tokyo

If a micromachine is to properly function in vivo, it must be "stealthy" to be immune from the foreign material recognition system of the living body. Otherwise, even a high functionality device cannot exert its performance as it is attacked by the foreign material processing mechanism inherent to our bodies. We tend to think that inside the human body is a relatively mild environment because it keeps standard temperature and pressure. Biochemistry textbooks say an enzyme is a catalyst that works under mild conditions. However, from another point of view, we can say that inside the living body is a kind of extreme environment where reactions that would not proceed without a high temperature and a high pressure at outside the living body are taking place very easily. Therefore, when preparing medical micromachines, we have to understand that their materials are to be used in an extreme environment.

There may be a variety of routes to introduce micromachines into a living body. The most popular way is the blood vessel. Selection of the route is important to deliver drugs or biologically active substances to a targeted seat of disease, or to use a micromachine that works at a specific part to remedy local disease. A special consideration with micromachines intended for such purposes is how to evade recognition by the reticuloendothelial system (RES). RES is a collective name of phagocyte systems located in parts directly contacting to blood or lymph flow. Primary function of RES is recognition and absorption of old blood cells and pathogenic germs invaded from outside. Therefore, RES is very sensitive to particles of external origins. A micromachine, too, is recognized as a foreign body by RES, almost for sure. RES developed especially in the liver, lungs, and spleen. These organs are checkpoints, so to speak, in blood vessels. If a micromachine is to be given in blood, preventing adhesion of hematoblast on the micromachine and the resulting thrombus is another important problem.

This research aims to establish fundamental technologies to stealthify micromachine surface easily and accurately. We promoted the development of the technology for synthesizing hydrophilic polymer chains that readily attach to metal surfaces and makes them biologically compatible, and for arranging the polymer chains on metal surfaces. We took notice of polyethylene glycol (PEG) known as hydrophilic polymer. PEG, as seen from the structural formula in Fig. 1, has little rotation hindrance by an oxygen atom on the principal chain. Consequently, skeleton of PEG is quite flexible. Its molecular form is relatively extended in water by coordination of water (hydration). The flexible structure and hydrated, extended molecular form repels foreign substance even in water, thereby suppressing mutual reactions with protein and cell. In fact, we already proved that a brush-like structure of smaller than 100 nm (polymer micelle) with dense PEG chains can survive in blood steadily for a long time.

In this research we formed biocompatible surfaces by growing dense PEG chains on metal surfaces tightly as shown typically in Fig. 2. To do so, we took two approaches below.

The first approach was polymerization of ethylene oxide using CH_2=CH-CH_2-OK for the initiator to obtain PEG with allyl group at the terminal. Then thioacetic acid was added and hydrolyzed to synthesize PEG with a thiol group at the terminal (PEG-SH). Since the thiol group is known to steadily bond to gold-evaporated surfaces, we evaporated gold on metal surface and attached PEG-SH on this surface via the terminal thiol group to form PEG-brush interface.

The second approach synthesized PEG macro monomer with an acetal group on one terminal and a polymerizable methacrylic group on the other terminal by use of acetal initiator for ethylene oxide and methacrylation of the other terminal after polymerization. Comb-like copolymers were prepared by replacing the acetal group with aldehyde group by acid treatment and copolymerizing the methacrylic group to other monomers. The copolymers were coated on metal surface to form the PEG surface shown in Fig. 2. On this PEG surface, various biologically active substances can be immobilized by utilizing the aldehyde group on the terminal of the PEG.

If surface of a micromachine is processed by the method established by this research, the machine can be safely introduced in blood system of a living body. We expect this method will revolutionize medical treatment of various diseases.

$$\mathbf{HO\text{-}(CH_2\text{-}CH_2\text{-}O)_{\mathit{n}}\text{-}H}$$

Fig. 1 Structural formula of polyethylene glycol (PEG)

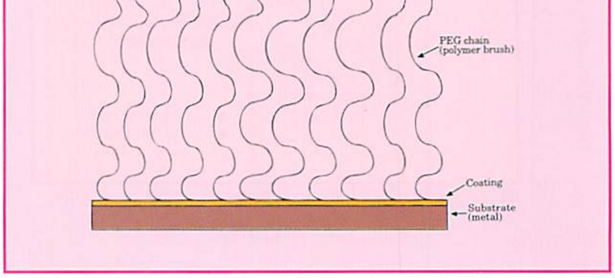

Fig. 2 Metal surface treatment with polyethylene glycol (PEG) chain

Microforming and Fabrication of Micromachines with Amorphous Alloys

Yasunori Saotome, Faculty of Engineering, Gunma University
Akihisa Inoue, Institute for Materials Research, Tohoku University

1. Introduction

There are two major requirements of micromachine materials: One is the material characteristics exploitable on a microscopic scale instead of conventional macro material characteristics. The other is that forming and machining methods to form micro geometries must be established. The micro geometries creation method including complex processes such as silicon process and LIGA process and the selection of materials are the two sides of the same coin. To make micromachine elements, especially the structural elements, suitable materials and micromachining technology must be developed. Amorphous alloys are highly useful to realize high performance micro actuators and structures for their excellent characteristics as functional or structural materials, including the isotropic homogeneity free from crystalline anisotropy. The goal of this research is to develop new materials categorized in the second generation of amorphous alloys, clarify its microforming properties, and establish a micromachine production method.

