MMC

MICROMACHINE

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Micromachine Center

Will Micromachines Change Medicine?

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Medicine: At the Forefront of the Quest for the Microworld

The discovery of microorganisms had a profound influence on the history of scientific thought, spurring the search for microworld in all areas of scientific endeavor. Although the existence of atoms and molecules had already been hypothesized, the impression made by living organisms seen under a microscope was beyond what anyone had imagined. Living things are still a major area of research in the microworld. Let us look at a few examples that demonstrate their significance.

The photosensitive cells in the eye are chemical sensors that convert light energy to electric potential by the reactions of photochemical substances. These long, narrow cells have four distinct portions (listed from the exterior of the retina going inwards): The outer segment, inner segment, nucleus, and terminal spherule. The cell membrane in the outer segment is folded in upon itself, forming a multilayered structure; it is in the outer segment that photosensitive pigments are found. An engineer looking at this arrangement would consider the cell a photomultiplier. It is as if nature has created a "function" just like the microchannel night vision devices of military technology.

A second example is the chemical communications technology of living organisms. Communication and control within organisms were originally mediated chemically, electrical signaling systems — that is, nervous systems — being a relatively new technology in the evolutionary process. Whereas nerve transmission takes place on a one-to-one basis, like cable communications, chemically mediated communication works more like a radio: Receptors on the cells receiving the message, analogous to tuning circuits, correctly detect the message sent specifically to them. The transmission channel is the blood that flows through the body, with numerous signals mingled together, just as electromagnetic waves are mixed as they are propagated through space. A living cell can be likened to a micromachine possessing the necessary number of tuning circuits.

Chemically mediated communication takes place not only within multicellular organisms but also between organisms of the same species, and can be used for recognition as well as communication. The most well known example of this phenomenon is insect pheromones. Chemically mediated communication occurs in various species of mammals, including odor-producing animals that use their smell to mark off territory and animals that secrete substances to indicate they're ready to mate. It seems that communications control in future micromachines would require robot technology that would give them individual autonomy analogous to that of living cells. Additionally, new communications systems with components having relationships similar to those between biochemicals and cellular receptors would need to be developed.

The Connection between Medicine and Micromachines

Everyone is familiar with the slender, millimachine-sized stainless steel tubes known as hypodermic needles, but few people are probably aware that the manufacturing of these needles requires processing technology capable of working with dimensions smaller than the bearing bore of a mechanical wristwatch. Although the mass production of hypodermic needles began some time ago, the metal-processing took intensive effort, and in the early days needles sometimes snapped in two in the middle of an injection. Subsequently, continuous drawing technology for metal tubes was developed, a sophisticated precision process in which the dies — of diamond — were short lived. Manufacturing costs were thus high, and consequently needle tips were ground off many times so that the needles could be reused. Recently, machining accuracy rapidly improved and costs dropped, so that today disposable syringes and needles are a matter of course.

Another example of medical millimachines is the equipment used in dental treatment. Since dentists work with object as small as teeth, their tools must likewise be small. Dental drills are millisized devices whose file has to be carved using submilli-processing. All dental tools — for example, scalers, used to remove tartar and the decayed parts of carious teeth, and excavators, for the disposal of pulp and soft tissue — require submilli-processing in their manufacture. The driving gear of a cutting turbine is itself a submillimachine with the precision of a wristwatch.

Will Micromachines Change Medicine?

It is in the field of medicine that researchers on the forefront of the microworld gather. Even if some technologies are not yet on the micro level, millilevel machines are common in day-to-day medical treatment. For this reason, the explanatory materials for the "Micromachine Technology," a large-scale project promoted by the Agency of Industrial Science and Technology, can be seen essentially as extrapolations of existing medical millimachine applications. If this is the case, it would seem that medicine will be the next recipient of the benefits of micromachine technology. They may be only extrapolative predictions now, but if, for example, it became possible to detect sound frequency using semiconductor micromachine resonance devices, the new technology will dramatically reduce the size of the frequency-analyzing device used in artificial internal ears. If hypodermic needles can be made using the LIGA process, painless injections and blood drawing will become a reality.

As a medical engineering researcher, I have a frank proposal to make to micromachine researchers who work from a purely engineering standpoint. Come to a clinic or other institution where medical treatment is given and see for yourselves the extensive use to which millimachines and submillimachines are put — and also the primitive environment in which they are working.

Research on Micromachine Technology at Electrotechnical Laboratory

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1. Outline

The Electrotechnical Laboratory (ETL) handles the "Evaluation of systematization technology" and the "Evaluation of 3-D micromachining technology" in the research related to micromachine technology under the Industrial Science and Technology Frontier Program "Evaluation of development of advanced maintenance technology for power plants" of MITI's Agency of Industrial Science and Technology (AIST).

In the evaluation of systematization technology, research is being conducted on an intelligent group robot system which allows maintenance work in the confined environment of a power station by operating multiple micro robots in both decentralized and parallel ways. This is based on the concept that the micromachine characteristic of smallness offers such benefits as the placing of many units in a narrow space compared with a single large robot and their various positioning to the operation target, thereby compensating for the limits of power and capability of individual units. Research is focused on the four elements: 1) coordinated working technology, 2) technology involved with learning how to coordinate work, 3) multi-telerobot technology, and 4) decentralized sensing technology.

In the evaluation of 3-D micromachining technology, research employes the high intensity convergent electron beam generated from a micro electron gun in the manufacture of micro component parts of micromachines. Latest research results are as follows:

2. Intelligent Group Robot System

Figure 1 is a schematic of the work to be done by the intelligent group robots.

For coordinated working technology, research is in progress on how to coordinate the operation of multiple robots. It is expected to be difficult in multiple operation to coordinate individual robots only through simple position and trajectory controls, since even a slight displacement in position will cause discontinuity in terms of force. It will therefore be necessary to have an arm capable of force control. Figure 2 is a small manipulator with two degrees of freedom capable of force control, a prototype manufactured for this purpose. We are currently producing a test bed for coordinated work by small locomotive robots with advanced arm functions.

