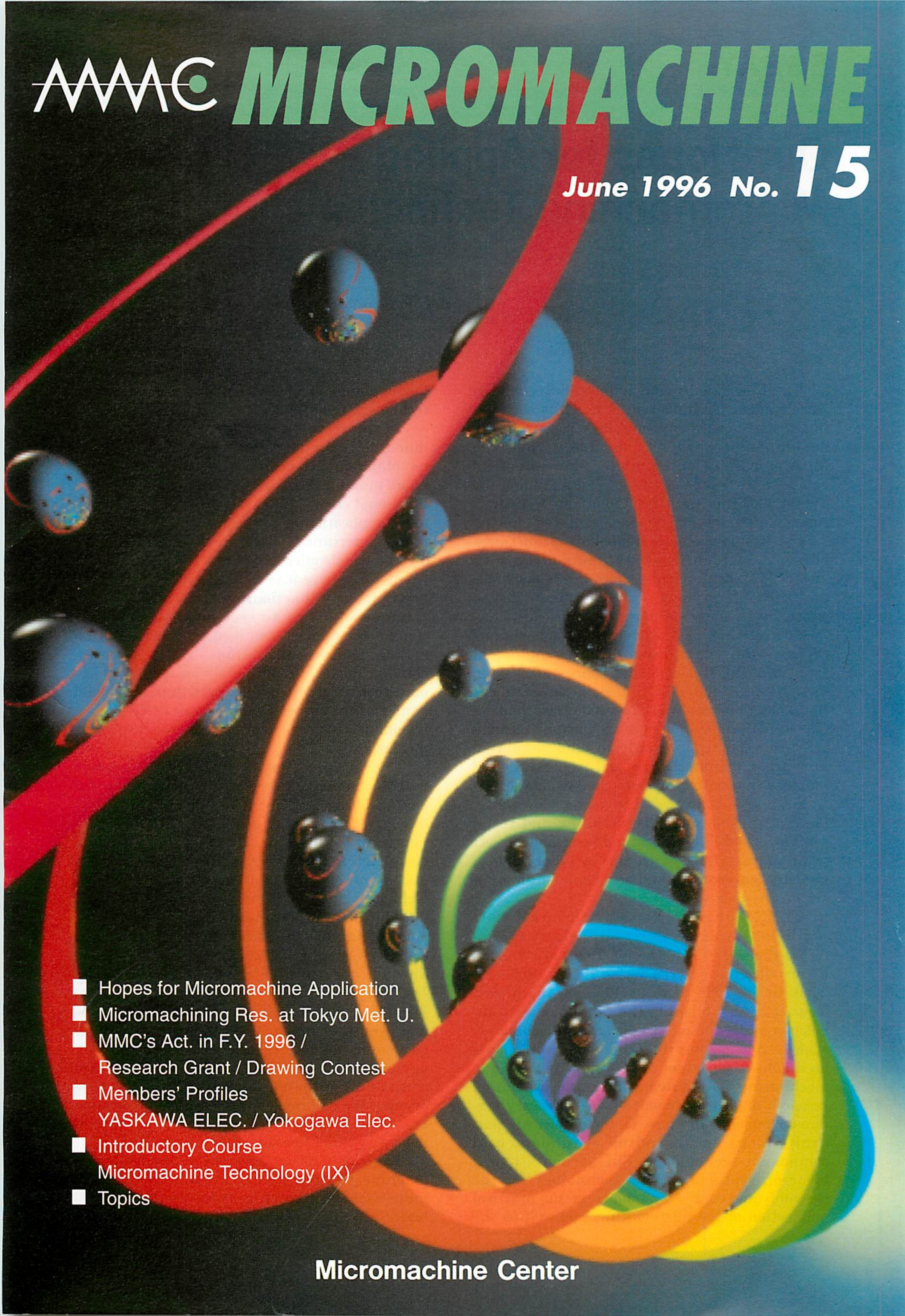

MMC MICROMACHINE

June 1996 No. 15

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Micromachine Center

Our Hopes for Applied Micromachine Technology

Hachio Iwasaki, Chairman
New Energy and Industrial Technology Development Organization

The New Energy and Industrial Technology Development Organization (NEDO) is conducting a micromachine technology research and development project, assisted by the Micromachine Center, under the Industrial Science and Technology Frontier Program of the Ministry of International Trade and Industry's Agency of Industrial Science and Technology. As the technological development of micromachines — which work autonomously with advanced skills in narrow space inside machines and the human body, and microfactories — which save energy significantly and lead to factory downsizing, have extremely unique characteristic, they have numerous technological problems, and it seems that there still remain many issues related to the social environment that need to be resolved. Nevertheless, the benefits of materialization of micromachine technology are expected not only in energy-related industries, manufacturing and medical related industry that will appreciate the benefits directly, but also to be extended to industry overall — i.e. distribution of goods, retailing and social welfare. Therefore, it is an indispensable project to be materialized with the collaboration of industry, government and academia for an affluent future society.

This 10 year project started in FY 1991 (April 1991 - March 1992). After having completed Phase I (FY 1991 - FY 1995) in FY 1995, it currently has entered Phase II (FY 1996 - FY 2000) in FY 1996. During Phase I, the project focused on establishing the fundamental technology required to materialize micromachines — such as downsizing the functional components as much as possible, developing new unique mechanisms as micromachines and promoting research and development of the necessary system technology. In Phase II, the project will naturally focus on upgrading of fundamental component technology. Furthermore, it will focus on systematization technology for the assembly and control system, targeting practical application of the micromachine, as well as the development of measurement and evaluation technology required for quality control.