2. Viscous Flow and Microforming Characteristics in the Supercooled Liquid State

If an amorphous alloy prepared by melt quenching is heated again, the alloy usually crystallize at temperature T_x. However, new amorphous alloys studied in this research showed obvious glass transition behavior at temperature T_g and developed supercooled liquid state in a wide range of temperature. Fig. 1 shows examples, which showed perfect Newtonian viscous flow characteristics. Strain rates under low stress of 10 MPa was 10^{-3} to 10^{-2} l/s. To clarify microforming characteristics on a submicron scale, first we studied the method to evaluate them, and selected conformability to a die with a V-groove 1 to 20 µm width as an index to microforming characteristics (See Fig. 2.). Micro transferability of the order of nanometers under low stresses of about 10 MPa was obtained by this method.

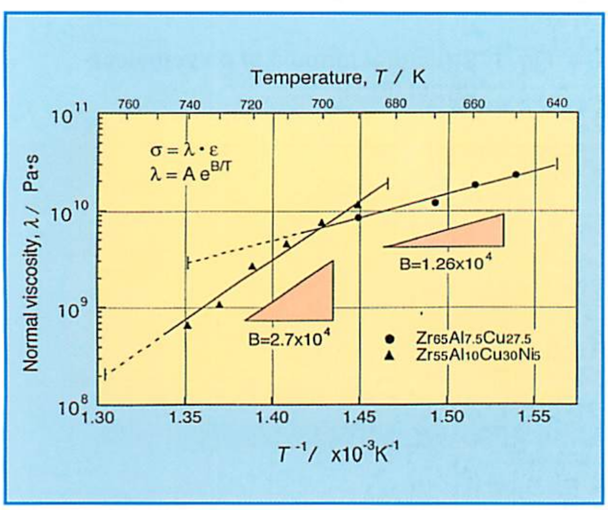

Fig. 1 Viscous flow characteristics of Zr-base amorphous alloy

3. Microforming Methods and Processing Characteristics

We developed micro forging (see Fig. 3) and micro extrusion process of amorphous alloys as a method of fabrication of micromachines. For the processing die, we used photosensitive glass on which we formed die geometries by photolithography. The surface properties of the die and its behavior of contacting the material become dominant factors in microforming.

4. Conclusion

Amorphous alloys in supercooled liquid state can be formed into micro structures of the order of nanometers, and are expected as one of the most useful materials to fabricate micromachines.

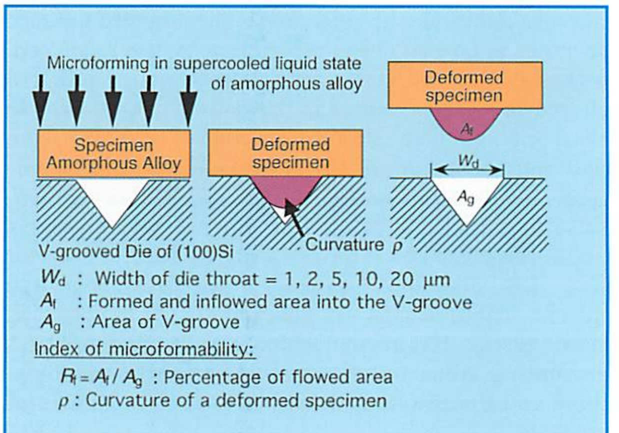

Fig. 2 Microforming characteristics evaluation method using V-grooved die of (100)Si

