MMC

MICROMACHINE

June 1995 No. 11

Micromachine Center

Promoting International Information Exchange

Seiuemon Inaba
Chairman, Micromachine Center

Since fiscal 1991, the research and development activities carried out under the Industrial Science and Technology Frontier Program of the Ministry of International Trade and Industry have produced a steady stream of effective results in line with our original plan. The specific areas of research under the program are fundamental technology, element technology, and systematizing technology for advanced maintenance functions of power plants, microsizing of the production equipment of small-scale industrial products, and micromachine technology for medical applications. Because the present fiscal year is the last of the first phase of this project, we need to make every effort to ensure that our objectives are achieved.

While micromachine technology is expected to contribute widely to the advancement of human well-being at the beginning of the twenty-first century, numerous issues relative to micromachine development remain, including (1) effective research and development, (2) the integration of multidisciplinary technology, (3) the development of applications, and (4) the possibilities for creating new industries. Given that these issues are common to all countries involved in micromachine development, it has become necessary to provide international forums for exchanges of opinions and information. The Micromachine Center held such a forum, a Micromachine Summit, this past March. The summit was attended by representatives from ten countries, who discussed ten micromachine-related issues, including those just mentioned, and agreed to hold further Summits on an annual basis.

Micromachine technology is expected to serve as revolutionary fundamental technology in a wide range of fields, including industrial and medical technologies. Research and development of micromachine technology has progressed rapidly, and applications in certain specific areas, such as micromechanical sensors, already exist. However, full-fledged applications will probably not be seen until after the turn of the century, in such areas as manufacturing plants, home appliances, communications, measuring instruments, medical treatment, outer space, and the environment. Last year our center estimated that by 2010, the micromachine technology market would be worth ¥3.15 trillion.

The further development of micromachines and related technology will require that we create an environment in which micromachines are better understood; this will in turn foster creativity in the field. Speaking of creativity, our center recently held a picture contest for school children—the adults of the twenty-first century—in Japan. We asked the children to envision the technology of the future—specifically, to draw their idea of a micromachine application. The winners depicted an earthquake-forecasting device and a device for removing small bones from fish during food preparation.

The Micromachine Center will continue to actively promote international exchanges in the field of micromachine technology.

Miura/Shimoyama Laboratory in The University of Tokyo

Hirofumi Miura, Professor
Isao Shimoyama, Associate Professor
Department of Mechano-Informatics
Faculty of Engineering, The University of Tokyo

1. Introduction

Our laboratory is involved in work on micromachines, with a background in robotics. Since the spring of 1989 we have been using plasma etching system, electron beam drawing system, sputtering system and other semiconductor processing equipment to build extremely small (i.e., 1 mm or less) kinetic mechanisms comprised primarily of silicon. A clean room was completed this spring, and the resultant further enhancement of our research and experiment environment is expected to lead to even greater achievements.

2. Three-Dimensional Microstructures

Semiconductor technology permits the creation of extremely complex two-dimensional structures, but is extremely limited in the creation of three-dimensional structures. We have solved this problem using folded-paper structures. First, we created a planar structure comprising several planes of polysilicon thin film connected by polyimide hinges. This becomes the developed face of a three-dimensional structure. Next, the structure is released from the wafer using the sacrificial layer technique. Lastly, a microscope and microprobe are used to bend the structure at the polyimide hinges. Figure 1 shows a microcube created with this technique.

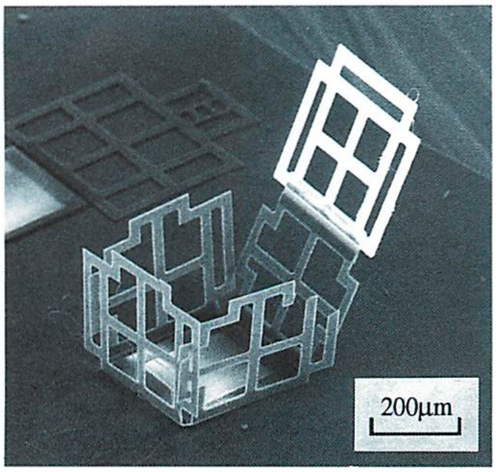


Fig. 1. Microcube (prepared by Kenji Suzuki, Research Associate)

This structure possesses several advantages. For instance, a kinetic mechanism with deformable polyimide hinges would be capable of avoiding the friction that is dominant in the microscopic world. In fact, insect wings make use of a similar structure: insects generate wing motions using the elastic deformation of their external skeletons. This folded-paper structure therefore represents a man-made application of the same mechanisms used by insects.

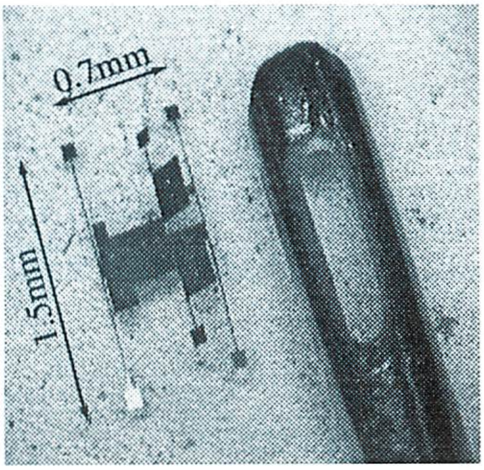


Fig. 2. Photograph of a walking microrobot (prepared by Takashi Yasuda, Research Associate)

3. A Walking Microrobot

We created a 1 mm-size microrobot in size that is capable of walking across a flat surface. This microrobot is shown next to the eye of a needle in Fig. 2 in order to give some sense of its size. The objective of this research was to find a wireless way to supply energy from an external source to a kinetic micromechanism. Although we tried to use ultrasonic waves or a combination of light energy and solar cells, the one we selected was an even simpler, more efficient one: using microscopic vibrations in the base to resonate the robot's vibrational actuator. Because the mechanical energy in the base is transmitted directly to the actuator without conversion into another form of energy, this method gives extremely high efficiency in energy conversion, as well as a high-speed drive.

The mechanism is shown in Fig. 3. As you can see, the microrobot has six legs, four of which are supporting legs that support the body, and two of which are kicking legs, which kick the base. Vibrating the two cantilevers, which consist of polyimide springs and masses, causes the two kicking legs to kick the base, thereby generating the forward driving force. Because the polyimide springs differ in length, each cantilever has a different resonance frequency. Thus, the two kicking legs can be made selectively to vibrate with a large amplitude, moving the microrobot forward or making it turn to the left or right. Maximum speed was 2 mm per second with a base vibration amplitude of 1 micron.

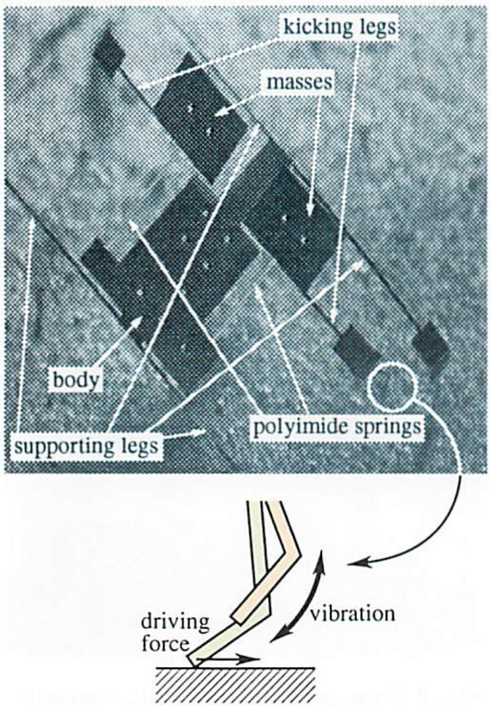


Fig. 3. Structure of a walking microrobot

4. A Flying Microrobot

It is debatable, however, whether walking is the ideal means of movement for microrobots. This is because the smaller a robot is, the more surface unevenness and other obstacles interfere with the walking process. It is for this reason that jumping and flying would seem more suited to microrobots. Moreover, looking at the way dust floats in the air, this would not seem too difficult to achieve. We are therefore striving to develop a flying microrobot. Because such a microscopic mechanism would have an extremely low Reynolds number, it was decided to actualize flying by utilizing not lift (as an airplane does), but rather the drag obtained from flapping.