In the research and development of micromachine technology, in terms of its further development, it is important to make every effort to miniaturize and improve the individual functional elements. However, if we aim for the early application of the technology, it should be more important to determine the appropriate size at which micromachines can be used efficiently. I believe it is rather important to develop technology functioning as a system and to refine it adjusting to specific applications. I think this approach can lead to discernment on specific and practical issues. Since micromachine technology is ultimately an industrial science technology, it is apparent that we should confirm and intensify its competitiveness, including cost performance, compared to existing technology.

Considering these points, we will proceed with technological development, realizing the goal of the technology during the Phase II. In order to achieve this goal, we think it is very important to obtain a wide range of information on related technological fields, as well as information on specific demand for micromachine technology.

The Micromachine Center has already engaged in various information exchanges and conscious-raising activities both in Japan and abroad, including sponsorship of the International Micromachine Symposium, Micromachine Exhibition, Evening Seminars, and even a Micromachine Drawing Contest for elementary and junior high school students. We appreciate having opinions from participants in this field and potential users through these events. We will make every effort to achieve for the actual application of the micromachine technology as soon as possible.

We hope that our progress in applied micromachine technology can vitalize the overall industrial infrastructure, which will lead to a brighter future society.

Study on Precise Micromachining

Nobuyuki Moronuki
Associate Professor, Faculty of Engineering,
Tokyo Metropolitan University

In my laboratory, researchers are studying various machining technologies especially to create both minute and accurate geometries as well as to understand their working processes. We also apply these technologies to fabricate accurate micro-mechanisms, and to evaluate its accuracy. Any machining process or shaping technique is based on either one of two principles: On one principle the accuracy of the machine tool is copied to the product, as is seen in cutting, whereas on the other principle inherent regularity such as the structure of single crystal is utilized. The focus of our research is the latter, as on this principle it is expected that minute geometries can be created accurately. Some of the researches ongoing in the laboratory are briefly explained in the following.

1. Micromachining by anisotropic etching and its applications

The anisotropic etching process utilizes the characteristic of a single crystal for which etching rate significantly differs by the orientation of the crystal, and the final geometry in this process is formed by the specific planes that the etching rate is low. Using single crystalline silicon as the work material, we study experimentally the effects of etchant and other conditions upon the final geometry to clarify the processing mechanism. We also study to establish the more practical processing technology, that is, to determine the conditions to improve final dimensional accuracy and the surface properties of minute mechanical elements manufactured by this method.

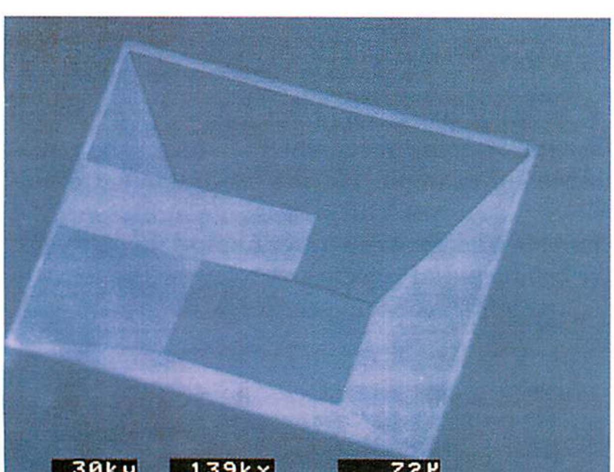


Fig. 1 Example of micro-cantilever

We have applied this processing technique to manufacture micro-mechanisms on a test basis. Figure 1 shows a micro-cantilever, which was fabricated to clarify the dynamics of micro-objects. It measures 40 μm wide, 260 μm long, and 0.8 μm thick. Its natural frequency is measured to be 10.6 kHz. This means that conventional theories for macro-objects hold relatively well to predict properties of micro-objects.

Figure 2 shows a micro-slider. This is a mechanism to guide linear micro-motion. The smallest slider we fabricated measures 187 μm wide, 400 μm long, and 450 μm high. Two V-shaped prisms are lying on the bottom surface of the slider, and two fitting V-shaped grooves are on the guide. Since the surface of these V-shapes are anisotropically etched and formed by silicon (111) crystal plane, they have a very high accuracy.

We are also researching the friction between micro-slider and guideways, and the measurement of motion accuracy.

To measure the displacements of micro-slider during motion, we are studying on the computer analysis of microscopic vision with high speed video camera using a geometric model. We have also studied on driving micro-sliders using a mechanism that consist of piezoelectric elements and electromagnets shown in Figure 3.