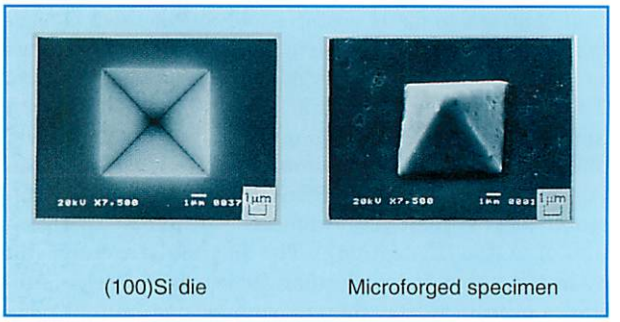

Fig. 3 Forming of $Zr_{55}Al_{10}Cu_{30}Ni_5$ alloy

The Stable Coating of Biocompatible Materials on Micromachine Surfaces

Ken Suzuki, Institute of Biomedical Engineering, Tokyo Women's Medical College

Recently, various medical micromachines are being developed. If a medical micromachine is to exert its functionality in living bodies, it must evade adhesion, cohesion, or phagocytosis of protein and blood cells (See Fig. 1.). About biocompatibility of metallic materials for macro machines, although a large number of studies have been made on stability such as toxicity and corrosion, little has been known about blood compatibility. We clarified that a block copolymer consisting of 2-hydroxyethyl methacrylate (HEMA) and styrene (St) which forms a hydrophilic-hydrophobic micro phase separation structure suppresses adsorption of protein and hematoblast and has an excellent blood compatibility. If the polymer material with such a good anti-thrombosis characteristics can be fixed steadily on a surface of metallic materials, it probably leads to stable use of micromachines in blood. However, since usually metal and polymer do not adhere to each other, peeling will be troublesome if the polymer is coated on metal in an ordinary manner. To avoid this, we studied the method of using thiol group (-SH) known of forming stable complex on gold surface, to prepare stable polymer layer on gold surface.

On stainless steel which is in wide use in medical field, gold thin layer was formed by gold-plating. Plating has a wide scope of application because it is an established industrial process and relatively easy to obtain stable gold layer. We tried to attach polymers onto metal surfaces by two approaches shown in Fig. 2. First, we copolymerized methacrylate chloride and butyl methacrylate, which have good film-forming properties, and allowed the copolymer to react with aminoethanethiol to prepare polymer with a thiol group. The polymer obtained by this process was insoluble, probably because of the S-S bond formed between polymers. To avoid insolubilization of polymers, we tried to fix polymers using the amino group after attaching amino group on gold surface. Part of a stainless steel plate plated with gold (20 mm × 30 mm × 0.5 mm) was masked and immersed in aminoethanethiol solution (2 wt% in chloroform) for 24 hours. Then the plate was washed and the angle of contact was measured by flat plate method (See Fig. 3.). The angle of contact on the surface changed on the border of the masked area, indicating that amino groups attached. The change was observed even after the plate was cleaned ultrasonically, proving stable chemical bound on the surface. At present we are fixing polymers on metal surface by making them react with this polymer having amino group and acid chloride attached on the surface, and evaluating the stability of the fixation. In former studies we found that stable polymer layer is obtained by chemically bonding polystyrene beforehand on glass surface and then coating it with anti-thrombogenic materials. We hope this technique is applicable to obtain blood compatible metal surfaces, which will be a basic technology to function micromachines steadily in blood.

We wish to thank Micromachine Center for the financial support to this research.

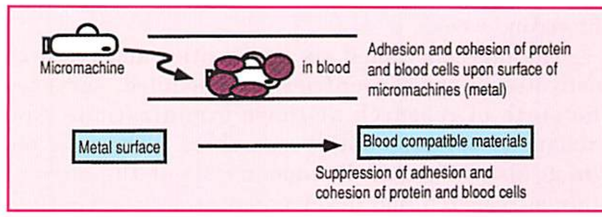

Fig. 1 Use of micromachines in blood

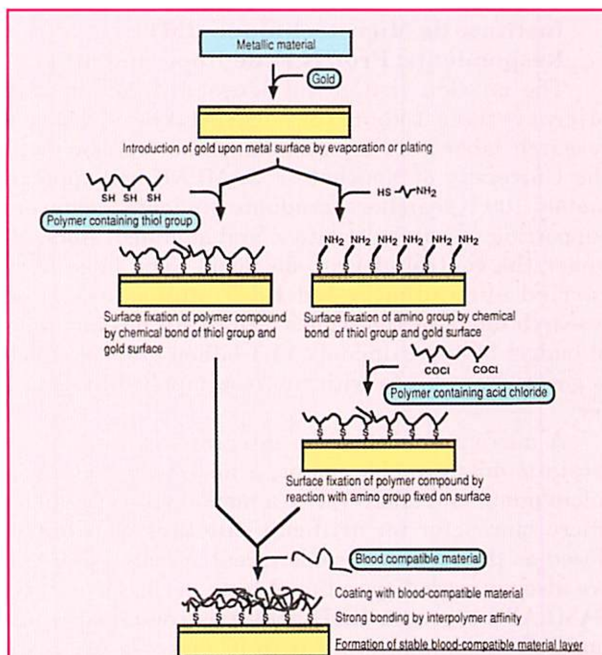

Fig. 2 Stable fixation of blood-compatible material upon metal surface

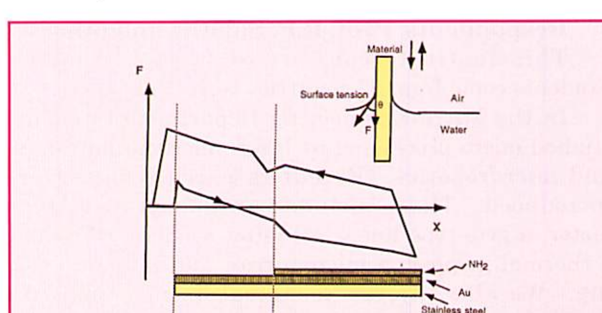

Fig. 3 Measurement of surface tension on amino group introduced metal surface by plate method

The First Mission to Europe in Fiscal 1996

One of the MMC's international exchange activities is organizing survey missions abroad. Taking advantage of the Second Micromachine Summit held in Montreux, Switzerland from April 24 through 26, the first mission in fiscal 1996 visited major research institutes in Europe for technical surveys.