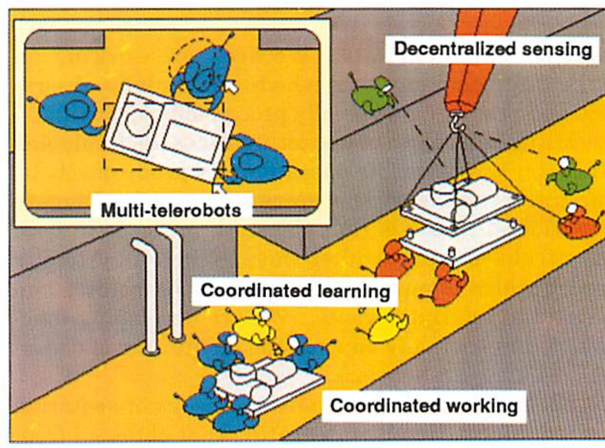

Fig.1 Schematic of a group intelligent robot system

In the technology involved with learning how to coordinate work, research is focusing on the learning functions of cooperative behavior by actually observing coordinated work in progress. The merits of this visual observation are to enable robots to coordinate without the necessity of special communication among them. This is important since, as the number of robots increases, complexity in communications will

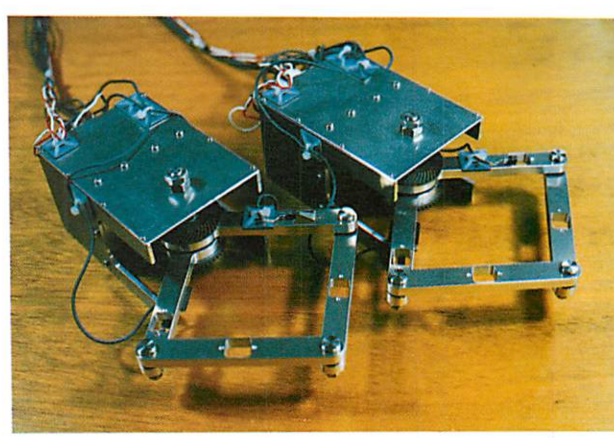

Fig.2 A small prototype manipulator capable of force control

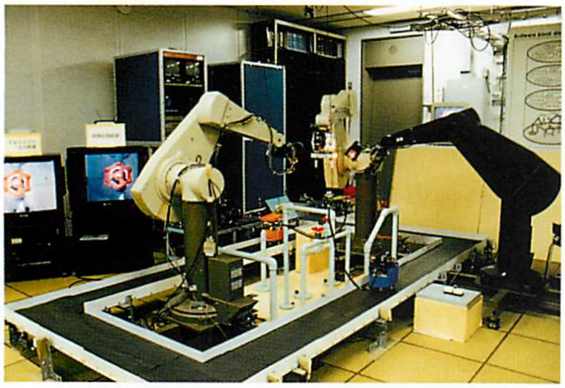

Fig.3 A test bed for decentralized sensing technology

increase exponentially. We are now working on extracting basic patterns which are visually observable and producing a visually processable algorithm.

Multi-telerobot research involves technologies necessary in the remote operation of a group of robots. The difference from the presently existing remote operation of robots is that the work proceeds in both decentralized and parallel ways. Thus a system is needed which allows a single operator to monitor and respond to multiple events. We are developing functions to intellectually support the monitoring of decentralized and parallel work.

For the decentralized sensing, means of acquiring desired information by integrating that obtained from multiple robots are being investigated. This capitalizes on the smallness of a micro robot and the merits of a system of multiple robots, but for effective integration of various pieces of information, a function is required which plans the allocation and shared role of each robot. Sensing planning programs and operation systems are being developed based on the concept of contract net protocol. Figure 3 is a photograph of a prototype test bed. Research is also under way on techniques to improve the accuracy of the overall picture by combining separate pieces of information.

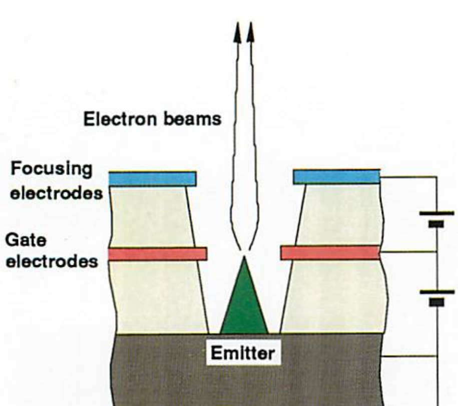

Fig.4 Principle and structure of a micro electron gun

3. High Intensity Micro Electron Gun

Micro electron guns are being studied for their use in processing micro component parts in 3-D micromachining. Specifically, a micro electron gun array is being manufactured which integrates field emitters and control electrodes. Figure 4 shows the principle of this gun. About 100 V voltage is applied to the gate electrode so that electrons are emitted from the emitter, and voltage is applied to the focusing electrode to control the convergence of the beams. Producing an array of this structure by the etching process of silicon substrates, processing a wide area of a surface by the micro electron gun will be possible. A photograph of a prototype array is shown in Fig 5. Preliminary experiments have confirmed the generation of fairly good beams.

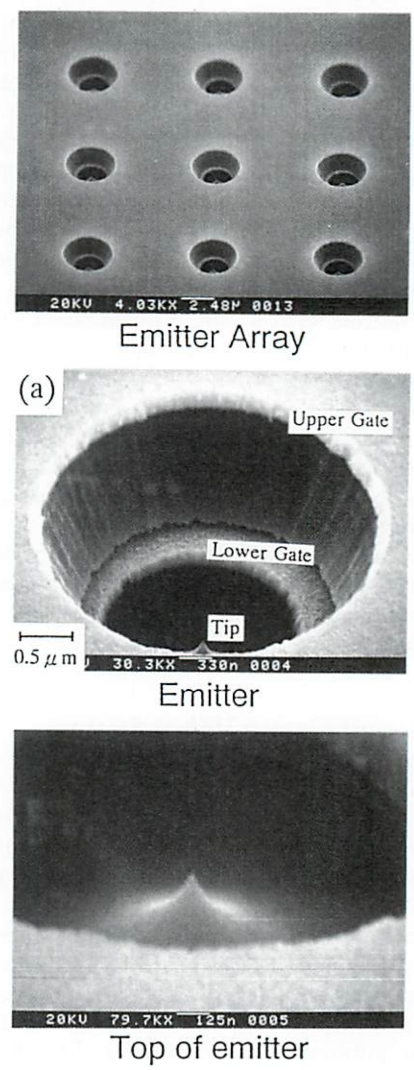

Fig.5 A prototype micro electron gun array

Activities of the Micromachine Center in Fiscal 1993

During fiscal 1993, the Micromachine Center (MMC) not only strove to strengthen its capabilities but, based on trends in Japan and overseas, conducted various investigations and research in joint efforts among industry, government, and universities, principally "Micromachine Technology" under the Industrial Science and Technology Frontier Programs of MITI's Agency of Industrial Science and Technology (AIST) and entrusted by the New Energy and Technology Development Organization (NEDO), collection and provision of information on micromachines, fostering of exchange and cooperation with related organizations in Japan and in other parts of the world, and publicity for and dissemination of micromachines.