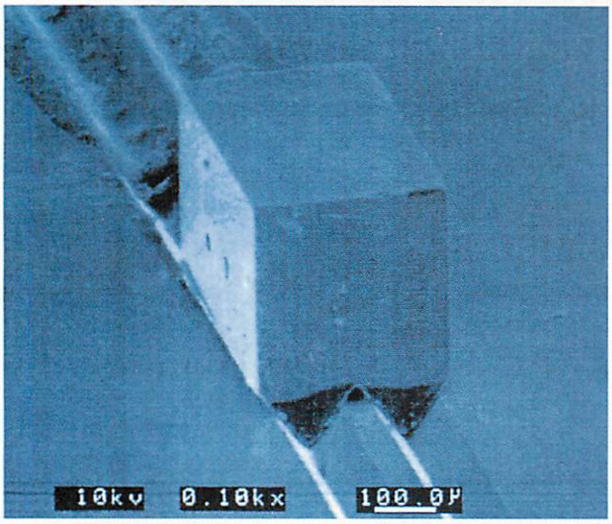


Fig. 2 Example of micro-slider

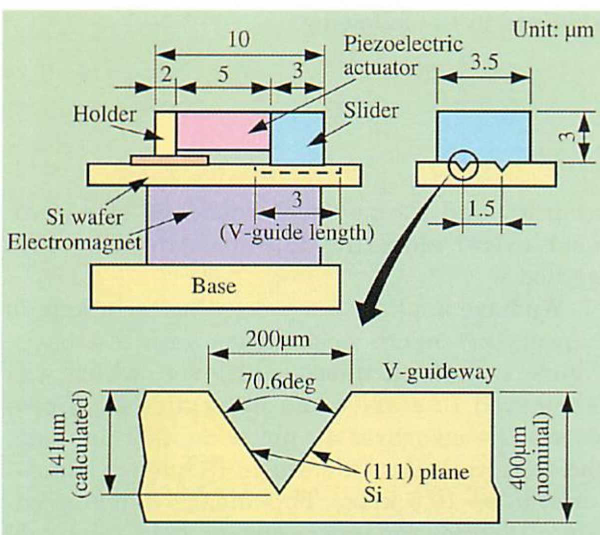


Fig. 3 Linear motion microsystem

2. Micromachining by reactive ion etching

Reactive ion etching is a dry etching process in which combined physical and chemical effects of ions and radicals contained in plasma of reaction gas are used for etching. Our laboratory staff are investigating the process of formation of three-dimensional geometries and clarifying the role of ions and radicals in the process.

3. Creation of ultra smooth surface by molecular beam epitaxy

Molecular beam epitaxy is a technique of growing single crystals in which flux of molecules or clusters (aggregate of molecules) sublimed in ultra-high vacuum environment (at 10^{-8} Pa or lower) are made to deposit on a heated substrate, giving rise to crystal growth following to the crystallographic axis of the substrate.

With the molecular beam epitaxy process, it is expected to form smooth surfaces with atomic order roughness. However, the exact mechanism of the process is unknown. Our laboratory staff are investigating the process mechanism of molecular beam epitaxy, and trying to create smooth free surface through theoretical analysis and experimental verification.

Figure 4 is an atomic force microscopic view of the processed surface of silicon crystals grown on a silicon substrate. It shows that large steps may be created on specific conditions. Extending our present theme of growing silicon crystals on a silicon substrate, we are going to apply this technique to SiC and other materials crystal growth.

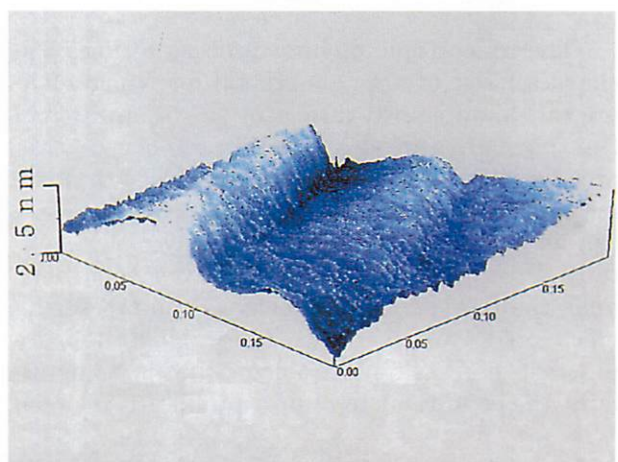


Fig. 4 AFM view of MBE processed surface

In other departments of Tokyo Metropolitan University, more researches related to micromachines, for example, plating process to form multilayer structure of minute geometries, and analysis and experiments of opto-microengines, are conducted. Project research over the fence of departments is now in progress.

Activities of the Micromachine Center in Fiscal 1996

1. Fundamental Policy

Micromachines are composed of functional elements only a few millimeters in size and are capable of performing complex microscopic tasks. The Micromachine Center (MMC) conducts various activities to establish basic micromachine technologies and spread micromachine technology throughout society. It strives to contribute to both development of domestic industry and international community through investigation and research, collecting and providing information on micromachines, and fostering exchanges and cooperation with related organizations in Japan and abroad In fiscal 1996, MMC will conduct the following activities actively disseminating information from Japan as the fundamental policy.

2. Main Activities

2.1 Investigations and Research on Micromachines

The Industrial Science and Technology Frontier Program of MITI's Agency of Industrial Science and Technology (AIST) has entered the first year of its second term. To achieve the goal of the basic plan for the R&D (Phase II), the R&D system will be further improved and research delegated to MMC will be actively promoted. Also MMC will exchange technical information with researchers in various countries and provide results of investigations and research for those concerned in and outside of Japan.

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

Based on the R&D results on fundamental device technology in the first phase, the ultimate purpose of this project is to establish technologies applicable to the realization of micromachine systems. These systems are mechanical systems composed of small functional elements that locomote within very narrow spaces in complicated equipment used at power plants and other facilities and inside of the human body. They can also perform intricate work autonomously, and produce small industrial products as a microfactory.