Dr. Naomasa Nakajima, professor of The University of Tokyo, was a group leader for the first week of the two-week mission. Mr. Kohei Ito, Executive Vice President of Fanuc Ltd., took over for the second week.

The mission visited six universities and research institutes in three countries as scheduled, surveyed the state of research at those organizations, and exchanged opinions with researchers. The mission, which also informed Europeans about the current state of research and development in Japan, concluded safely with its initial aims achieved.

At the Swiss Federal Institute of Technology Lausanne

(1) University of Neuchâtel, Switzerland
Institute de Microtechnique (IMT)
Respondents: Prof. N.F. de Rooij and others

The mission visited the Sensors, Actuators and Microsystems Laboratory (SAMLAB) of IMT, a research laboratory for micromachine technology at the University of Neuchâtel. SAMLAB has approximately 100 researchers, graduate students, engineers supporting research activities, and administrators, all under the control of Prof. de Rooij. The laboratory carried out industry-led R&D, and is assigned research topics by companies. SAMLAB has an annual budget of approximately ¥1.1 billion (40% of which is government funds with the rest supplied by industry).

A microanalysis system integrated with an electrostatic micro wobble motor, a micro odor sensor, a micro pump and micro valve, a micro gyroscope, and a micro bioreactor for artificial satellites were introduced as the results of some recent research projects. We also witnessed operational tests in the laboratory. SAMLAB's vigorous R&D activities combined traditional precision machining with IC processes to create original technologies.

(2) Swiss Federal Institute of Technology Lausanne, Switzerland
Respondents: Prof. R.P. Salathe and others

This Institute consists of 12 departments. Students come from 87 countries worldwide.

In the Micro-Engineering Department, students studied micro processing by laser, micromechatronics, and microrobotics. Recent research results were introduced. These included an impact-drive-type motor, a grip-type linear actuator, a micro X-Y stage, a thermal gripper, a micromirror, and laser processing. We also enjoyed technical discussions with researchers in the laboratory while looking at samples of their achievements.

The Department was steadily preparing for multidisciplinary researches by inviting students and researchers from all over the world. A building exclusively for the Micro-Engineering Department will be completed in 1998, and a systematic research and educational environment for micromachine technologies should be established.

(3) Milan Polytechnic University, Italy
Respondents: Prof. A. Rovetta and others

At Milan Polytechnic University, the research focuses on robotics. In close cooperation with medical departments the Institute researches and develops medical robots to assist in medical treatment. A mannequin robot called Michelangelo (the bust only) was developed and is useful for medical training. Communication technologies are also being researched. Communication tests with Italy, the United Kingdom, and the United States are being conducted as a UNESCO project. The Milan Polytechnic University will one day probably develop small robots, but its robot development has not yet reached the level of micromachines. The Institute's efforts to develop micromachines will no doubt continue.

(4) Scuola Superiore Sant'Anna, Pisa, Italy
Microfabrication Technology Laboratory (MiTech Lab.)
Respondents: Dr. C. Carrozza and others

Scuola Superiore Sant'Anna places the greatest emphasis on micromachine technology in Italy. Its graduate school was established in 1987. The University's two faculties are the Faculty of Social Science and the Faculty of Experimental and Applied Science. Micromachine-related technologies belong to the latter and are researched at the Microfabrication Technology Laboratory (MiTech Lab), which we visited.

MiTech Lab, established five years ago, is researching micromachines under the leadership of Prof. Paolo Dario. Only about 20 graduate students are admitted to the Laboratory a year. Ninety percent of the Laboratory's funding is from the EU, with the rest coming from industry.

Recent research results introduced included records of nerve activities, the intelligent nerve interface for stimulating muscle motion, a water micro-analysis system for environmental monitoring combining a micropump, valves, sensors and circuits, and a self-locomotive endoscope to monitor the intestines. At the Laboratory, we enjoyed technical discussions with researchers who showed us samples at the site of their experiments. In addition to Prof. Dario's research into the nerve interface, which is also well known in Japan, we learned about other research projects. Many highly able postdoctoral researchers were engaged in research, and their enthusiasm for their work came through strongly.