Also, to further improve its foundation and activities, the Center devoted itself to increasing its membership, and joined the Federation of Micromachine Technology, established in April 1993, to make closer tie-ups with micromachine-related organizations.

1. Investigations and Research on Micromachines

(1) AIST's Industrial Science and Technology Frontier Program "Micromachine Technology" *(Entrusted to MMC by NEDO)*

The ultimate purpose of this project is to establish technologies applicable to the realization of micromachine systems. These systems are composed of microminiature functional elements that locomote in very narrow spaces in complex equipment at a power plant or in a living body and can perform intricate work autonomously.

This project has entered its third year and the following R&D was carried out, based on the investigations and research done previously on microminiature functional elements, energy supply, and system control technologies.

[Industrial Use]

To ultimately establish technologies applicable to the realization of micromachine systems composed of microminiature functional elements that locomote in very narrow spaces in complex equipment at a power plant and can perform intricate work autonomously,

(i) R&D on element technology for microcapsules, mother ships, cableless inspection modules, and cabled operation modules, which are components of an advanced maintenance system for power plants, were carried out, including trial manufacture and operational experiments, and

(ii) the requirements for an advanced maintenance system for power plants as a total system were defined, the R&D trends of technology necessary to construct the system were investigated, and the directions of micromachine systems based on user needs were examined.

[Medical Use and Basic Technologies]

Among element technologies necessary to construct micromachine systems, R&D on micro actuators and basic micromachine technologies were carried out.

However, because some of the necessary equipment was not installed in time, part of the program was carried forward to the next year.

(i) In the "research on micro actuators," MMC started:

a) basic experiments on shape-memory processing, fabricating, assembling, and driving control methods appropriate for miniaturization of SMA actuators,

b) structural optimization by simulation of a expansion actuator composed of heat-sensitive polymer or bimorphs, and research on the components of a hydraulic actuator integrated with a drive unit, and

c) research on an integrated micro actuator in which a displacement enlarging mechanism and a control circuit are integrated with a laminated PZT to obtain high displacement output at low voltage.

(ii) In the "research on basic micromachine technology," MMC carried out:

a) basic studies to develop element technologies necessary for intra-luminal diagnostic and therapeutic systems into a total system,

b) basic studies on microtactile sensing, including technological investigations, partial trial manufacture, and experimental evaluation,

c) basic studies on laser-applied diagnostic and therapeutic technology, including technological investigations, partial trial manufacture, and experimental evaluation, and

d) basic studies on blood pressure and flow sensing technology, including technological investigations, partial trial manufacture, and experimental evaluation.

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

Seeing that materials are very important for micromachine technology, the following joint researches on micromachine materials were carried out with the Mechanical Engineering Laboratory of AIST.

(i) Operating environments for micro functional elements

(ii) Micromachine materials in general

(iii) Feasibility study on micromachine materials

(3) Research on basic design and manufacturing technologies

To establish basic technologies for designing and manufacturing micromachines, joint research on basic design and manufacturing technologies was carried out with the Mechanical Engineering Laboratory of AIST.

(4) Investigations on basic micromachine technology systems *(Aided by the Japan Motorcycle Racing Organization)*

Technical "seeds" were explored in micro science and engineering (material engineering, mechanical dynamics, and tribology in micro environments) and design technology, which are necessary to construct diversified micromachine systems, through joint research among industries and universities *(Eight subjects)* .

(5) Investigations on the economic effects (technical prediction) of micromachine technology *(Commissioned by the Japan Machinery Federation)*

To predict the commercialization of micromachines and their economic effects in the 21st century, investigations were carried out on the following two items, whose conclusion, however, was carried forward to the next year.

(i) Prediction of the commercialization of micromachines

(ii) Prediction of changes in the industrial infrastructure caused by the introduction of micromachines

(6) Investigations on R&D trends of micromachine technology in Japan and in other countries *(Commissioned by the Japan Machinery Federation)*

To effectively promote R&D on micromachine technology, MMC investigated the current state of R&D at universities, public research institutes, and private companies in Japan and overseas.

(7) Construction of micromachine database

Based on the data acquired from the investigations of (6), MMC started preparing maps classified respectively by R&D item, application, and technical data.

2. Collection and Provision of Micromachine Information

1) Information and data on micromachines published in periodicals, books, and other data were obtained from universities, industry, and public organizations within and outside Japan. These materials were categorized along with MMC's own research data, kept in the Center's documentation room, and made available to interested researchers *(Sixty-one books were collected during fiscal 1993)* .

2) Largely based on these data, MMC published its periodical "Micromachine Index" for free distribution to relevant bodies *(Eight volumes were issued during fiscal 1993)* .

3) Investigations on the following items were carried out to construct a micromachine technological information database *(Commissioned by Database Promotion Center)* .

   i) Kinds of information to be collected in the database

   ii) Types of information expected from users

   iii) System configurations meeting the above requirements

   iv) Prediction of economic elements necessary in the implementation of the above system

3. Exchange and Cooperation with Worldwide Organizations Related to Micromachines

MMC arranged technical exchanges to further affiliation and cooperation with related organizations with common interests as well as exchanges among government, industry, and universities.

(1) Grants for R&D projects relevant to micromachine technology

To further promote studies on micromachines through exchange between industry and universities, MMC made the following research grants:

(i) Object of research grants
Basic research on fundamental technology, functional element technology, and systematizing technology of micromachines.

(ii) Research period
Late March 1994 to March 31, 1995 (Subject A) or
Late March 1994 to March 31, 1996 (Subject B)

(iii) Decision of subjects and granting
Grants were made on March 7, 1994, for eight

subjects, including "Basic research on the development of shape-memory alloy thin film for micro actuators."

(2) International exchange on micromachine technology

(i) Acceptance of missions from overseas
MMC received research missions from five countries, including Canada, the U.S., and Germany, and opinions were exchanged on the "Micromachine Technology" under AIST's Industrial Science and Technology Frontier Program and MMC activities.

(ii) Dispatch of a mission *(Five members)*
MMC's research mission was sent from June 13 to 24, 1993, to participate in the IARP Workshop held in Germany and visit universities and research institutes in Germany and Switzerland to exchange opinions on the R&D trends of micromachines.