In fiscal 1996, MMC will conduct the following R&D activities.

[Development of advanced function maintenance technology for power plants]

(a) R&D of systematization technology (in-pipe self-propelled environment recognition system)

R&D of systematization technology will be conducted through production of an experimental system for a wireless micromachine. Inside a metal pipe with a curved section, this micromachine will be able to move forward, backward, horizontally and vertically, stop optionally, and recognize its surroundings as well as detect defects of pipelines.

R&D topics are: realization of an experimental system for an in-pipe self-propelling environment recognition system through developing a mobile device and a microwave energy-supply/communication device as the main technology; systematization of a microvisual system to detect defects and transmit this image with low power consumption, and an optical energy transmission system for energy-supply and communication using light.

(b) R&D of systematization technology (external inspection system for fine multiple pipes)

Systematization technology will be developed through production of an experimental micromachine system composed of a group of single machines capable of combining or separating according to the form of the object to be inspected.

R&D topics are: creation of an experimental external inspection system for complex pipes through developing a driving device to propel the machine; systematization of reduction and traveling devices that convert the power of a driving device into movement and a microconnector for combining multiple machines.

(c) R&D on systematization technology (working system inside the equipment)

R&D on systematization technology will be conducted by producing an experimental micromachine system capable of entering the equipment of various structures and performing measurements or repairs of minute internal flaws.

R&D topics are: creation of an experimental working system inside the equipment through developing a multi-degrees of freedom flexible pipe structure as the main device or a manipulator for repair; and systematization of a position detection device composed of small gyros and a monitoring device using an optical scanner.

(d) R&D technology to improve functional devices

R&D will be conducted to promote micronization, high performance, and multi-functionalization of functional devices that form the components necessary to realize future micromachine systems and highly advanced micromachine technology.

R&D will focus on creating the following: an artificial muscle consisting of an actuator with large displacement and output power used for driving and working; a micro-joint capable of delivering signals and energy by combining devices with different interfaces; an extremely low-friction suspension device such as magnetic bearings to reduce friction in microdriving parts; a rechargeable microbattery used as an emergency constant-voltage source when energy is not supplied externally; and an optically driven free joint device driven by power generated by photoelectric transfer of a laser that precisely positions work tools.

(d) R&D of common basic technologies

R&D will be conducted on common basic technologies such as technologies for control, measurement, design, and evaluation necessary for realizing micromachine systems. R&D will center on achieving: pattern forming technology for a group of distributed micromachines in which a number of machines form a pattern suitable for work and at the same time conduct inspections; hierarchical group control technology for realizing a ultra-multidegrees of freedom holonic mechanism to move in a narrow and complicated environment; measuring technology for micromachines that measures minute shapes or dynamic behavior of micromachines and the minute power or torque of actuators; and measurement technology by micromachines that conducts micro optical analysis to detect defects inside a pipe.

(f) Comprehensive investigation and research

Comprehensive investigation and research on micromachine technology will be promoted including investigation and research to conduct the basic design of maintenance micromachines necessary for maintaining future power plants, and leading investigations and research on micromachine systems expected to be used for maintenance.

With the Mechanical Engineering Laboratory of AIST, MMC will also conduct joint research to analyze microdevice characteristics.

[Development of microfactory technology]

(a) R&D of microprocessing and microassembling technology

R&D will be conducted on systematization technology by producing an experimental system for microprocessing and microassembling capable of manufacturing models of small parts by integrating processing, assembly, conveyance, and inspection machines in a limited narrow space. R&D topics include: microprocessing technology, microassembling technology, microfluid technology, micro optical driving technology, micro electric driving technology, microconveyance technology, and microinspection technology.

(b) Comprehensive investigation and research

Comprehensive investigation and research on micromachine technology will be promoted including: investigation and research on the influence of microfactories including problems such as electromagnetic interference caused when various devices are integrated or concentrated in a narrow space; leading investigation and research on micromachine systems that will be applied in the production field.

MMC will investigate: the downsizing of production systems with microfactory technology that achieves considerable energy, space, and resource savings by microsizing industrial products; analyze economic efficiency of microfactories. MMC will also conduct joint research with the Mechanical Engineering Laboratory of AIST to form a concept for a future microfactory system.

[Intraluminal diagnostic and therapeutic system]

(a) Research on micromachine systems

In the medical field, R&D involving the micro-miniaturization and multi-functionalization of micro laser catheters and micro tactile sensor catheters will be conducted. These catheters are the major functional components of a microcatheter for diagnosis and treatment of cerebral blood vessels, an intraluminal diagnostic and therapeutic system.

(b) Comprehensive investigation and research

Comprehensive investigations and research will be conducted on effectively using micromachine systems for future medical applications.

(2) R&D of micromachine materials

The following R&D will be conducted on micromachine materials jointly with the Mechanical Engineering Laboratory of AIST.

a) Operating environments for micro functional elements;
b) Micromachine materials;
c) Feasibility studies on micromachine materials.

(3) Research on basic design and manufacturing technologies for micromachines

The following joint research will be conducted with the AIST's Mechanical Engineering Laboratory on basic design and manufacturing technologies for micromachines.

a) Basic processing technology;
b) Transforming mechanisms into devices;
c) Microassembly.