(5) Fraunhofer Institute, Germany Institut ZuverLaessigkeit und Mikrointegration (IZM)

Respondents: Prof. H. Reichl and others

Although the Institute was made of brick in traditional European style, on the inside the Institute was anything but traditional. It has been developed into a very functional and modern building using advanced technology. The Institute is located on the same site as Technical University of Berlin and they are connected by a corridor. The institutes share research facilities and some of the IZM researchers teach at the Berlin Institute of Technology.

The major research topics at IZM are:

1) Mechanical reliability
2) Multi-chip modules
3) Chip bonding technology
4) Reliability evaluation

Results of recent research projects were introduced. These included multi-layer printed circuit boards for high-density IC mounting, mounting on flexible tapes, microstructure (membranes, etc.) analysis, and high aspect structure formation technology. Technical discussions were held with researchers at the Institute's laboratory.

(6) Technical University of Berlin, Germany

Respondents: Prof. E. Obermeier and others

Technical University of Berlin is not only physically connected to the IZM by a corridor, but the two institutes also share research facilities. They fully cooperate in terms of human resources, and professors and researchers communicate closely.

Results of recent research projects at this University were introduced. These included pressure sensors, temperature sensors, infrared ray sensors, gas flow sensors, humidity sensors, RF power sensors, and microshutters. We visited the University's laboratory for technical discussions with researchers.

The University was also researching and developing micro devices for practical use. Sensors seemed to be the main focus of the University's research. Full use of computers in the evaluation and analysis of experiments improved the University's research efficiency and hinted at the German talent for thorough organization.

Emphasis on standardization was strong, and it was decided to exchange information between the MMC and this Institute.

At Technical University of Berlin

The Second Micromachine Drawing Contest

Speech by Prof. Hirofumi Miura, Chairman of the Screening Committee (Full text)

The Second Micromachine Drawing Contest Award Ceremony was held on March 28 at the Tokai University Alumni Association Hall, the Kasumigaseki Building in Tokyo. Prof. Hirofumi Miura, Department of Engineering, Graduate School, The University of Tokyo spoke as the chairman of the screening committee.

(A related article and award-winning entries are published in Micromachine No. 15.)

Ladies and gentlemen, let me introduce myself.

I'm Miura of The University of Tokyo. Congratulations to the award winners! A particularly high standard of entries was received this time.

Selecting the winners was very difficult indeed. As you already know, 19 schools participated in this contest. In the primary school category, 470 entries from 11 schools were received. In the junior high school category, 903 entries from 8 schools were submitted.

The official judges were Mr. Hiroshi Shima of the Machinery Promotion Association who is right here, Dr. Ken'ichi Matsuno of the Mechanical Engineering Laboratory, Dr. Keiko Nakamura of the Biohistory Research Hall who is absent today, and myself. Mr. Takayuki Hirano, Executive Director of the MMC also helped. Before the judging, the MMC performed pre-selections because of the large number of entries. Entries eliminated in the pre-selection process did not receive awards.

Entries that were pre-selected were judged over a full day. Fifty-five entries in the primary school category and 72 in the junior high school category were pre-selected for the final judging. The pre-selections alone were a huge task. Most of the pictures were hung on a wall, though some were placed on the floor. We examined each of them carefully and expressed our opinions after evaluating them from various viewpoints.

Since this is a drawing contest, selection points were awarded for coloring, technique, and expression of the painter's intentions. As various points were discussed pictures were selected. And the best entry and first-prize winning entry respectively of the two pupils present here today were selected. These two pictures were selected carefully from among very many fine entries, and the award winners can be proud of themselves. I offer them my warmest congratulations.

Personally, I was surprised at the large number of entries compared with last year, and the standard of the pictures was much higher this year. One point that impressed me was that many entries were related to insects, although not last year. Like the prize winning pictures, several featured insects. I think it a very good idea to relate insects to micromachines. I am an insect lover. My present research objective is to make an insect robot.

Today, before I came here, 300 cockroaches were delivered to my laboratory by door-to-door delivery service. They were given to us by Earth Chemical Co., Ltd. The National Institute of Health also raises cockroaches and they supply them to us too. Today we received cockroaches from Earth Chemical for the first time. 150 male cockroaches and 150 female cockroaches were delivered by door-to-door delivery service. They are very handsome cockroaches. Their color and gloss are good. In addition, the cockroaches we use in the laboratory are of good lineage. Because they are specially raised, their parents and grandparents are all known. They are sons and daughters of good families. They live in the laboratory and like cat food. When they are raised on cat food, they multiply rapidly even in the laboratory. In six months or so, they

produce another generation.

You may wonder why we are raising cockroaches like this. It's for making micromachines. At present it's not yet clear how useful micromachines will be. As Mr. Kondo told you, micromachines will definitely lead the way in the 21st century. It is a technology that we must research before the new century comes. So this Micromachine Center was established to promote research on micromachines in Japan. There is surely no country whose government promotes research in this technology as eagerly as Japan. Although we don't clearly know how useful micromachines will be, we have started creating small machines anyway. The Ministry of International Trade and Industry invited us, as people associated with universities, to join its program. This is a fairly rare case. So we are working with young students to try to make something interesting, without worrying too much about how useful micromachines will be.