Figure 4 is a schematic diagram of this flapping mechanism. The wings of this structure are made of polyimide and nickel. When it is placed in an alternating magnetic field, the magnetic force acts on the nickel film, causing the wings to flap. An upward aerodynamic force is obtained by combining the pair of wings in a way that creates the right difference in drag force during upstroke and downstroke.

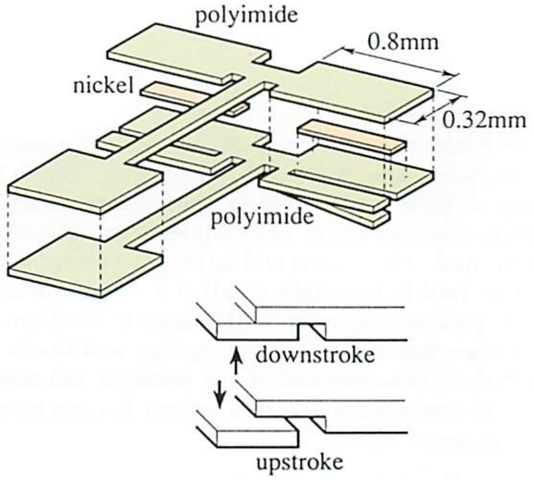


Fig. 4. Schematic diagram of a flapping micromechanism

5. Conclusion

We are also engaged in a variety of research in addition to that described above. These projects include the validation of a neural network used to control microrobot gait (which we incorporated into a six-legged microrobot about 30 cm in size); research on using actual insect muscle as a microrobot actuator; and the construction of a micro manipulation system based on magnetic fields.

Activities of the Micromachine Center in Fiscal 1995

1. Fundamental Policy of the Activities

Micromachines are composed of functional elements only a few millimeters in size and capable of performing complex microscopic tasks. The Micromachine Center (MMC) plans to conduct various activities with the following objectives: establish basic micromachine technologies and disseminate micromachines in society, thus contributing to the development of domestic industry and to the international community through investigation and research; collect and provide information on micromachines; foster exchanges and cooperation with related organizations in Japan and abroad; and promote micromachine standardization. In this year, continuing efforts will be made to promote international exchange through discussions of various issues involved in the advancement of micromachine technology, including effective R&D, development of future applications, and creation of industries, and positive transmission of information from Japan by holding international symposia.

2. Details of Main Activities

(1) Investigation and Research on Micromachines

MMC will continue to aggressively promote research on "Micromachine Technology" commissioned by the Industrial Science and Technology Frontier Program of MITI's Agency of Industrial Science and Technology (AIST), whose first phase terminates this year. MMC will also precisely deal with the program's interim evaluation, while exchanging technical information with many foreign countries and transmitting its research results to other countries and to Japan.

(1) AIST's Industrial Science and Technology Frontier Program, "Micromachine Technology" (This project has been delegated to MMC by the New Energy and 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 microminiature functional elements, locomote in very narrow spaces in complex equipment or inside of the human body, can perform intricate work autonomously, and help realize a micro factory for small industrial products. R&D includes trial manufacture and evaluation in the following areas:

[Development of advanced function maintenance technology for power plants]

(a) Microcapsule

Magnets, coils and high-speed microbearings for micro-generators, oscillators for signal generators, ultrasonic sensors for inspection, microgyros, and magnetic driving suspension mechanisms are all applicable to a microcapsule that checks the pipe and sends information to the control center located outside.

(b) Mother ship

Optical scanning mechanisms and optical systems, joints for coupling mechanisms, microbatteries, and electrostatic artificial muscles, transformation and behavior control techniques are all applicable to a mother ship that transports inspection and operation modules to a point near a suspected area with information from control center.

(c) Inspection module without wire

Actuators for expansion and contraction type power mechanisms, energy supply photovoltaic effect devices, CCD micro-camera for microvision, wideband photodetectors for analysis, functional connection methods, and a communications network are all applicable to an inspection module that moves inside tubes or pipes and performs environmental recognition, coordination control, energy supply, and communications.

(d) Operation module with wire

Tubular manipulator mechanisms and efficient photoelectric converters are all applicable to an operation module that makes repairs and takes samples.

(e) Total system research

Investigation of actual conditions, trends of micromachine technology, and database preparation related to inspection, maintenance, and repair work in the pipe line of power plants, feasibility study of micromachine systems, and construction of system concepts in which multiple functional devices are combined into a system.

[R&D of micromachine technology for medical applications]

To develop the element technology necessary for intra-luminal diagnostic and therapeutic systems for cerebral blood vessels, trial manufacture and evaluation will be made and technical problems identified for the following technologies:

(a) Laser-applied diagnostic and treatment technology
(b) Microtactile sensing technology
(c) Blood pressure and blood flow sensing technology

[Micro-factory technology]

The following R&D will be conducted as necessary technologies (microfactory technology) for constructing micromachines and systems usable in manufacturing processes to make compact factories for small industrial products.

(a) Micro processing and assembling systems

Micro processing technology, micro assembling technology, micro optical driving technology, micro fluid working technology, micro transporting technology, micro inspection technology, and micro control technology are all used to process, hold, and transport small parts and recognize their positions and shapes accurately.

(b) Total system research

Investigation of the applications and needs of micro factory technology, investigation and feasibility studies of designs of total systems and related technologies.

(c) Research on technologies for measuring energy-saving effects

Investigation and research of technologies for the evaluation and measurement of the energy-saving effects obtained from microsizing of factory.

(2) R&D on micromachine materials

The following joint researches on micromachine materials with the Mechanical Engineering Laboratory of AIST will continue.

(a) Operating environments for microfunctional elements
(b) Micromachine materials in general
(c) Feasibility studies on micromachine materials

(3) Research on basic designs and manufacturing technologies

The following basic research will be carried out with the Mechanical Engineering Laboratory of AIST:

(a) Processing technology
(b) Development of mechanisms into devices
(c) Microassembling

(4) Joint research on micro factories

Joint research will be conducted with the Mechanical Engineering Laboratory of AIST to conceive future micro factory systems that will save energy consumption, space, and natural resources, by "microsizing" of production equipment for small industrial products. The following research will be carried out on trends to down-size production systems and economical analysis of future micro factories.

(a) Analysis of current trends in down-size industrial production systems
(b) Construction of micro factory systems
(c) Economic analysis of micro factories

(5) Investigation of fundamental micromachine technology

The following joint studies on fundamental micromachine technologies, such as micro science and engineering, material engineering, and design engineering, between industries and universities will be carried out to explore fundamental technical "seeds," to evaluate them in detail by experiments and other means, to choose the promising ones, and to clarify promotion methods:

(a) Exploration of technical "seeds" of basic technology
(b) Exploration of technical "seeds" of functional element technology
(c)Exploration of technical "seeds" of systematization technology

(6) Investigation of social and economic impacts expected from the introduction of micromachine technology

R&D on micromachine technology, which realizes advanced mechanical systems consisting of minute functional elements, has been steadily progressing and the technology is already partially incorporated in commercial products making a significant contribution to society. For its long-term direction, MMC will decide the R&D direction to take by assessing the expected effect in industrial fields, and will contribute to R&D's effective establishment, dissemination and promotion, while preparing the basic conditions for the introduction of micromachine technology. This will require the following:

(a) Evaluation of economic impact on various industries expected from the introduction of micromachine technology
(b) Evaluation of social impact expected from the realization of micromachines

(7) Construction and maintenance of a micromachine database

MMC will construct and maintain the following charts as a micromachine database and distribute them in annual reports to aid other researchers in the field.