(4) Investigation and research on fundamental micromachine technology

To contribute to the promotion of micromachines and the dissemination of micromachines information, basic technology for the systematization necessary to construct various micromachine systems and promising technology in other fields will be explored and verified. This technology will be promoted jointly in the industrial and academic circles, and improvement of basic micromachine technology will also be undertaken. The following investigations and research will be conducted this fiscal year.

a) Exploration of promising technology in basic systematization technology;
b) Exploration of promising technology in other fields.

(5) Investigation and research on effects of the introduction of micromachine technology on industry and society

R&D of micromachine technology to realize highly functional mechanical systems composed of minute functional elements has steadily produced results. These achievements have already been partially incorporated in products, and are displaying their practical effects on society. To contribute to the effective establishment, dissemination and promotion of the technology in various fields, the changes in industrial structure in the 21st century and effects of the technology on industrial economy and social life need to be clarified and guidelines for R&D micromachine technology require establishment. At the same time, the foundation for introducing micromachine technology will be prepared.

a) Investigation on effects of micromachine technology on the industrial and social structures;
b) Investigation on societal changes caused by micromachines.

(6) Study on applications of micromachine technology

Micromachine technology will be further developed by seeking additional R&D projects and applications of new-generation micromachine technology in new fields. Furthermore, technology under development and new-generation technology will be systematized and needs for the technologies according to application in Japan and overseas will be identified.

a) Investigation and research to examine technical feasibility of new applications for agriculture;

b) Investigation and research on new micromachine applications related to the global environment and urban life;
c) Overseas survey and workshop.

(7) Compilation and maintenance of micromachine data base

A data base on micromachines will be investigated, constructed, and maintained as follows, and the results will be compiled in an annual report and used for R&D activities.

(a) A R&D map will indicate the results of questionnaire surveys on micromachine researchers in and outside Japan concerning their research activities, papers, and plans; surveys on results presentation trends at research meetings, surveys on related research projects will be classified by technical item.
(b) A map indicating application examples or use of micromachine technology in Japanese and overseas companies will be made by collecting micromachine-related questionnaires, patents, technical magazines, and newspapers. These will be examined, then classified by application field as well as by technical item.
(c) A map that will classify technical information obtained from technical documents and results of MMC's research activities will be created.

2.2 Collection and Provision of Micromachine Information

Information and documents on micromachines in universities, industry, and public organizations in Japan and overseas will be collected, combined with survey results and documents produced by MMC, and made freely available in the MMC reference room.

a) Publication of a micromachine information magazine;
b) Completion and improvement of the reference room;
c) Effective use of Internet WWW home page.

2.3 Exchange and Cooperation with Worldwide Organizations Involved with Micromachines

To promote affiliation, exchange, and cooperation with related organizations with common interests, MMC will make research grants as part of joint projects with government, industry and academic organizations. It will also invite or send researchers and scholars for exchanges with related organizations in and outside Japan, participate in the micromachine summit, and sponsor international symposia and seminars.

(1) Aid for R&D of micromachine technology

To smoothly and efficiently promote micromachine technology R&D, MMC will aid universities in their fundamental research as part of its promotion of joint research with government, industry and academia.

(2) Exchange of micromachine technology researchers

To promote exchanges, authorities will be invited from the United States, Europe, and Australia, and Japanese authorities and researchers will be sent abroad.

(3) Dispatch of researchers to overseas countries

Researchers will be sent to Europe and the United States to exchange information and promote international cooperation. In addition, MMC will participate in international symposia and academic meetings to be held in the overseas.

(4) Participation in a Micromachine Summit and bilateral technical exchange

MMC will participate in the 2nd Micromachines Summit attended by the United States, Europe, Australia and Japan to discuss a wide range of tasks on micromachines. Also opportunities for bilateral technical exchanges will be provided to allow discussion on technical and other matters on micromachines.

(5) Sponsorship of symposia on micromachine technology

To establish and disseminate micromachine technology, symposia will be held and applications of R&D results of micromachine technology overseas and measures to promote this technology will be presented. The 2nd International Micromachine Symposium will be held. Moreover, to promote exchange with Asian countries, forums focusing on technical exchange will be opened.

(6) Micromachine seminars

Seminars will be held overseas to supplement exchanges of specialists and to widely disseminate results of R&D in Japan to countries keenly interested in developing micromachine technology.

2.4 Standardization of Micromachines

To further the standardization planned in the previous year:

(a) Related technical terms will be systematized and compiled into a collection of technical terminology.
(b) Standardization will be promoted through individual detailed surveys of the instrumentation/evaluation method.
(c) Furthermore, to establish international standards at an early stage, cooperation with overseas standardization activities will be strengthened.

2.5 Dissemination of and Education about Micromachines

Dissemination of and education about micromachines will be promoted by publishing and distributing public relations magazines and sponsoring seminars and exhibitions.

(a) As public relations organs, ***MICROMACHINE*** (a magazine in Japanese and English) and newsletters will be periodically published and distributed, and an Internet WWW home page will be effectively used.
(b) Through micromachine drawings contests, publishing information magazines, and producing videos, dissemination of and education about micromachines will be promoted. Also, by sponsoring evening seminars and local seminars, exchanges among government, industry and academia will be promoted.
(c) The 7th Micromachine Exhibition will be held and preparations for the next exhibition will be made.
(d) As the Federation of Micromachine Technology secretariat, MMC will strive for cooperation among organizations related to micromachines and work to reinforce this cooperation.