(3) Cosponsorship of a symposium on micromachine technology

MMC cosponsored the 4th International Symposium (October 13-15, 1993, in Nagoya) with the City of Nagoya, the Chubu Industrial Advancement Center, and the Federation of Micromachine Technology.

(4) Holding of a workshop on micromachine technology

MMC held an IARP workshop on micromachine technology and systems from October 26 to 29, 1993, in Tokyo; 131 people from 13 countries participated.

(5) Cooperation with and participation in the MEMS-94

MMC cooperated with and participated in the MEMS-94 (Micro Electro Mechanical Systems) held in January 1994 at Oiso-machi, Kanagawa Prefecture, Japan.

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

(1) MMC investigated standardization items, technical terms, and evaluation methods that contribute to R&D and dissemination of micromachine technology. For technical terms, classification and analysis of relative importance were made for 3,000 terms collected during the previous year.

(i) Studies of the standardization program

(ii) Extraction and analysis of technical terms related to micromachine.

5. Dissemination and Enlightenment about Micromachines

MMC disseminated and enlightened people about micromachine through the publication and distribution of a micromachine magazine and through seminars and exhibitions.

(1) Publication and distribution of a public relations magazine

To win broad understanding and recognition of its activities, MMC carried out publicity activities by distributing its public relations magazine ***MICROMACHINE*** in Japanese *(Nos.4-6 issues)* and English *(Nos.2-6 issues)* to relevant bodies.

(2) Holding of a "Micromachine Technology" R&D Presentation in fiscal 1993

R&D presentation of "Micromachine Technology" under AIST's Industrial Science and Technology Frontier Programs and entrusted to MMC by NEDO was held on Wednesday, November 24, 1993, at the Gas Hall, Ginza, Tokyo, and 264 people participated.

(3) Holding a symposium on micromachine

MMC jointly organized the 5th Micromachine Symposium held on Tuesday, April 20, and Wednesday, April 21, 1993 at the Science Hall of the Science Museum in Kitanomaru Park, Tokyo. Twenty-seven papers were presented and 501 people participated.

(4) Holding a micromachine exhibition

MMC jointly organized the 4th MICRO SYSTEM Technologies Japan (MST Japan '93) held from Tuesday, April 20, to Thursday, April 22, 1993 at the Science Museum with 3,592 participants.

(5) Holding evening seminars

To disseminate the results of investigations and research on micromachine technology, MMC regularly held evening seminars about once every month *(Every third Wednesday, seven times during fiscal 1993)* .

6. Participation in the Federation of Micromachine Technology

To fully use the characteristics and functions of various organizations involved, which differ in each academic field, and to simultaneously promote the exchange of micromachine-related information and cooperation in research, MMC participated in the Federation of Micromachine Technology, which was established in April 1993 and whose secretariat is in the MMC office *(Currently 32 organizations participate in the Federation)* .

NIPPONDENSO CO., LTD.

Research Laboratories

1. Introduction

We visited the Research Laboratories of NIPPONDENSO CO., LTD. located at Nisshin-cho, about 16 km northeast of Kariya City, Aichi Prefecture near the head office. With the motto ***Challenge heart and soul to realize the dream embraced***, 330 research staff are involved in leading-edge research project such as semiconductor process and device technologies, robotics, and biotechnology. Micromachines have been one of the company's research areas since the establishment of the laboratory.

2. What do micromachines make possible?

While we are apt to imagine a micro mobile mechanism from the word, **micromachine**, Nippondenso looks upon micromachines as meaning the microminiaturization of all machinery now available. Considered in this manner, everything around us could become micromachines. In automotive parts, for instance, there are innumerable items including various types of actuators which could benefit by microminiaturization; the merits derivable therefrom are obvious and are not limited to reducing weight, redundancy, and improving intelligent functions. It is these expectations that have attracted Nippondenso to micromachines, a true frontier in mechanical engineering.

3. Microcar

Nippondenso's microcar was produced with precision machining and semiconductor process technologies, and its introduction two years ago through newspapers and TV as one aspect of micromachine technology attracted a lot of attention. While the intention was to demonstrate the abilities and future potential of the micro processing technology by manufacturing a car which is one one-thousandth the size of an actual car, the tremendous reaction to this micromachine concept model surprised even Nippondenso. Regrettably, however, because of its solid body, Nippondenso was unable to incorporate gears into this model so that it would operate. We nonetheless applaud this initial achievement, and the company's continuing enthusiastic efforts to develop a functioning microcar have now borne fruit.

Photo1 Microcar's shell body

The latest model has a micro-motor 1 mm in diameter. With power supplied by a 25 micron copper wire, the car runs smoothly at a speed of about 1 cm/s with 3 V voltage and 20 mA current. The use of a shell body construction as shown in Photo 1 reduced the weight and allowed accommodation of the driving gears. The body is made by electroless nickel plating and sacrificial layer etching, and the surface is gold plated. It is 30 microns thick yet strong enough to be picked up by the fingers. Since this process has proven excellent in the manufacturing of 3D structures, it has been a main research interest in this project.

4. Varifocal mirrors and lenses

Another example of R&D is a varifocal mirror and lens.

A silicon diaphragm about 10 microns thick is bent electrostatically and the bent surface is used as a concave mirror; Fig. 1 shows its sectional structure. If the diaphragm has a uniform thickness, the deformed surfaces are not completely parabolic and give rise to an aberration. This was resolved using the thickness distribution. The thickness distribution was realized by developing a distributed exposure technique in addition to the photolithography used in typical semiconductor processes. This technique allows the intensity of light shed on the photoresist to be appropriately distributed so that it matches the form to be processed. This resist was developed to create 3-D forms, and was used as a mask for dry etching and eventually to form a diaphragm having the desired distribution of thickness.

Technological problems still to be solved involve reducing the operating voltage, now about 1 kV, and shortening the focal length.

Lenses whose focal length is variable with the application of fluid pressure to the distributed thickness of a glass substrate are also being developed, making adjustable focusing possible.

5. Conclusion

We have introduced two research areas in which Nippondenso is now involved in solving technological problems through the trial manufacture of a microcar and an application of micromachine techniques. Nippondenso plans to develop micromachines for use in broad ranging frontiers of mechanical engineering pursuing basic research in micro science and engineering as well as micro processing technology and devices.