(a) R&D charts categorizing by technical item the findings of questionnaire surveys of current research themes, future plans and published papers on micromachine researchers in Japan and elsewhere in the world, investigations of the trend of study session presentations, and details of related projects.
(b) Application charts categorizing by field and technical item the findings of questionnaire surveys of the applications and practical uses of micromachines in industries in Japan and elsewhere, investigations of patents, technical magazines, and newspapers.

(c) Technical chart storing information available from the literature and learned from MMC's research activities.

(2) Collection and Provision of Micromachine Information

Information and data on micromachines will be obtained from universities, industry and public organizations within and outside Japan. These materials will be categorized along with MMC's own research data, made available in the Center's documentation room, and broadly disseminated to interested researchers worldwide through:

(a) Publication of a newsletter on micromachines
(b) Maintenance of a documentation room
(c) Continued construction from the previous year of an information network and study on establishment of an information retrieval system as part of the micromachine database

(3) Exchange and Cooperation with Worldwide Organizations Related to Micromachine

MMC will make research grants through joint projects with government, industry, and academia, invite and send researchers and scholars to and from Japan, participate in a micromachine summit, sponsor international symposia and seminars, and arrange technical exchanges to further affiliation and cooperation with related organizations with common interests.

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

To promote studies on micromachines smoothly and effectively, MMC will make grants for fundamental and basic research to universities as part of promoting these joint projects with government, industry, and academia.

(b) International exchange among researchers on micromachine technology

MMC will invite scholars from the United States, Europe, and Australia to Japan and will send Japanese scholars and researchers to other countries on missions for international exchanges.

(c) Sponsorship of symposia on micromachine technology

MMC will establish and disseminate micromachine technology through presentations of R&D achievements and their applications as well as technological promotion policies for each country.

Since this fiscal year is in the year for the interim evaluation of AIST's Industrial Science and Technology Frontier Program, "Micromachine Technology," MMC will also sponsor a meeting at which research results of the project will be presented.

(d) Participation in the micromachine summit and bilateral technical exchanges

MMC will participate in the second summit on micromachines with the United States, Europe, Australia, and Japan, and discuss a broad range of issues. MMC will also provide places for bilateral technical exchanges to discuss various problems related to micromachines.

(e) Sponsorship of micromachine seminars.

To supplement the international exchange of specialists and assure the most extensive awareness of the results of Japanese research, MMC will hold seminars in those countries actively developing micromachine technology

(f) Dispatch of missions to other countries

Research missions will be sent to Europe and the United States to exchange information and promote international cooperation with universities and other micromachine-related organizations. The missions will also participate in international symposia and meetings of academic societies held abroad.

(4) Promotion of Micromachine Standardization

Based on the micromachine standardization program established in the last fiscal year, MMC will conduct the following activities:

(a) Detailed surveys of the meaning of related technical terms
(b) Identification of technical problems in standardization through the instrumentation/evaluation method
(c) Closer cooperation with standardization activities in other countries

(5) Dissemination and Promotion of Micromachines

MMC will disseminate information and enlighten people about micromachines through the publication and distribution of micromachine magazines and through seminars and exhibitions.

(a) Periodically publish and distribute to relevant bodies a public relations organ, Micromachine (in Japanese and English), as well as a newsletter.
(b) Hold contests on micromachines, issue introductory booklets, and produce videos. Also hold evening seminars for exchanges among industry, government, and academia.
(c) Cosponsor a Micromachine Exhibition and prepare for the one to be held next year.
(d) As the secretariat of the Federation of Micromachine Technology, strive for closer affiliation among micromachine-related organizations.

The 1st Micromachine Summit was Held.

After nearly one year of preparations, the Micromachine Summit was held at Miyako Hotel in Kyoto over a three-day period from March 13 (Monday) to 15 (Wednesday), and was a huge success.

This summit, a part of the MMC's international exchange operations, was held to promote micromachines through the forthright discussion on various issues covering from R&D to commercialization by high-level representatives of universities, research institutes and private corporations in 10 countries being involved in micromachine and micromachine technology. Another objective of the Summit was to increase understanding of micromachines at home and abroad by announcing the opening of the Summit.

This Summit was the first international meeting on micromachine held at Japan's initiative. All of the representatives participated in the meeting had positively appraised the aim of the Summit. Through the discussion, it was decided to hold further Summit on annual basis and the next Summit will be held in spring, 1996, in Switzerland.

This lively Summit was attended by the total of 111 persons: 83 observers and 28 representatives of 10 countries, which are comprised of 23 delegates from 9 foreign countries and 5 representatives of Japan, the host country. Discussions were held on March 14 and 15, with Professor Naomasa Nakajima of The University of Tokyo (who was also chief delegate for host country) serving as chairman.

Below are the Japanese representatives, other than Professor Nakajima, each of whom helped make the summit the huge success it was by actively participating in the discussion:

Seiuemon Inaba, Ph. D., President of FANUC LTD.

Toshiro Shimoyama, Chairman of OLYMPUS OPTICAL CO., LTD.

Taro Tanaka, Chairman of NIPPONDENSO CO., LTD.

Reinosuke Hara, Ph. D., Vice Chairman of Seiko Instruments Inc.

While the Summit had a definite private-sector character, being represented by industry and academia, the chairman's opening remarks were followed by those of guests Mr. Tatsuo Fujino, Director of the Industrial Machinery Division, Machinery and Information Industries Bureau, and Mr. Masayuki Kondo, Director for Development Program, Agency of Industrial Science and Technology both of the Ministry of International Trade and Industry.

Discussion at the Summit was divided into 10 topics, each of which was assigned to a different attending nation, whose representatives made a presentation synopsizing the relevant problems.

After the discussions on these topics were completed, comprehensive discussions were held, with the following conclusions;

(1) To expand discussions on future management and policy, similar Summit should be held on an ongoing basis.

(2) International cooperation in the field of micromachines requires continuous international exchange to handle a wide range of issues and problems. As a first step, regular and scheduled forums should be held, organized by the representatives from each country.

(3) Standardization through international cooperation is an urgent issue; the countries involved should begin discussions aimed at standardization work in international standard organizations such as ISO and IEC.

(4) Advances in the exploitation of applications, in parallel with research and development, will accelerate the research itself; we should begin a study based on cooperation among all the countries involved.

Presentation by a foreign representative

Representatives of the Micromachine Summit

Topics and Related Discussions

At the Summit, ten vital issues were presented by the delegates and discussed at length.

The main points raised were:

1) Scope of Micromachine

Each country has started from a different technical base, taken a different technological approach, and used different terminology. To produce micromachines efficiently, all these technologies should be joined together, and future work should be in the same direction. The Summit considered the many different approaches and found that a number had common threads running through their programs.

2) Effective R&D

Much of the Micromachine Technology is at the pre-competitive stage; it includes a wide range of technological elements, such as processing, assembly, packaging, materials and systems construction. Although this research and development is being carried out in a distributed manner, close linking these efforts is important. As such both national and international exchanges of R&D are important.

3) Combining Multidisciplinary Knowledge

The design of a micromachine requires a balanced mix of different disciplines such as electrical and mechanical engineering, electronics, chemistry, biology and materials science. At the research and development stages, it is important to exchange information; at the marketing stage exchange between different industries is important.