For example, now in our laboratory, an ant robot 1 mm in size is walking around. A 1.5 mm mosquito robot is flying about. We have made various robots so far.

For instance, we made a robot that plays with a cup and ball (*kendama*). Its success rate in catching the ball in the cup is 95%.

We also made a top-spinning robot. When we show the robot how to spin a top, it decides the movement itself and goes ahead and spins the top.

A horizontal bar robot first just hangs down from the bar, but while it swings its body, it gradually becomes more skillful until it can do giant swings. We make such robots that are not directly useful for anything. But some technologies that will be useful someday and somewhere are being developed. As we are researchers at universities, we can do this. I intend to keep this attitude in researching micromachines. I'm going to carry on trying to make small things.

When thinking about the usefulness of micromachines, young primary and junior high school pupils will think of much fresher ideas than adults. Each entry in the contest had a significant theme. How can we use micromachines? Well, we are trying to relate this to our research. But when I think about how to make a robot, I think of insects. The structure of an insect is quite different from that of a mammal. Insects have a structure suitable for their small size. That may be God's design. Therefore, when we make a micromachine, we must design it with a completely different concept from conventional machinery. We can understand this if we look at insects. Insects have a structure that makes sense because they are small. Cockroaches are the same. Cockroaches have endurance, patience, and long life, and are very convenient for our experiments. So from the point of view of designing micromachines, insects have a very special meaning.

Because insects have excellent functions despite their small size, micromachines were likened to insects in many pictures. I was very glad to see this. But how to make the micromachines is our responsibility. If primary and junior high school pupils give us ideas about how and where to use micromachines, I believe this contest will have been very meaningful. Congratulations again!

Micromachine Technology (X)

Microhandling

Recent studies on microprocessing technology, some of which have been introduced in this course, have reported fabrication of micro gears, micro actuators, micro sensors, and other small components of micromachines on a test basis. To realize micromachines, these micro components need be assembled by systematization technology. This time, we introduce the Microhandling System II developed at the Research Center for Advanced Science and Technology, The University of Tokyo, and the Two-finger Micro Hand developed at the Mechanical Engineering Laboratory, Agency of Industrial Science and Technology, MITI.

1. Microhandling System II

An important factor of successful micro operations is the vision of ongoing process. To improve work efficiency, real-time view of the operation is indispensable. If the object or working point goes out of the field of view at every step of handling, the missing object or point must be found out again. Because the field of view on a microscope is very narrow, searching for missing things is a huge waste of time.

To avoid this, all microhandling tasks must always be executed within the field of view. This means that the field of view on a microscope determines the operational space. On this point micro operation is much different from the case with conventional robot manipulator where the operational space of the manipulator is limited only by itself. Thus, a micro operation system should be so designed that the manipulator system has an operational space matching the field of view of the microscope. At the same time, the entire system configuration should be such that a maximum visual information is obtained. Specifically, features listed below are required:

(1) The operating point agrees with the point where the operator's eyes are aimed.
(2) The tip of the manipulator must not go out of the field of view (around the operating point).
(3) Fields of view of two or more microscopes are integrated in the operational space of the manipulator.
(4) The microhandling system, consisting of the manipulators and the work table, have rotational DOF (degree of freedom) and translational DOF for adjusting attitude and position to the monitors about the operational space.

The Microhandling System II has been constructed based on these considerations (See Figs. 1 and 2.). This system consists of two manipulators, two microscopes, and one work table.

A scanning electron microscope (SEM) is the main and the optical microscope with a CCD camera is the sub. The monitor microscope with a CCD camera has rotational DOF about the axis of vision. The entire system is mounted on a 2-axis translation stage. The main manipulator performs major operations, whereas the sub manipulator fastens the objective on the work table. The main manipulator has 2-axis rotational DOF and 3-axis translational DOF (resolution of 10 nm). To align the tip of a tool and the center of rotation, 3-axis translational DOF (for coarse and fine

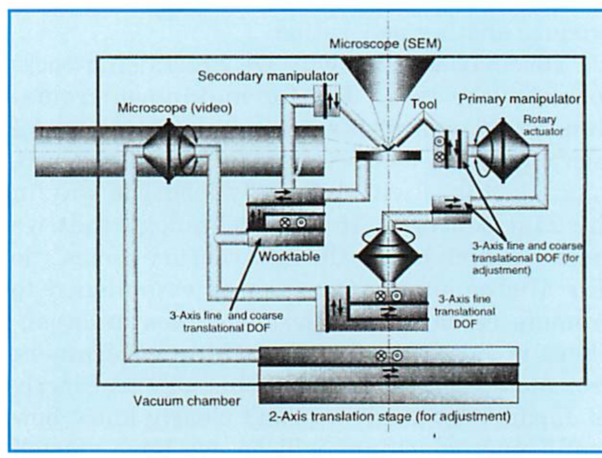

Fig. 1 Configuration of Microhandling System II (The Research Center for Advanced Science and Technology, The University of Tokyo)