Subjects for the 3rd Micromachine Technology Research Grant Determined

Subjects for the 3rd (1995) Micromachine Technology Research Grant were determined by MMC's Board of Directors in March. We received many applications again this year. After careful consideration, seven new projects and five projects carried over for the second year, as shown in the table below, were selected to receive grants totalling ¥18 million. This research grant system started in 1993 as an independent activity of MMC intending to assist university researchers engaged in basic researches related to micromachines, contribute to further progress of micromachine technology, and promote cultural exchanges between industrial and academic circles.

On March 22, the ceremony of presenting the research grant was held at Tokai University Alumni Association Hall, Kasumigaseki Building, Tokyo. In the ceremony, Mr. Kanji Yonemoto, Vice-Chairman of MMC and Mr. Tatsuo Fujino, Director of Industrial Machinery Division, MITI, gave speeches, and Professor Hirofumi Miura, Industry-Academia Joint Research Committee of MMC, reported the selection results. Lists of grant were presented to the twelve recipients of the grant by Mr. Yonemoto. Professor Koji Ikuta gave a speech representing the recipients, then seven researchers in charge of the seven new projects presented the outline of their research plans. After the ceremony, a celebration party was held.

The research grant program will be continued in fiscal 1996. The next invitation will be from July to October this year.

New Research Projects Granted for Fiscal 1995

Leader & Co-Worker	Positions	Subjects	Period
Naoe Hosoda	Research Associate Research Center for Advanced Science and Technology, The University of Tokyo	Reversible micro bonding	2 Years
Koji Ikuta	Professor School of Engineering, Nagoya University	Micro integrated fluid system using micro photoforming process	2 Years
Haruma Kawaguchi	Professor Faculty of Science and Engineering, Keio University	Development of functions in polymer microsphere having on-off function	2 Years
Susumu Sugiyama	Professor Faculty of Science and Engineering, Ritsumeikan University	Distributed microactuator using high aspect X-ray lithography	2 Years
Kaoru Torii Koichi Nishino	Professor Associate Professor Faculty of Engineering, Yokohama National University	Development of three-dimensional measurement technology for micro flow	2 Years
Takeshi Nakata	Professor Faculty of Engineering, Tokyo Denki University	Optical microactuator using ER fluid	2 Years
Takao Aoyagi	Lecturer Institute of Biomedical Engineering, Tokyo Women's Medical College	Basic research on target orientation control of medicine delivery micromachines	1 Year

Carried-Over Projects Granted for Fiscal 1994

Leader & Co-Worker	Positions	Subjects	Period
Kunihiro Ichimura	Professor Research Laboratory of Resources Utilization, Tokyo Institute of Technology	Molecule-assisted molecular system driven by external stimuli	2nd Year
Takashi Yasuda	Research Associate Faculty of Engineering, The University of Tokyo	Microrobot control using reflex actions of insect	2nd Year
Hiroyuki Matsuura Iwao Fujimasa	Research Associate Professor Research Center for Advanced Science and Technology, The University of Tokyo	Physical quality of the artificial muscle in micro and sub-micro region	2nd Year
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	2nd Year
Makoto Ishida	Associate 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	2nd Year

2nd Micromachine Drawing Contest Award Ceremony Held

With the objective of promoting better understanding of micromachines in society, as well as to pick up novel ideas from the people in various fields as reference for research and development, the Micromachine Drawing Contest invited participants from primary schools and junior high schools for the second time. The winning drawings for the first contest were used in many ways to successfully advertise activities of the Micromachine Center.

With the cooperation of supporting member companies of MMC, pupils of primary schools and junior high schools of Tsukuba City (Ibaraki Prefecture), Kariya City (Aichi Prefecture), and Kita-kyushu City (Fukuoka Prefecture) have been invited to turn in their drawings for the second contest.

Drawings outnumbered those submitted in the previous contest. From among these, 26 works received prizes after passing the preliminary jury. The number of works turned in and a list of entry schools is shown below.

Number of applications

Primary schools	470
Junior high schools	903
Total	1,373

Entry schools

Category of primary school
- Namiki Primary School (Tsukuba City)
- Ogakie-higashi Primary School (Kariya city)
- Kameshiro Primary School (Kariya city)
- Karigane Primary School (Kariya city)
- Kinuura Primary School (Kariya city)
- Kodakahara Primary School (Kariya city)
- Sumiyoshi Primary School (Kariya city)
- Fujimatsu-higashi Primary School (Kariya city)
- Fujimatsu-minami Primary School (Kariya city)
- Futaba Primary School* (Kariya city)
- Kumanishi Primary School* (Kita-kyushu City)

Category of junior high school
- Takezono-higashi Junior High School (Tsukuba City)
- Asahi Junior High School (Kariya City)
- Isami Junior High School (Kariya City)
- Kariya-higashi Junior High School (Kariya City)
- Kariya-minami Junior High School (Kariya City)
- Karigane Junior High School (Kariya City)
- Fujimatsu Junior High School* (Kariya City)
- Hikino Junior High School* (Kita-Kyushu City)

[*: School prize awarded]

The winners received their prizes on March 28 at the Tokai University Alumni Association Hall, which is located on the 33rd floor of Kasumigaseki Building, Chiyoda-ku, Tokyo. About forty people attended, including the winners, judges and guests.