4) Exploiting Applications

Micromachines promise to blaze a trail through a new frontier for human beings. Although their applications are limitless, there are specific applications that will improve the welfare of mankind in every country. Full exploitation requires integration of culture and customs from different professional disciplines, and an infrastructure that serves small and medium sized enterprises.

5) Coexistence and Competition with Conventional Technologies

In addition to creating products that have not previously existed, micromachines will improve many products that are in production now. This latter production will account for most of the spread of micromachines in the near future.

6) Potential New Industries

Future of micromachine technology enable processing and assembly to be performed at extremely minute levels of detail, through which functional devices can be implemented. A processing industry based on processing and assembling technologies, and a functional device and machine systems manufacturing industry to accommodate the many new fields of application will emerge.

7) Intellectual Property Rights

Technological exchange is the most important issue in advancing micromachine technology. Intellectual property rights protect the inventor but can impede the proliferation of technological applications if they are enforced too strictly by the inventor. The harmonization of the International Intellectual Property Rights system and the early publication of technical information are advisable.

8) Standardization

Even though micromachine technology is still at the research and development stage, the process of standardization should be started at the first possible opportunity, this will support research and development and make the best use of both investment and personnel. To this end, international harmonization must be considered as the first principle.

9) Role of Government

The establishment of a new technological paradigm for micromachines require efforts to be directed across a wide range of technical areas and high-risk, long term, research and development. As this technology will benefit on daily lives in every field of human endeavor — industry, society and private life — vigorous support by each Government is justified.

10) International Relations

As a new multidisciplinary paradigm, micromachines require the exchange of capabilities distributed widely over many countries. The common understanding that will be achieved through these exchanges will benefit the smooth development of the world economy in all areas of future trade. The establishment of regularly scheduled forums was deemed to be one effective means of maintaining continuous international exchange.

The 2nd Micromachine Technology Research Grant

The 2nd Micromachine Technology Research Grant Presentation Ceremony (for fiscal 1994 grants) was held on March 24 in the Tokai University Alumni Association Hall in the Kasumigaseki Building in Tokyo. The Micromachine Center established this research grant system last fiscal year as independent program intended to support professors and other university personnel engaged in fundamental research on micromachines, the objective being to promote micromachine technology and encourage further exchange between academia and industry. Of the numerous applications received this year, eight new projects and three continuing projects in their second year were selected (see attachment), for a total of 18 million yen in grant money.

At the presentation ceremony, Seiuemon Inaba, Chairman of the MMC and Tatsuo Fujino, Director of Industrial Machinery Division respectively delivered the host's address and guest's address, which were followed by the announcement of the selections, made by Professor Yoji Umetani, the Chairman of the Industry-Academia Joint Research Committee of the MMC. Chairman Inaba then presented the 11 recipients with a list of the grants, after which Professor Kunihiro Ichimura gave a speech on behalf of all recipients, and each of the eight recipients in charge of new projects gave a brief summary of their research plans.

The presentation ceremony was followed by a celebration party, where the recipients and those in attendance enjoyed pleasant conversation.

This research grant program is scheduled to continue through fiscal 1995 as well, and applications will be accepted beginning roughly in August.

Chairman Inaba and the recipients

• Research projects selected for fiscal 1994

Leader & Co-Worker	Positions	Subjects	Period
Kunihiro Ichimura	Professor, Research Laboratory of Resources Utilization, Tokyo Institute of Technology	Molecule-Assisted Molecular Systems Driven by External Stimuri	2 years
Kazunori Kataoka	Professor, Department of Materials Science and Technology , Science University of Tokyo	Development of Superior Biocompatible Surfaces for Micromachine Engineering,	1 year
Takashi Yasuda	Research Associate, Department of Mechano-Infarmatics, The University of Tokyo	Microrobot Control Using Reflex Actions of Insects	2 years
Hiroyuki Matsuura Iwao Fujimasa	Assistant, Professor, Research Center for Advanced Science and Technology, The University of Tokyo	Physical Quality of the Artificial Muscle in Micro and Sub-Micro Region	2 years
Nuio Tsuchida Jun Ohsawa	Professor, Associate Professor, Department of Control and Information Engineering, Toyota Technological Institute	Studies on Micro Pump Employing Liquid Stream by Ion Drag Force	2 years
Makoto Ishida	Assistant Professor, Faculty of Electrical and Electronic Engineering, Toyohashi University of Technology	Multi-SOI Structures for New Micromachine-Material with Single-Crystalline Al_2O_3 and Si Films	2 years
Yasunori Saotome Akehisa Inoue	Associate Professor, Faculty of Engineering, Gunma University Professor, Institute for 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

• Projects selected for fiscal 1993

Leader & Co-Worker	Positions	Subjects	Period
Shuichi Miyazaki	Associate Professor, Institute of Materials Science, University of Tsukuba	The Development of Shape-Memory Alloy Thin Films for Microactuators	2nd year
E. Yeatman R. Syms	Lecturer, Head of Section, Imperial College of Science, Technology and Medicine	Surface Tension Micromolding and Microactuation	2nd year
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 a Micro-Telesurgery System — A Basic Study	2nd year

Awards of the 1st Micromachine Drawing Contest

With micromachine technology expected to become a new generic technology in the 21st century, dynamic R&D activities are currently under way at universities, research institutes and corporations both in Japan and abroad. An essential aspect of support for such research and development is proper understanding of micromachines and micromachine technology among the general public. To this end, MMC has sponsored a micromachine drawing contest for boys and girls of primary and junior high schools, who are to bear the responsibility for the coming age, so that they can learn about and become familiar with micromachines while still young. This marks the first such contest held by MMC, which, with the cooperation of MMC's supporting members, held the contest on an experimental basis at a total of five primary and junior high schools in Ina City, Nagano Prefecture and the town of Shizukuishi, Iwate Prefecture.

A total of 1,001 entries were submitted, from which the screening committee selected twenty-four winning entries, listed in the attachment. A breakdown of the number of entries received, as well as the names of each participating school, are as follows.

- Number of entries from:

Primary schools	390
Junior high schools	611
Total	1,001

- Participating schools
  - Ina Primary School, Ina City
  - Ina-higashi Primary School, Ina City
  - Shizukuishi Primary School, town of Shizukuishi
  - Nishi-minowa Junior High School, Ina City
  - Shizukuishi Junior High School, town of Shizukuishi

The awards ceremony was held on March 27 at the Tokai University Alumni Association Hall, on the 33rd floor of the Kasumigaseki Building, and was attended by roughly 40 persons, including winners, guests and screening committee members.

Remarks from Masayuki Kondo, Director for Development Program at the Agency of Industrial Science and Technology (Ministry of International Trade and Industry) were followed by those of screening committee chairman Hirofumi Miura, a professor at The University of Tokyo, who stated, "I am extremely pleased that so many imaginative entries were submitted, and I hope that this contest is held every year. I can't wait to see the kind of entries we get ten years from now." After the twenty-four winning entries were presented, the awards and certificates of appreciation were presented by MMC's Chairman, Dr. Seiuemon Inaba to the winners — including Best Entry winners Yumiko Misawa, a third grader at Ina Primary School, and Michiko Fukusaki, a first grader at Shizukuishi Junior High School — and to teachers representing each participating school. Lastly, the two Best Entry winners each gave a speech expressing their delight in winning and their hopes and dreams concerning micromachines.

Being an awards ceremony for boys and girls of primary and Junior high schools, this ceremony had a very congenial ambiance. Even the guests' speeches were delivered in a simple style to accommodate the children, making this ceremony fundamentally different from any the MMC has ever held. It was also encouraging to hear these children, who will grow into the next generation of adults, express their interest in micromachine technology. All in all, it was chance to forget the complications of daily work.