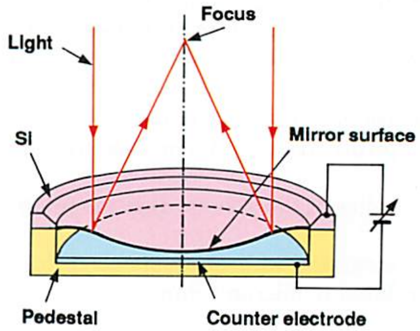

Fig.1 Sectional structure of varifocal mirror

Hitachi, Ltd.

Mechanical Engineering Research Laboratories

1. Introduction

We recently visited the Mechanical Engineering Research Laboratory (MERL) of Hitachi, Ltd. in Tsuchiura, Ibaraki Prefecture. Hitachi is an electrical machinery and appliances manufacturer, and one of Japan's foremost companies.

Hitachi, Ltd. itself employs about 80,000 individuals. The entire population, including those working for companies in the Hitachi group, reaching 330,000. Nine laboratories with 4,400 research staff are working on a variety of projects, all under the control of the head office in Tokyo.

Since its establishment in 1910, the company has been known for its devotion to research and subsequent maximization of its own technologies, rather than using technology that may be more easily obtained from outside. Hitachi is also noted for its large number of employees holding doctorates: 935 in Hitachi, Ltd. alone and about 1,200 in the entire group. Most of these degrees have been acquired based on work done after the individual joined the company, and holders often work in sections not directly related to laboratories. This is indicative of the high level of Hitachi's technological standards and its attitude toward education.

2. Role of the MERL

After being established in 1966 in Kameari, Tokyo, the laboratory headquarters were moved to Tsuchiura in 1974. Other branch laboratories are located in Hitachi (Ibaraki Prefecture), Shimizu (Shizuoka Prefecture), and Kudamatsu (Yamaguchi Prefecture), employing a total of about 700 people.

The main product lines range broadly from large machinery such as power generating equipment and JR's Shinkansen trains to thermal equipment such as air conditioners, mechatronics equipment, including magnetic disc storage systems and cash dispensers, and computers and semiconductors with their own unique problems of heat generation and mechanical stress. Basic mechanical engineering issues such as the strength of the materials, reliability, heat, and types of fluid, are addressed in developing these products regardless of their size. As a center for mechanical engineering technologies, this laboratory contributes to the company through its advancement of basic technological understanding, application and its comprehensive capability.

New concepts emanate not just from an engineering standpoint but in response to customer desires and requests, as Hitachi strives to stay abreast of the expectations of this innovative age. Together with advancements in traditional mechanical engineering technology come organizational reforms and an awareness of the buzzword "innovation." An example of this is a movement now in progress to allow individual employees the opportunity to work more creatively on their own by providing an internal information infrastructure.

3. Tackling micromachine technology

Hitachi began working on micromachine technology in 1983, earlier than most other companies and universities. At the Central Research Laboratory, research was conducted on 3-D processing for single-crystal silicon and bold attempts were made to use this silicon in machines or in sensors such as in biological cell fusion devices, ultrasonic microscope lenses, acceleration sensors, and AFM probes. The MERL has also engaged in element technology related to micromachines, such as ion beam machining, high-precision bonding of micro parts, and micro manipulation technology. At the start of MITI's micromachine project, the Central Research Laboratory's micromachine study group was integrated into a similar group at the MERL.

Micromachining, especially that for microprocessing and microbonding techniques, is currently being emphasized. As applications of this, we were shown the acceleration sensor displayed at the '93 Micromachine Exhibition, a micro pump which appeared at the '94 Micromachine Exhibition, an electrostatically driven prototype micro valve shown at MEMS-94 and other products.

In reference to the field of mechatronics, as it relates to the equipment for information, analysis, and semiconductors, the staff told us of their expectations that micro systems employing light, electricity, and fluid will gradually but increasingly find a wider variety of uses. We left the laboratory confident that the equipment and systems to which micromachining technology is being applied will be available in the not-too-distant future.

Report on Current Micromachine Technology in Australia

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1. Introduction

I visited several universities in Australia in March 1993 to exchange information on micromachine technology. The following is an outline of the research activities I observed at each university I visited.

2. Royal Melbourne Institute of Technology

This university, located in Melbourne, has been participating in The Industrial Science and Technology Frontier Program as one of the overseas subcontractors of Micromachine Center. They are working on research into drive and suspension mechanisms. Under the leadership of a professor from the Electrical Engineering Department and a professor from the Electronic Materials Engineering Center, they are aiming to achieve a micro electromagnetic motor incorporating a suspension. For this purpose, they are in the process of making the motor mentioned above and its control circuit on a metallic substrate by using mainly physical vapor deposition equipment, wet etching equipment, and a sputtering machine. They are now fabricating a prototype measuring 3 mm x 3 mm x 3 mm.

The researchers showed enthusiasm as overseas participants in the Japanese national project. They seemed to be enjoying the exchange of straightforward opinions with the engineers from the Japanese businesses who were joining the project through various activities of the Micromachine Center.

3. University of Queensland

At this university, located in the suburbs of Brisbane, they are engaged in research mainly into two-dimensional semiconductor devices as part of the research activities on micromachine technology. More specifically, their main research topic is MOSFET. Activities include gate capacity measurement and numerical simulation, evaluation of local charge and interface conditions through gate capacity measurement, and evaluation of the characteristics of submicron charged conditions.

4. Griffith University

The major research themes at Griffith University, also located in the suburbs of Brisbane, are microsystems, including chemical sensors of carbon monoxide, carbon dioxide, nitrogen, and ammonia, insulating materials for semiconductors, and micromachining such as photolithography, ion etching, and ion implantation. They have a mask aligner and other equipment for vapor deposition, etching, and spinning coating installed in a simplified clean room.

Research Equipment at the Australian National University

5. University of South Australia

At this university, located in the suburbs of Adelaide, they are engaged in basic research into microsystems such as micro accelerometers, electromagnetic micro pumps, micro sensors, the materials for silicon, Hall elements, thick films, thin films, micromachining such as chemical etching, and ultraviolet lithography. For the micro sensors, in particular, they seemed to be energetically working with major facilities in Australia.

6. Australian National University

Australian National University is located in central Canberra, the capital of Australia. The researchers at this university are studying optical devices such as micro systems and micromachining techniques such as plasma etching, electron gun/plasma vapor deposition, sputtering, and photolithography. More specifically, they are constracting an experimental model of an optoelectronic distributor by etching silicon with plasma, and also carrying out the in situ measurement of film thickness by laser beams. They have substantial equipment for experimental manufacturing; a class 10 booth in a class 1000 clean room, which is partitioned with an air curtain, and precision NC machines.