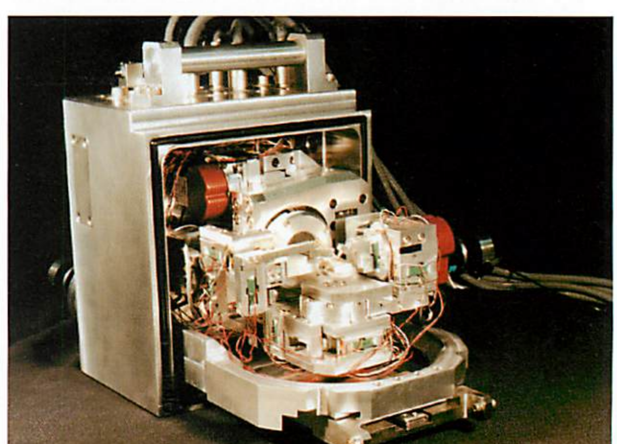

Fig. 2 Exterior View of Microhandling System II (The Research Center for Advanced Science and Technology, The University of Tokyo)

movements) are also provided. The sub manipulator has a single-axis fine and coarse movement mechanism. The work table has 3-axis translational DOF (for coarse and fine movements). This Microhandling System II successfully carried out micro operations. (See Fig. 3. The thicker finger is made of tungsten, the thinner a glass needle. The object is a solder ball of a diameter of 20 μm.)

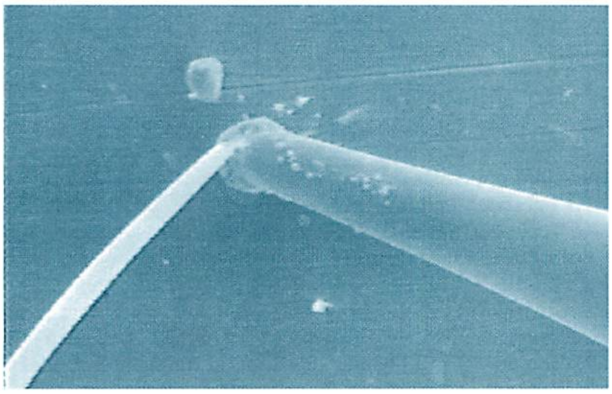

Fig. 3 SEM Image of Minute Operation (The Research Center for Advanced Science and Technology, The University of Tokyo)

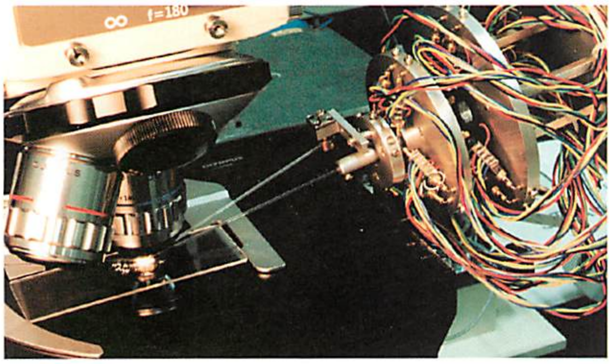

Fig. 4 Two-finger Micro Hand (Mechanical Engineering Laboratory, AIST, MITI.)

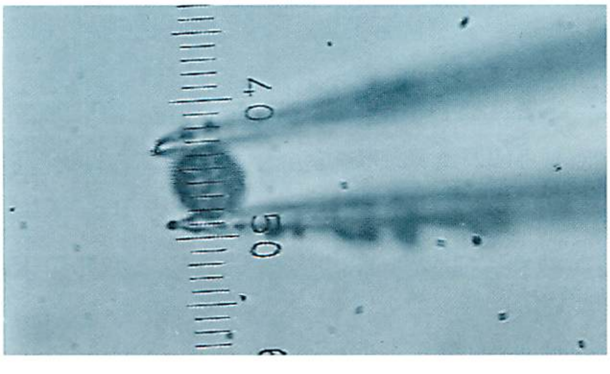

Fig. 5 Micro Manipulation of Latex Particles (5 μm dia.) (Mechanical Engineering Laboratory, AIST, MITI.)