The members of the screening committee are as follows.

Chairman:	Prof. Dr. Hirofumi Miura, The University of Tokyo
Member:	Mr. Hiroshi Shima, Japan Society for the Promotion of Machine Industry
	Dr. Keiko Nakamura, Biohistory Research Hall
	Mr. Ken'ichi Matsuno, Mechanical Engineering Lab., AIST, MITI

Commemorative photograph of contest winners

Yumiko Misawa, winner of Best Primary School Entry, receives her award.

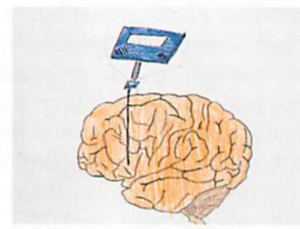
Winners of the First Micro

• Category of Primary School

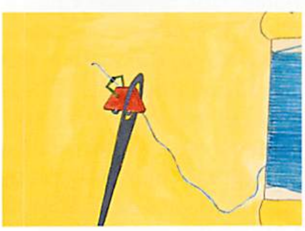
Best Entry:
Earthquake Forecasting Micromachine
Yumiko Misawa
Ina Primary School (3rd grade)

First Prize:
Harmful Insect Killer
Yoshinori Hirasawa
Ina Primary School (3rd grade)

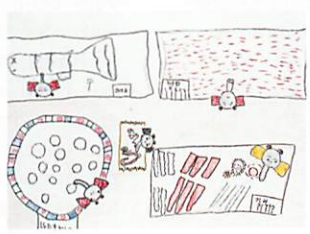
Second Prize:
Talking Micromachine
Masayuki Kitahara
Ina-higashi Primary School (6th grade)



Second Prize:
Mr. Convenient
Namiko Kasuga
Ina-higashi Primary School (6th grade)



Third Prize:
The I-wonder-if-I-can-eat-it Machine
Yuri Murakami
Shizukuishi Primary School (5th grade)



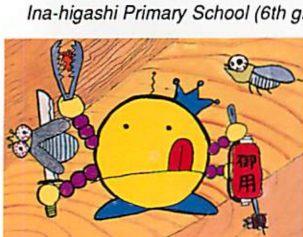
Third Prize:
Toddling Ladybug
Natsumi Ikegami
Ina Primary School (3rd grade)

Third Prize:
Nature Observation Micromachine
Yumi Miyashita
Ina Primary School (3rd grade)

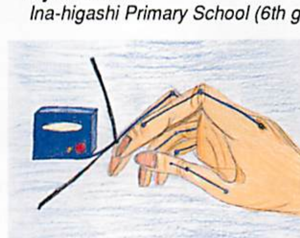
Honorable Mention:
Shaving Micromachine
Takamitsu Sasaki
Shizukuishi Primary School (5th grade)

Honorable Mention:
Tick-sucking Elephant
Kanako Tanifuji
Shizukuishi Primary School (6th grade)

Honorable Mention:
Harmful Insect Killing Machine No. 1
Heita Murakami
Ina-higashi Primary School (6th grade)



Honorable Mention:
Finger Supporter
Ayuko Iwane
Ina-higashi Primary School (6th grade)



Honorable Mention:
Micromachine Science
Yuki Matsuo
Ina-higashi Primary School (6th grade)

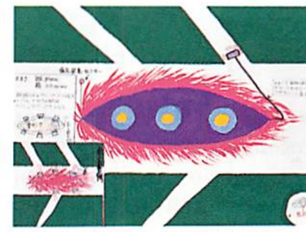
machine Drawing Contest

• **Category of Junior High School**

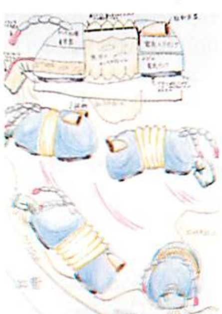
Best Entry:
Small-fish-bone Removing Device
Michiko Fukuzaki
Shizukuishi Junior High School (1st grade)

First Prize:
Air Purifying Machine
Sayuri Ohshiro
Shizukuishi Junior High School (2nd grade)

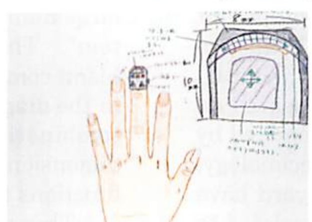
Second Prize:
Plant Hospital No. 3
Azusa Ikegami
Nishi-minowa Junior High School (1st grade)



Second Prize:
Cholesterol Remover
Eri Kobayashi
Nishi-minowa Junior High School (1st grade)

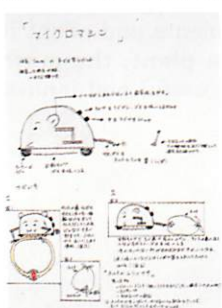


Third Prize:
Nail Clipper
Shiho Itoh
Nishi-minowa Junior High School (1st grade)



Third Prize:
Diet Machine
Sumika Sakai
Nishi-minowa Junior High School (2nd grade)

Third Prize:
Good Rat
Ayumi Odauchi
Nishi-minowa Junior High School (2nd grade)



Honorable Mention:
Needle/Thorn Remover
Asami Kirino
Nishi-minowa Junior High School (1st grade)

Honorable Mention:
Insect Exterminating Robot
Chizuru Wada
Nishi-minowa Junior High School (1st grade)

Honorable Mention:
Flea/Filaria Exterminating Robot
Mariko Ozaki
Nishi-minowa Junior High School (1st grade)

Honorable Mention:
Water Pipe Patrol
Shinya Takahashi
Shizukuishi Junior High School (1st grade)

Honorable Mention:
Ear Cleaning Machine
Yuko Yonekura
Shizukuishi Junior High School (2nd grade)

MITSUBISHI HEAVY INDUSTRIES, LTD.

— Developing Innovative Robots —

1. Introduction

MHI R&D Activities on robots originated from the automation of fuel exchange and inspection units for nuclear power plants about 20 years ago and has since covered diversified types of plant maintenance robots. The company's applications now include thermal power plants, ships, and petrochemical plants, as well as nuclear power plants, and it is developing higher value-added ones to relieve us of the so-called 3-D work (dirty, dangerous, and difficult) and to eliminate manual labor near radiation from nuclear plants. R&D activities for these robots are principally conducted by the Takasago Research & Development Center of the Technical Headquarters. Takasago R&D Center is located at Takasago, Hyogo, about 60 km west of Osaka. Participating in the Research on the "Advanced Robot Technology" project promoted by MITI's Agency of Industrial Science and Technology, MHI Takasago R&D Center and Kobe Shipyard have jointly undertaken the most advanced R&D related to manipulation technology. As industrial structures undergo extensive changes worldwide and we enter into the era of increasingly older generations, the arena of robots is becoming increasingly important not only in maintenance but also distribution, construction, leisure (entertainment), and welfare. To cope with these needs for small mechanisms, the company strives for active R&D.

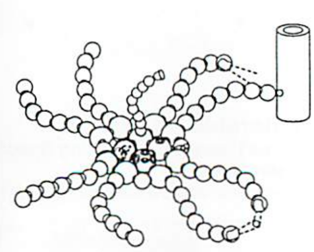
2. Tackling Micromachine Technology

While the arena of robots is expected to broaden as mentioned above, in the small world where a micromachine works, we need a system able to respond to and deal with phenomena beyond previous concepts. As the micromachine becomes smaller, its functions tend to weakening. Individual elements have difficulty functioning usefully. To fill the gap between limited functions from miniaturization and needs for advanced functions, an investigation of "group or colony control" based on system control is in progress as a solution, employing the idea of grouping many individual units. To construct and control the new mechanisms, the company proposes a "holonic mechanism and form change control" and is conducting basic technological development.