7. Conclusion

Research activities at all the universities are focused mainly on the silicon process; however, there seems to be limited application for their research results because there is no semiconductor industry in Australia. Yet, they are very active in promoting exchange with other countries, including student exchange programs. They mentioned that they are seriously thinking of developing a high technology industry in Australia. I am looking forward to seeing it.

Interview on the Current Investigations of Micromachines in China

When Dr. Zhou Zhao Ying (***Photo:Left***), Professor, Chairman, Dept. of Precision Instruments & Mechanology, Tsinghua University and Dr. Li Yong (***Photo:Right***), Post Doctoral Researcher, Dept. of Precision Instruments & Mechanology, Tsinghua University, came to Japan to attend IMTC '94 held in Hamamatsu, they visited the Micromachine Center on May 18. We took the opportunity to request an interview with them. Despite their tight schedules, they very kindly took the time to tell us about current investigations and future prospects of micromachines in China, only a little of which had previously been known. After the interview, they attended the evening seminar hosted by the Micromachine Center.

Q: *"Please give us a brief introduction to Tsinghua University."*

A: I believe that you all are familiar with the name of Beijing University. While Beijing University is an institution of humanities, our Tsinghua University specializes in science and engineering. Tsinghua University has about 15,000 students. Of those students, about 5,300 are in the Department of Precision Instruments & Mechanology, with 34 professors and 105 associate professors.

Q: *"How are investigations of micromachines being implemented at Tsinghua University?"*

A: We started our investigations of micromachines five years ago. At present, five groups are engaged in micromachines at Tsinghua University. Dr. Li Yong, who studied micropumps at Niigata University in Japan, has continued his investigations after returning to Tsinghua University. His investigations have been subsidized by the National Natural Science Foundation of China and the State Education Commission of China. Also, at our Institute of Electronics, we are researching many fields, including pressure and other types of sensors, micro-sensor arrays, electrostatic motors, micro-mechanisms, micro-flow, micro-tribology, and micro-measurement. The department of Applied Physics is working on investigations of STM, the detection of single atoms, and investigations of ultrasonic motors. The department of Material Technology is engaged in the research of thin-film technology and micromachining of parts as part of their research activities. The department of Electrical Technology is engaged in research of soft X-rays, and have developed soft X-ray apparatus.

Q: *"Could you tell us about the research activities at facilities other than Tsinghua University?"*

A: At Southeast University, which is located in Nangching and has about 10,000 students, they are studying micromotors. At the Shanghai Branch of the Chinese Academy of Science, they are investigating micro-mechanisms such as micro-gears. Also at the Changchun Institute of Optics and Fine Mechanics of the Chinese Academy of Science, they are studying ultrasonic motors. These are major institutions, but several other institutions are engaged in micromachine-related investigations. Currently, however, all these investigations are being carried out independently, and we have no system for exchanging information between the researchers. In the future, I hope that China will also have a national project on micromachines.

Q: *"Where are you planning to visit during your stay in Japan?"*

A: We will visit major research departments at universities and businesses in addition to the Micromachine Center.

Q: *"A wide range of fields seems to be involved in micromachines. Which of these fields do you consider most promising?"*

A: I think that the market for micro-sensors will grow most quickly. I expect that the demand for pressure and other types of sensors and sensor systems will grow, also. And I believe that there is a high demand for sensors for communication applications, followed by those for medical applications. I feel that lasers and micro-optics are also promising. We should definitely take advantage of IC technology, which has a lot of advantages. Its batch processing is ideally suited for mass production. We cannot, however, cover all of the processes just by IC technology. We will probably use it in combination with micro electric discharge machining and precision machining.

Q: *"Which field of study in micromachines makes use of Chinese characteristics?"*

A: We are good at studying interdisciplinary areas and we can probably find our special strengths in such fields. For example, I think it would be very interesting if we were to successfully incorporate micromachines into Chinese medicine.

Micromachine Technology (II)

1. Configuration of Micromachine Technology

During the last session, we learned that micromachine technology integrates diverse technologies for adapting machines to micro environments, thus making up a technological system. The technological system consists of fundamental technology, functional element technology (functional device technology), and the systematizing technology. We also learned that, since the micromachine technology covers an extremely wide range of applications, it is expected to become one of the fundamental technologies of industry.

In the technological system, fundamental technology comprises the various basic technologies for producing micromachines, including machining, assembling, material, design, measurement, and micro science and engineering. The functional device technology is the technology for embodying the principles of operation and the structures of various devices required for micromachine systems. This includes the technologies of driving devices, energy devices, sensor devices, and electronic devices. Systematizing technology integrates the technologies involved in configuring and operating micromachine systems. It primarily consists of hybridization technologies (interface technology and integration technology) and communication/control technology.

This technological classification, however, is based on an analogy to conventional technology system, and the boundary lines among the individual element technologies have not yet been clearly defined. For instance, silicon process, one of the processing technologies (fundamental technology), includes a step for producing a thin-film material from a gas source, a step for etching a sacrificial layer, and even a simple assembly step. Thus, it combines the technologies of machining, materializing, and assembling. Such integration or re-configuration of several different element technologies is likely to be further promoted through R&D activities in the future, leading to the creation of a distinctive system of micromachine technology.

2. Fundamental Technologies

2.1 Machining technology

Table 1 shows various micro-machining methods suitable for producing micromachines. The following outlines major methods shown in the table.

(1) Silicon process

During 1987 and 1988, a series of micro parts about 100 µm such as link mechanisms and electrostatic motors, had been produced using the silicon process. It is said that this triggered the microma-

Table 1 Types of micro-processing methods

Type of process	Outline and major characteristics
Silicon process	• Combines lithography and etching/deposition. • Permits mass production by subassemblies and batch processing.
LIGA process	• Combines soft X-ray lithography, electroplating, and molding. • Permits the manufacture of parts with a high aspect ratio and mass production by molding.
Beam machining	• Direct machining or assisted machining by using laser, electron or ion beams. • Mask-less machining. Permits three-dimensional machining.
Electro-discharge machining	• Combines wire electro-discharge grinding and electro-discharge machining. • Permits machining of metal into any three-dimensional shape.
Photoforming	• Locally polymerizes liquid resin by laser beams. • Permits forming of any three-dimensional shape.
Injection molding	• Injects liquid resin or metal-powder-mixed resin into molds and solidifies it. • Permits the manufacture and mass production of components having three-dimensional shapes.
Conventional machining	• Based on mechanical removal by cutters. • Permits forming of any three-dimensional shape.
Others	• Electro-chemical machining, ion implantation, STM machining, etc.