2. Two-finger Micro Hand

The idea of a mechanism for a two-finger micro hand to make micro operations involves tough challenges. For example, position of the hand holder of each finger (micro hand module) is controlled based on actuator position data and rotary angle data. Even if the data is accurate, error-free control of hand holder position is impossible because of the inherent error of the mechanism. This problem cannot be ignored for a micro hand expected to perform highly accurate operations. This problem is confined to a permissible extent by precise calibration. However, if a two-finger micro hand mechanism having two hand modules arranged in parallel is employed, guaranteeing the accuracy of operations of the two fingers is difficult under aging and thermal fluctuations. Besides, operating space of this parallel mechanism is confined in the overlapping area of the operating spaces of the two hand modules, which will naturally be narrow. To solve these problems, people's use of chop sticks would be inspiring. Manipulations by chop sticks are performed mostly by the dexterous upper (forefinger side) stick and motion of the forefinger side generates the relative motion of the thumb side against, while the lower (thumb side) stick stays immobile on the hand, or we can say, the lower stick moves together with the hand.

Based on this idea, the two-finger micro hand has been designed by arranging two hand modules in series (See Fig. 4.). The three disk plates are fastened to each other via six links. A finger which works as a chopstick at the side of thumb is set on the middle plate through a hole of the upper plate. And the other finger which works as a chopstick at the side of forefinger is set on the upper plate. The upper hand module finger moves to form relative motion of the two fingers in minute operations, thereby avoiding the first problem, the mechanical error. The entire operating space of the needle on the lower parallel link mechanism is preserved as the operational space for the two fingers, evading the second problem. The two-finger micro hand succeeded in handling of latex particles (of a diameter of 5 μm). (See Fig. 5 in which both fingers are made of glass needles.)

3. Conclusion

This time, we have introduced the recent systematizing technologies under research and development. In the future, systematization technologies will be established upon manipulation technologies with microenvironment-specific phenomena taken into consideration.

The Second International Micromachine Symposium

The MMC will hold the second International Symposium (the first was held last year) on micromachine technology. The aims of the Symposium are to establish and disseminate micromachine technology by presenting R&D result, information on application, and measures to promote the technology worldwide.

Based on the outstanding success of the first Symposium, the second will repeat the same theme as last year: "Foundation of Industrial Technology in the 21st Century," examining possibilities to create industrial technology for the 21st century or next-generation technologies.

The first day of this symposium will include keynote and invited lectures. Several speakers will be invited from abroad, and there will be sessions for discussing "The Paths to New Industry," "Activities in U.S.A. and Europe," and "Presentation on Innovative R&D." On the second day, a session will be held on The Progress of the Industrial Science and Technology Frontier Program "Micromachine Technology." Presentations will be scheduled to introduce research in systematization technology in the second phase of the program.

In preparation, an organizing committee was formed, chaired by Dr. Naomasa Nakajima, professor of the Division of Engineering, Graduate School, The University of Tokyo. A program committee, an international advisory board, and a working group were also formed. The program committee will draw up a detailed program and select lecturers to be invited. The international advisory board, consisting of nine overseas chief delegates from the first Micromachine Summit, will give advice based on international viewpoints. Many are expected to participate again this year.

Period: Oct. 31 (Thur.) and Nov. 1 (Fri.), 1996
Place: Science Museum
2-1, Kitanomaru Koen, Chiyoda-ku, Tokyo
Sponsor: Micromachine Center
Supporters (Planned):
Ministry of International Trade and Industry
Agency of Industrial Science and Technology
New Energy and Industrial Technology Development Organization
Address inquiries to:
International Exchange Department
Micromachine Center
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The Seventh Micro System Technologies Japan (MST Japan '96)

In the future, micromachines will spread to various sectors of the economy and play important roles. Micromachines are expected to find wide application in industrial plants, space, the ocean, medical treatment, welfare, and daily life-related fields. However, further technical developments and exchanges of information are still needed.

"Micromachine technology" is a national project of the Industrial Science and Technology Frontier Program promoted by the Agency of Industrial Science and Technology, Ministry of International Trade and Industry. The project aims at establishing the basic technology for micromachines and has yielded steady results. At the previous exhibition the comprehensive results of the first phase of the project were exhibited and favorably received.

The MMC planned MST Japan '96 to provide an opportunity for engineers and researchers from various fields to present their findings, collect information on fields other than their own, learn about new technological possibilities, and resolve various problems in technical development. MST Japan '96 will be held according to the following schedule, and will suggest the direction of the second phase of the project, which started this year, as well as reveal the latest R&D results.

Period: Oct. 30 (Wed.) through Nov. 1 (Fri.), 1996
Place: Science Museum
2-1, Kitanomaru Koen, Chiyoda-ku, Tokyo
Sponsors: Micromachine Center
Micromachine Society (Tokyo)
Supporters (Planned):
Ministry of International Trade and Industry
Agency of Industrial Science and Technology
Applications or inquiries:
Secretariat of MST Japan '96
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On the front cover: *Visions of micromachines drawn by children (the best entries received in the micromachine drawing contest for primary and junior high school pupils) will have been fully realized in the 21st century by new technology (an image of a machine on the background) to be yet developed.*

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