The so-called holonic mechanism "can develop different functions if identical elements or elements having the same kind functions (holon) are gathered in large numbers and mechanically assembled into a system". The robot illustrated below (holonic mechanism) combines a large number of holons (round ones in the diagram). Each holon can only bend/turn, but a combination of many of them allows various three-dimensional forms; changing the form allows desired functions to be added.

This new mechanism has tremendous freedom that requires new control methods. The form change control method that gives several basic forms to the holonic mechanism, which is capable of having innumerable forms, controls only certain joints to limit the degree of freedom, and realizes intended functions.

If this allows a machine to change form in accordance with functional requirements and adapt itself to various environments in a plant, the machine might become one of the most useful and innovative micromachines.



MITSUBISHI MATERIALS CORPORATION

1. Introduction

MITSUBISHI MATERIALS CORPORATION, which originated when its predecessor the Tsukumo Co. entered the mining business in 1871, has since then undergone an extensive change in its line and scale of business. It now functions as an overall material processor and manufacturer handling such areas as the refining of nonferrous metals, cement manufacturing, metal processing, aluminum can processing, and the production of semiconductor materials and electronic parts.

We recently visited the company's laboratory in Ohmiya, 30 km north of central Tokyo, which is in charge of the research and development of these products. Mitsubishi Materials has four research laboratories and five development centers, to which about 1,000 people, over 10% of the total employees are assigned. Two of these laboratories (the Central Research Institute and the Cement Research Institute) and two development centers (the Mechatronics & Manufacturing System Development Center and the New Products & Process Development Center) are the core of the company's R&D activities, and are located in Ohmiya.

The Central Research Laboratory is one of Japan's most comprehensive research institutions. Since 1939 it has been housed in one of the earliest Western-style buildings and now handles projects from resources and energy to raw materials, basic materials, processed products, new materials and develops means for their recycling.

2. Characteristics of Technological Development

With "originality" as the guiding principle for its technological development, Mitsubishi Materials seeks to advance the level, functions, and value-added aspect of technology related primarily to energy, recycling, information, and electronics as its "four pillars"; it is also devoted to expanding the basic technology needed as an overall material processor and manufacturer.

In the energy field, the company successfully commercialized the multi hearth continuous copper smelting "Mitsubishi Process" to achieve a level higher than any known to date. Toward the urgent goal of new energy sustaining environmental conservation, it has developed key technologies, such as hydrogen storage alloy which stores and discharges hydrogen electrochemically for heat pumps, high-performance Ni-based alloy as an electrode material for fuel cells which is promising as a power generator for the next generation, thermoelectric devices for power generation employing the heat dissipated from cities, and geothermal power generation. A Nb-Al intermetallic compound, an ultra- high temperature material for hypersonic passenger aircraft and reentry vehicles which will support the aerospace transport systems of the next generation, was also pioneered in this field employing a plasma melting and gas atomizing process.

For the past century, Mitsubishi Materials has taken

"symbiotic steps with nature" to transform the blessings of the earth to forms benefiting society. To this end, the company has focused on research to develop recycling technology, including recovery of aluminum cans, reuse of various kinds of nonferrous metals, used household electric appliances and automobile products.

In the information area, the company has tackled improvement of the quality of silicon, a basic material for the advanced information society, from the pulling of single crystals to the manufacture and characterization of the wafer. Most recently it was successful in pulling the world's longest high-quality single crystal silicon of two meters, employing the continuous Czochralski method. Various electronic parts such as surge absorbers have also been developed.

3. Advancing Micromachine Technology

With the approach of the 21st century technology maximally employing the function of a material is expected to progress rapidly. The function of a material can be obtained and utilized from even a small quantity. Thus, technological advancements and societal trends should omit the non-functional or useless portions from a material. Micromachines should develop technically following this trend.

For material manufacturers, too, the direction is inevitably from "structural" toward "functional" materials. In the present "micromachine research," the company is miniaturizing a secondary battery employing a hydrogen storage alloy which is capable of storing as much as 1000 cm^3 of hydrogen in 1 cm^3 volume, is very safe, and can be recycled, utilizing thick and thin film production processes. In the development of piezoelectric materials, an important element in micromachine technology, the company originated the sol-gel process, which seems promising in the miniaturization of various components.

The 4.2 mm diameter stepping motor, the thinnest of those mass produced for commercial use resulted from the development of a strong Nd-Fe-B magnetic material. The micro-processing of silicon and various element technologies made possible with the thin film of functional materials is also expected to play an important role in the progress of micromachines.

Finishing the visit, we left the laboratory and its rich green setting with the conviction that it is entirely natural for Mitsubishi Materials with its guiding principle of symbiosis with the globe and nature to seek to advance micromachine technology.

Interview with Prof. Richard S. Muller from the U.S.A.

Dr. Richard S. Muller who is an authority on Micro Electro-Mechanical Systems, a Professor at University of California, Berkeley, and also a Director of the Berkeley Sensor & Actuator Center (BSAC), has come to the Micromachine Summit at Miyako Hotel in Kyoto as the chief delegate for the U.S.A.

We had an opportunity to interview him regarding current micromachine research in the U.S.A.

Q: *What kind of research concerning micromachine technology is being done in BSAC?*

A: The BSAC research program is quite broad. Our project range from processes to materials research, to new kinds of devices and systems. We have four directors and 30-40 students from Electrical Engineering, Mechanical Engineering, Material Science, and Chemical Engineering in the Center. So with that broad base, we feel comfortable in going into this variety of areas. Probably, the most recent high-profile work for us has been on integrated micro electro-mechanical devices in systems similar to the accelerometer project of Analog Devices Inc. Analog Devices is one of 20 member companies in the Center. Others include Motorola Inc. which is also heavily working on accelerometer systems. A project jointly done at BSAC together with Analog Devices is called iMEMS (integrated MEMS) and it is targeted both at physical sensors and also at mechanical devices made especially for integrated-circuit applications. For example, high-quality resonators for frequency references and for filtering applications. At BSAC, We developed a fabrication process that we call (in house) MICS (Modular Integration of CMOS and Microstructure). MICS consists of nearly conventional CMOS process followed by an additional two polycrystalline-silicon mechanical layers for structures. The principal investigator for MICS is Prof. Howe. A new project on microphotonic devices such as automated feedback-control system for laser-fiber coupling, is directed by myself. Another project just getting underway is for micro-information storage like a micro disc drive, headed by Prof. Pisano. The fourth BSAC director, Prof. White has concentrated on acoustic pumping and acoustic sensors and on microfluidics. BSAC also does fundamental work on characterizing the mechanical properties of various materials.

Q: *By whom are the research activities financed?*

A: Roughly 50% of our budget comes from membership fees for BSAC and the other 50% of budget comes from government agencies.

Q: *What kind of micromachine researches are done in mechanical engineering in your country?*

A: Within BSAC, we have a number of mechanical engineers. UCLA has begun an intensive program in their ME Department. I am very proud of fact that we have 11 of our Ph.D. graduates teaching at various universities including ones in Korea and Spain. Many other graduates work for our member companies.

Q: *What will be the application and impact of micromachine technology in the near future?*

A: Physical sensors for acceleration and position measurement will have a major impact. I am also confident that the display area such as the DMD (TI) will be important. The same is true for medical devices and those for process control. I think that micromachine technology will impact conventional signal processing by combining mechanical devices into microelectronics. Based on some material studies at BSAC, an important new silicon material called HEXSIL (technique for using silicon as a mold for hexagonally structured polysilicon) has been invented. With HEXSIL you can use micro technology to make milli-scale devices.