To open the meeting, Mr. Masayuki Kondo, Director for Machining and Aerospace R&D, at the Agency of Industrial Science and Technology, MITI, made a guest speech for the children. In the speech, he stressed the importance of having future dreams, of fabricating and using real things, and of discussing democratically to avoid false use of things.

Commemorative photo of award winners

After the speech, Prof. Hirofumi Miura, a professor at the Faculty of Engineering of The University of Tokyo and the chief judge in the contest, explained the process of judgment and commented on some of the drawings in plain language.

Prof. Miura continued, "Because so many drawings were collected this year the judges had a hard time. The winners should be proud of their works since they have been selected from so many good works. Many people are studying micromachines, and there are sure to be helpful micromachines in the future; only we do not know now what they will be like. In my laboratory we are trying to fabricate something special modeled after insects. You are requested to contribute ideas for how to use micromachines, like what sort of machines fit what purposes."

After the award-winning drawings were shown and explained, certificates of commendation and prizes were handed to the winners including Saiko Sugiura, the best entry winner in the category of primary school who is a fifth grader at Fujimatsu-minami Primary School, and Eri Nomura, the best entry winner in the category of junior high school who is a second grader at Kariya-minami Junior High School. School prizes went to four primary and junior high schools that submitted the most applications.

Finally, the two best entry winners expressed pleasure at winning and told about their hopes and expectations on micromachines.

Having primary and junior high school boys and girls in the spotlight, the ceremony proceeded in a friendly atmosphere, but the tone was somewhat different from the usual MMC meetings. Grownup guests made speeches as if they were talking to their own children and grandchildren, fully understanding the importance of enlightening and spreading knowledge among the coming generation.

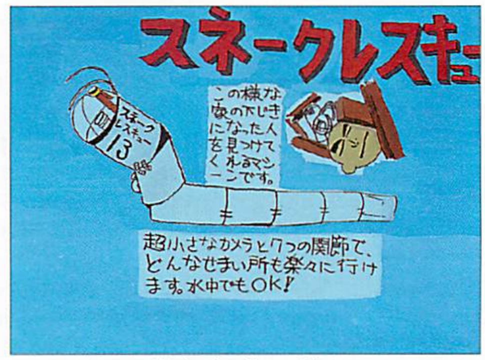
Winners of the Second Micr

Category of Primary School

Best Entry:
Corner cleaner tooth pick machine

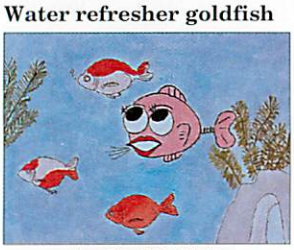
Saiko Sugiura
Fujimatsu-minami Primary School (5th grade)

First Prize:
Snake rescuer



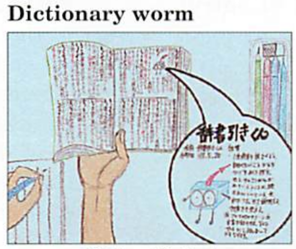
Keisuke Suzuki
Sumiyoshi Primary School (6th grade)

Second Prize:
Water refresher goldfish



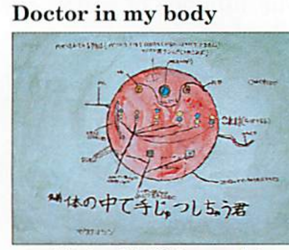
Ayako Nishida
Namiki Primary School (6th grade)

Second Prize:
Dictionary worm



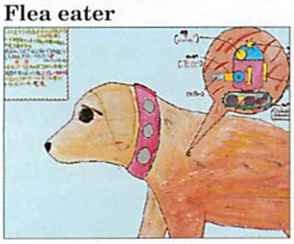
Chisa Kokai
Namiki Primary School (6th grade)

Third Prize:
Doctor in my body



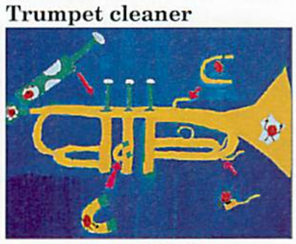
Natsuki Kobayashi
Namiki Primary School (5th grade)

Third Prize:
Flea eater



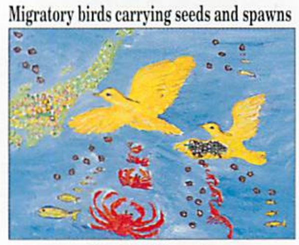
Minoru Niwa
Futaba Primary School (6th grade)

Third Prize:
Trumpet cleaner



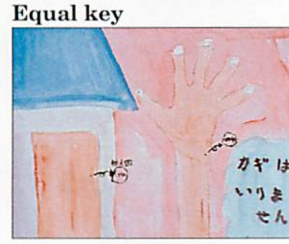
Runa Moriya
Kinuura Primary School (6th grade)

Good Idea Mention:
Migratory birds carrying seeds and spawns



Yuki Kondo
Kameshiro Primary School (5th grade)

Good Idea Mention:
Equal key

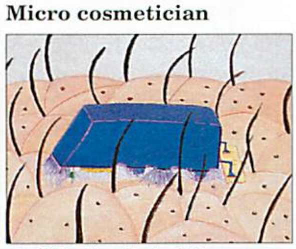


Eri Uramoto
Kumanishi Primary School (6th grade)