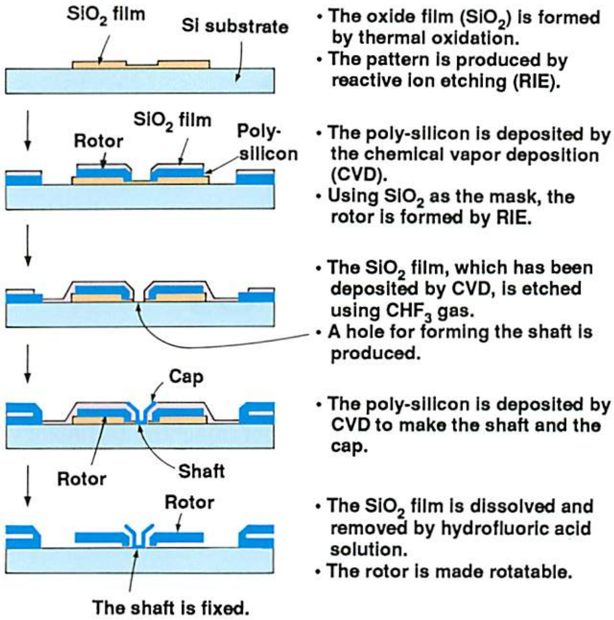

Fig. 1 Typical procedure for manufacturing a mechanism by silicon process

chine boom. The silicon process, also called the IC process, was developed as a method for integrating electronic circuits on a single-crystal silicon substrate. Later, this technology was used to miniaturize the mechanical parts of pressure sensors and acceleration sensors, and was further applied for the manufacture of the micro motors described above.

The basic procedure of the silicon process employed for producing micromachines is shown below:

(a) First, the surface of a silicon wafer is oxidized to make an extremely thin oxide film (SiO_2).
(b) A thin photosensitive resin (positive or negative photoresist) is coated on the oxide film.
(c) The resist is exposed through a mask having the desired pattern.
(d) The exposed portions of the resist are removed from the wafer by the development process (in the case of a positive resist).
(e) The SiO_2 thin film, in the exposed portions, is etched to expose the silicon surface.
(f) A silicon or metal thin film is produced on the surface by chemical vapor deposition (CVD) and so forth.

This series of steps is repeated to make a multilayer structure (an assembly of components), and the SiO_2 thin film portion (sacrificial layer) is removed by etching in the last step. This process completes the assembled mechanism.

Figure 1 shows a specific example of the procedure for making a mechanical device consisting of a rotor and a bearing. (In this figure, the explanation of the resist processing step is omitted.) The shape of components made using this process is obtained by projecting a plan-view pattern, therefore, the resulting assembled mechanical component is not a fully three-dimensional structure. Hence, the structure is known as a 2.5-dimensional structure.

In the early stages of the silicon process, only micromachines consisting of extremely thin components measuring about 2 µm or thinner could be manufactured, and only silicon-based materials could be used. Later, however, improvements were made, of which the high-accuracy machining of thick resist by the use of shorter-wavelength light (ultraviolet rays) and the combination with an electro-plating process are typical. Such improvements have made it possible to manufacture mechanisms consisting of thick components by using a variety of materials.

The photograph in Fig. 2 shows an electrostatic motor, which has recently been manufactured by the silicon process. The rotor, bearing, and the fixed electrodes are made of nickel. In addition, the substrate, which comes in contact with the rotor, is provided with many projections to reduce the frictional resistance of surface force or the like working on a contacting portion (although this photograph does not show this improvement).

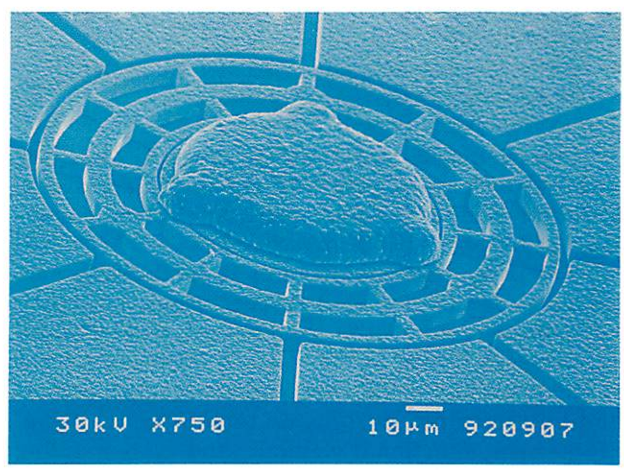

Fig. 2 Example of electrostatic motor made by silicon process ***(Presented by Professor Hiroyuki Fujita, Institute of Industrial Science, The University of Tokyo)***

Summary Report on "Investigations of the Economic Effect (Technical Predictions) of Micromachine Technology"

The Micromachine Center implemented "Investigations of the economic effect (technical predictions) of micromachine technology" as one of its project activities for fiscal 1993. Here is the summary report on the investigations.

There still remains a long wait before the technology for producing micromachines that can act autonomously is established to benefit our daily lives. Quite a few products now on the market, however, are manufactured by applying micromachine technology, and are closer to us than we realize. These include the acceleration sensors used in automotive air bag systems and the printing heads of personal computer printers.

Micromachine technology is applied to the following mechatronic application fields that require compactness and extreme accuracy:

- Information communications equipment and precision equipment
- Microsurgery
- Artificial organs and advanced medical systems
- Microminiature measuring systems

The technologies and investigations of the fields listed above extend across interdisciplinary areas, including mechanical engineering, electronic engineering, biology, physics, and chemistry.

The investigations attempt to make long-term technical predictions with respect to micromachine technology according to the current research and development trends in the major fundamental areas of micromachine technology, including micro science and engineering, design, materials, machining, assessment, functional element, and systematizing technologies. We are studying the possibility of a future introduction of technologies and applications and are forming estimates using algorithms built to predict the resulting economic effects. We are also working on predictions of effects that will result from the introduction of micromachine technology into various industrial fields and the market scales that they may achieve by the years 2005 and 2010.