Q: *What are the principal barriers to the success of the micromachine research?*

A: I don't believe there are any fundamental barriers which are going to stop MEMS. To me, the highest barrier has to do with how you can transfer MEMS into a commercial application considering cost. One of the problems is having an application that will pay the cost of development. It is the same problem that VLSI technology had to overcome.

Q: *How do you feel about Japanese micromachine researches or research activities?*

A: I feel overall very impressed as summarized by comments in the recent JTEC report. In Japan, you have looked very broadly at what a micro mechanical system is while, in the USA, we have been much more selectively thinking about it. Your approach may be exactly right. The point is whether or not it leads to economical systems.

Q: *Could you please tell us your dream about micromachine technology?*

A: It is almost impossible to forecast the future for MEMS just as, no one could forecast the microprocessor. Bringing intelligence into many areas is right now the brightest aspect of MEMS. As Dr. Ken Gabriel has said, "VLSI technology took computers out of room-sized consoles and put them on your desk. MEMS will probably take them off the desk to put them in your pocket." My vision is to bring about highly intelligent functional systems that efficiently interface with, and directly influence their surroundings.

Micromachine Technology (V)

Bonding and Micro Assembly Technology

As shown in Fig. 1 of the Third Course, the beginning of micromachine technology is said to be in prototype making of electro-mechanical devices such as electrostatic motors and gears made by the silicon semiconductor process at the ATT Bell Research Laboratory and University of California. The devices that can be produced by surface micromachining are only very thin, nearly two-dimensional shapes, due to the process constraints. The major objective of microprocessing technology, therefore, is to develop three-dimensional structures and to produce greater output from those structures. The advantage of micromachining is that actuator, sensor, and semiconductor may be combined. In this meaning, bonding technology is considered one of the most important aspects of micromachine technology; it deals with problems of making micro structures three-dimensional and integrating actuator, sensor, and control circuit.

Bonding, which is used to produce micromachines, includes the technology for bonding a group of devices collectively in wafer levels as well as the technology for bonding each component sequentially. The former technology includes anodic bonding, silicon direct bonding, and surface activation bonding. Combinations of these methods and other bonding methods have also been proposed. The latter technology includes bonding using electron beam and laser beam, and the more advanced and microsized bonding methods used for conventional size products such as fusion welding and pressure bonding.

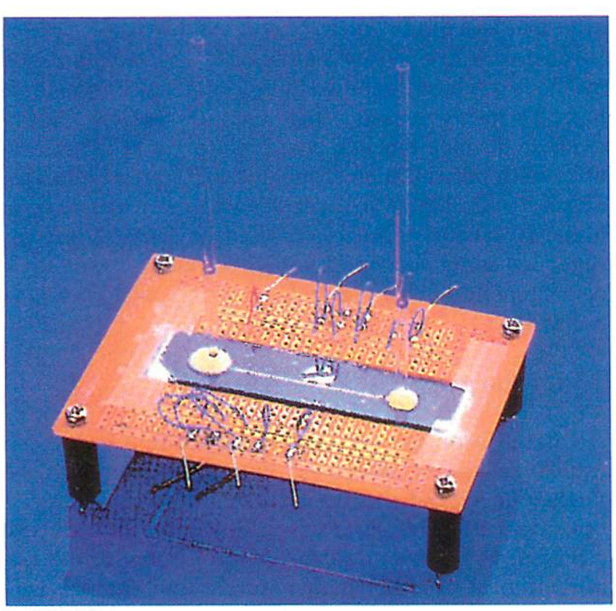


Fig. 1 Micro pump produced by the anodic bonding process *[Mech. Eng. Lab., MITI and Saimon Fraser Univ., Canada]*

Fig. 2 Small hole provided by the excimer laser process for an electrical feedthrough in the Pyrex glass (the oval area: a heat affected zone) *[Mech., Eng., Lab., MITI]*

(1) Batch bonding technology

Initially, anodic bonding is introduced. The bonding can be performed through ion transfer and electrostatic pressure through the boundary by heating Pyrex glass and silicon to a temperature of 400°C or more and supplying a high voltage. By this method, sample structures containing an internal cavity, such as capacitive pressure sensor or micro pump, can be produced (Fig. 1). Researches are being carried out to decrease process temperature by using low-melting-temperature glass, and to expand the application area other than glass and silicon by using a glass film as an intermediate layer. The technology for making electrical feedthrough with silicon by piercing a small hole in the Pyrex is also quite an important research subject, although its importance does not appear so obvious. (Fig. 2).

Secondly, silicon direct bonding is introduced below. This technology, developed in Japan, is a useful bonding method that is also used for forming an impurity diffusion layer and insulation layer. The basic bonding principle is assumed to be as follows (Fig. 3).

Initially, clean and dry the wafers, and after surface hydroxyl is formed, bond them at room temperature. The wafers are bonded by hydrogen bonding. When the wafers are heated to a temperature of 1000°C or higher, dehydration occurs. When the temperature is increased, oxygen is removed and firm bonding between silicons is achieved. By bonding wafers with a surface hole or a groove, a structure which has an internal micro cavity structure can be achieved. A pressure sensor and a heat exchanger for laser diode with internal cooling groove are fabricated by this process.

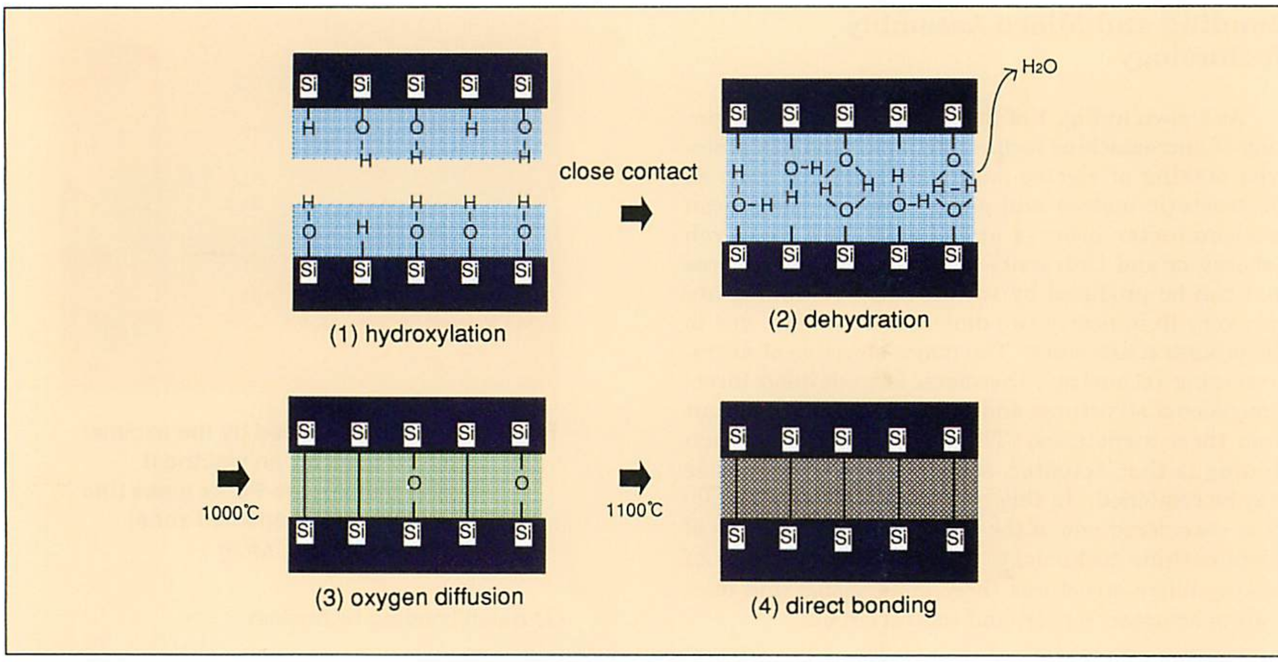


Fig. 3 Principle of the direct bonding of silicon

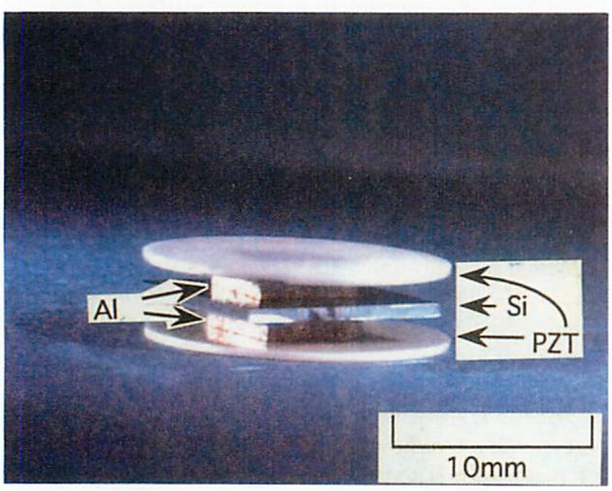


Fig. 4 Actuator prepared by bonding PZT and aluminum, an example of the direct bonding of dissimilar materials *[Nippondenso Co., Ltd.]*

The biggest disadvantage of silicon direct bonding is its requirement of high processing temperature, 1000°C or higher. As a result, processes that are carried out at low temperatures must be performed after this process. It is reported that silicon wafers can be bonded together with plasma oxidation at a temperature of 450°C. This technology, which resembles surface activation bonding, was initiated by the group in the Research Center for Advanced Science and Technology, The University of Tokyo and in the Mechanical Engineering Laboratory, MITI. Japan has made world-class advances in this field. Research for producing an actuator by bonding metals and piezoelectric elements is currently in progress (Fig. 4).

(2) Sequential bonding technology

In the sequential bonding process, the wiring leads to devices and for mounting chips to cantilevers are considered to be micro tasks. As described earlier, these tasks are carried out using existing process methods such as laser welding, brazing, and soldering. To improve task efficiency, attempts are being made to develop jigs and manipulators and to systematize with optical microscope and electron microscope. These technologies are referred to as micro assemblies. Currently, however, they have not been yet regarded as generic technologies, future systematic development (such as microfactory technology) is to be required.

(3) Summary

Batch bonding and sequential bonding have been introduced here. Micro bonding technology will be further developed in line with such key objectives as the integration of actuators and sensors into control circuits, the systemization of micromachines, the reduction of process temperatures, and the achievement of high density assembly, micro assembly, and self-assembly.

MEMS '95 Held in Amsterdam

Many presentations were given by members of the MMC mission to Europe.

This year's MEMS '95 Workshop was held at the Hotel Krasnapolsky, a renowned hotel in Amsterdam, the Netherlands, from January 29 through February 2, 1995. This conference was a Micro Electro Mechanical Systems (MEMS) workshop of the Institute of Electrical and Electronics Engineers (IEEE), which has been held once a year since 1988, moving its venue by turn to Europe, the U.S., and Asia, and is a highly reputed international conference in which research exclusively related to micro devices, micromachines, and micro systems technologies is presented. The MMC research mission to Europe also participated in this conference.

Registered participants numbered 247 from eighteen countries (including 43 from Japan), and 37 oral presentations (including two invited lectures) and 43 poster presentations were given.

Their contents were related to actuators (12 oral and 15 poster), processing and fabrication (10 and 11), sensors (6 and 7), and other applications (9 and 10), indicating a strong tendency toward manufacturing by micromachines.

This workshop proceeded in plenary rather than parallel sessions following its tradition and from 180 to more than 220 participants attended in the conference hall which was the size of an auditorium. Presentations and discussions were enthusiastic, sometimes exceeding the allowed 25-minute time. In the poster session held from 7:00 through 10:00 p.m. on the 30th, posters were placed on all four sides of about one-meter square pillars two meters high. Buffet-style food and beverages were provided in an adjacent room, where presenters and participants enjoyed amiable and enthusiastic chatting until well into the night.

MMC members gave three oral presentations on:

- Piezoelectric composites for micro ultrasonic transducers realized with deep etch X-ray lithography
- Development of coil winding process for radial gap type electromagnetic micro rotating machine
- Groove depth uniformization in (110) Si anisotropic etching by ultrasonic wave and application to accelerometer fabrication

Their five poster presentations were on:

- Optical tactile sensor using surface emitting laser
- High voltage photovoltaic micro devices fabricated by a new laser processing
- A micromachined vibrating gyroscope
- Evaluation of the micro wobble motor fabricated by concentric build up process
- 2 dimensional optical scanner applying torsional resonator with 2 degrees of freedom

All of them drew an appreciative audience.

Notable among Japanese presentations were the four by the group of Prof. Toshiro Higuchi of The University of Tokyo and the Kanagawa Academy of Science and Technology.

Many foreign presentations, many were given by members from the MESA group of the University of Twente of the Netherlands, the U.S. group of Carnegie Mellon University and Case Western Reserve University, and Research Center Karlsruhe and Institute of Microtechnology Mainz of Germany.

The participating MMC mission had significant discussions and exchanges of information and opinions with those present from many parts of the world, including Prof. Miko Elwenspoek (University of Twente) and Prof. Nico F. de Rooij (University of Neuchâtel, Switzerland), who hosted the conference.

Next year's MEMS '96 is scheduled for February 11 (Sun.) through 15 (Thu.), 1996, in San Diego, California of the U.S., as a 9th International IEEE Workshop.

MMC mission at the MEMS '95 workshop

Preliminary Announcement for 1st INTERNATIONAL MICROMACHINE SYMPOSIUM

MICROMACHINE TECHNOLOGY: A BASE of INDUSTRIAL TECHNOLOGY for NEXT GENERATION

November 1 - 2, 1995
Science Museum, Tokyo

Scope

1. Establishment and Dissemination of Micromachine Technology through the presentation of the R&D results, current status of applications and the measures for the promotion on Micromachine Technology
2. Presentation of the 1st Phase results of the ISTF Program "MICROMACHINE TECHNOLOGY"

Sponsor

Micromachine Center

For More Information:

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Mr. T. Okazaki
MICROMACHINE CENTER
Fax: +81-3-5294-7137

Notice of Relocation

The Micromachine Center (MMC) moved to a new office located at the address below. We respectfully ask for your continued support and cooperation.

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2-2 Kanda-tsukasacho, Chiyoda-ku, Tokyo 101, Japan
Phone: +81-(0)3-5294-7131
Fax: +81-(0)3-5294-7137

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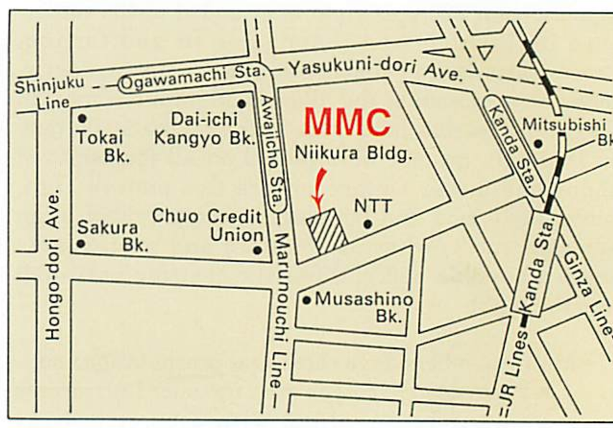

MICROMACHINE No.11

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