The applications are divided into two groups; one group covers products that replace existing products partially or completely by utilizing micromachine technology (the type that replaces existing products), and the other group covers entirely new products that will be achieved by applying micromachine technology (the type that creates new markets). Accordingly, our forecast efforts are focused on the market scales of the following two application fields:

(1) Applications for replacing existing products
(2) Applications for creating new markets

Particularly in the case of applications that will create new markets, the scale of those markets to be studied is still undefined since micromachine technology has just been born. For this reason, the market growth is being projected, referring to the growth rate of the three examples listed below:

Case 1: Semiconductor ICs
Case 2: Industrial robots
Case 3: PCs

The fields under discussion include:

- Information communications equipment field
  —*Information communications equipment, OA equipment, and AV equipment*
- Precision equipment field
  —*Timepieces and cameras*
- Medical application field
  —*Medical aids, functional aiding devices, and medical equipment*
- Measurement field
  —*Measuring equipment and SPM*

This report involves daring assumptions of diverse conditions for the forecasts. When the applications for creating new markets are included, the market scale is estimated to be about 530 to 1,500 billion yen by the year 2005 and about 1,300 to 1,900 billion yen in 2010.

The report has been prepared by the committee, chaired by Professor Kiyoshi Itao at Chuo University. The committee consists of experts engaged in investigations related to micromachine technology at universities and three national research institutes, and businesses deeply involved in micromachines.

The Micromachine Center will continue these interesting investigations as well as further discussion.

★ TOPICS

Fifth MICRO SYSTEM Technologies Japan '94 Held

From May 11 (Wednesday) through 13 (Friday) of this year, the 5th MICRO SYSTEM Technologies Japan '94 (MST Japan '94) was held at the Science Museum in Kitanomaru Park, Tokyo, where the most advanced technologies of micromachines were exhibited. Under the umbrella topic, ***Micromachine — a Dream Fostering Technology*** , 63 companies, organizations, universities, and national research institutes displayed the results of their research. With 3,700 visitors, the event drew more people than last year.

Firms, including supporting members of the Micromachine Center (MMC), exhibited parts, systems and related micromachine equipment, while 18 universities and governmental institutes displayed their latest findings. All these aroused great interest among the visitors.

In the MMC exhibition booth, the research and development results of the Industrial Science and Technology Frontier Program of the Agency of Industrial Science and Technology, the Ministry of International Trade and Industry, were displayed on panels as well as the activities the Center has been engaged in for the two years since its establishment. These include: investigative projects of various kinds, international exchanges in the form of workshops and missions sent abroad, the fostering of research, and education and the dissemination of information through such means as evening seminars.

In the booths of the MMC's supporting members, the individual research advances made under the Industrial Science and Technology Frontier Program were interestingly displayed and explained, and the results achieved were apparent.

Micromachine Center Booth

Exhibition Room

6th Micromachine Symposium Held

The 6th Micromachine Symposium was held on May 11 and 12 (Wednesday and Thursday), 1994 in the Science Hall of the Science Museum in Kitanomaru Park, Tokyo under the joint organization of the Micromachine Center, Micromachine Society, the Federation of Micromachine Technology, and the Japan Industrial Technology Association. Sponsorship was by the Ministry of International Trade and Industry and support was provided by the four organizing groups.

Research results were reported in 19 areas: *Contact and Non-contact Manipulation (3 reports)/Cellular Machine and Micromachine (2 reports)/Video Assisted Surgery, Computer Assisted Surgery and Micromachine Technology (5 reports)/New Actuators (5 reports)/Application of Micromachine Technology to Information and Communication (4 reports)*

There were two special lectures, and two invited lecturers spoke, one from abroad and one from Japan.

The two-day symposium had a total of 379 participants.

Second Operations Council of the Federation of Micromachine Technology Meets

Representatives from 16 of the 32 organizations making up the membership of the Federation of Micromachine Technology held their second Operations Council meeting on May 11, 1994, at the Science Museum in Tokyo.

Reports of the activities of the Federation and the events cosponsored or supported were made and future plans discussed.

Fifth International Symposium on Micro Machine and Human Science (MHS '94)

Date:
October 2 (Sun) - 4 (Tue), 1994

Place:
Nagoya Congress Center
1-1, Atsuta Nishimachi, Atsuta-ku, Nagoya
Tel.: 052-683-7711

Subject:
The Development of Micro-mechatronics

Cosponsored by:
City of Nagoya, Nagoya University, IEEE, Micromachine Center, Federation of Micromachine Technology, and others — 11 organizations in total

In Cooperation with:
Chubu Bureau of International Trade & Industry of MITI, Aichi and four other prefectural governments, Nagoya Chamber of Commerce & Industry, and others (planned)

Participation Fee:
¥3,000 per person to cover reference materials (no charge to students)

Program:

I. Symposium

- **October 3 (Mon)**

10:00 Greetings by the cosponsors:
Takeyoshi Nishio, Mayor, City of Nagoya and others
Greetings by special guest:
Akinobu Yasumoto, Director-General of the Chubu Bureau of International Trade & Industry of MITI

10:30 Keynote address:
"The Outlook for Micromachine Technology" (tentative title) by MITI staff in charge

11:00 Keynote address:
Roger Howe, Professor, University of California, Berkeley, USA

12:00 Lunch break
(Meeting of the Operations Council of the Federation of Micromachine Technology will be held.)

13:00 Special lectures (No particular order will be observed.)
W. Menz, Professor, Kernforschungszentrum Karlsruhe GmbH, Germany
Iwao Fujimasa, Professor, Research Center for Advanced Science and Technology, The University of Tokyo
M.G. Allen, Associate Professor, Georgia Institute of Technology, USA
Hiroyuki Fujita, Professor, Institute of Industrial Science, The University of Tokyo
John Bates, Research Staff Member and Group Leader, Oak Ridge National Laboratory, USA
M. Elwenspoek, Associate Professor, University of Twente, The Netherlands

17:30 Reception

- **October 4 (Tue)**

Technical session throughout the day [A total of 29 papers, 22 from Japan and 7 from other countries have been accepted (as of June 28)]

II. Third International Micro Robot Maze Contest

- **October 2 (Sun)**

III. Exhibition of Micromachines

- **October 2 (Sun) — 4 (Tue)**

Throughout the symposium period, micromachine-related exhibits will be on display.

For Further Information, Contact:
5th International Symposium on Micro Machine and Human Science Secretariat, Industrial Promotion Office, Commerce & Industry Department, City of Nagoya
Tel.: 052-972-2419, Fax.: 052-972-4138

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