Honorable Mention:
Micro mender

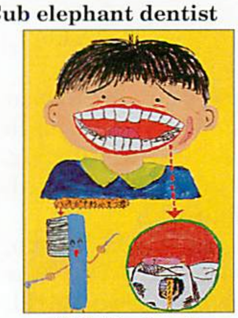
Satoshi Iida
Namiki Primary School (5th grade)

Honorable Mention:
Micro cosmetician



Kimiyo Sakakiyama
Kinuura Primary School (6th grade)

Honorable Mention:
Cub elephant dentist



Akie Sugimoto
Kinuura Primary School (6th grade)

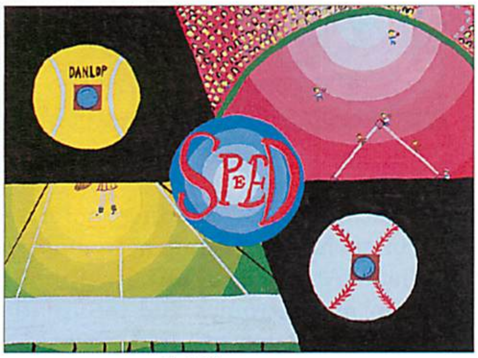
Honorable Mention:
Mr. Mosquito-repeller

Maiko Ino
Kinuura Primary School (6th grade)

machine Drawing Contest

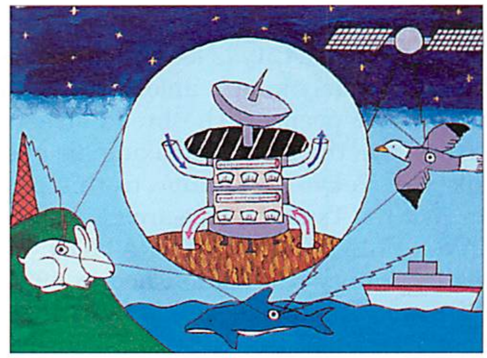
Category of Junior High School

Best Entry:
I became a ball!



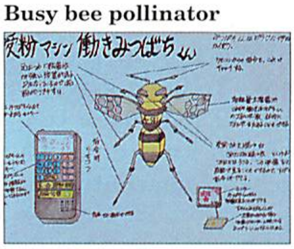
Eri Nomura
Kariya-minami Junior High School (2nd grade)

First Prize:
Eco-monitor



Kanako Morita
Takezono-higashi Junior High School (2nd grade)

Second Prize:
Busy bee pollinator

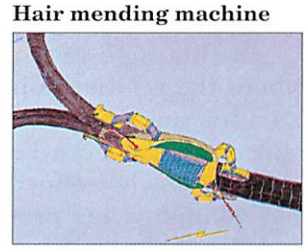


Kanako Ito
Fujimatsu Junior High School (2nd grade)

Second Prize:
Micro-cleaner for machines

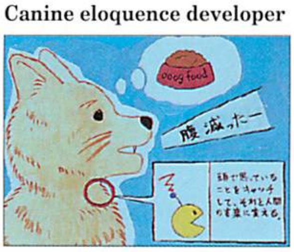
Natsuki Kato
Kariya-minami Junior High School (2nd grade)

Third Prize:
Hair mending machine



Hiroaki Terasawa
Takezono-higashi Junior High School (2nd grade)

Third Prize:
Canine eloquence developer



Akiko Isomura
Karigane Junior High School (3rd grade)

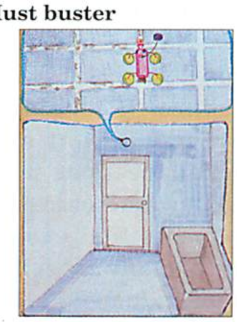
Third Prize:
Ultrasonic pest killer

Yuji Inoue
Kariya-minami Junior High School (3rd grade)

Good Idea Mention:
Micro-doctor for insect patient

Tsukasa Murase
Kariya-minami Junior High School (3rd grade)

Honorable Mention:
Must buster



Chikage Yokoyama
Fujimatsu Junior High School (1st grade)

Honorable Mention:
Mosquito fighter

Hideo Miura
Fujimatsu Junior High School (1st grade)

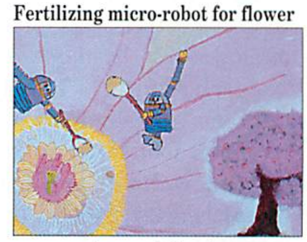
Honorable Mention:
Lost property retriever

Sachiko Suzuki
Fujimatsu Junior High School (3rd grade)

Honorable Mention:
Honey-collecting hummingbird robot

Sachie Ina
Takezono-higashi Junior High School (2nd grade)

Honorable Mention:
Fertilizing micro-robot for flower



Ayumi Ikeda
Hikino Junior High School (1st grade)

YASKAWA ELECTRIC CORPORATION

1. Introduction

Tsukuba Science City is located at the base of Mt. Tsukuba, widely known among the Japanese in many classic poems. The broad streets and green trees give the town a relaxing air one cannot expect in Tokyo. We came to this peaceful town to visit the Tsukuba Research Laboratory of YASKAWA ELECTRIC CORPORATION.

This laboratory was established in 1991 as a branch organization of the Basic Research Center of Yaskawa Electric in Kita-kyushu City, to research possible technology foundations for future business of the company.

Aiming to extend the scope of activities, the company participates in the Tsukuba Research Consortium that comprises enterprises across a wide spectrum of industries, playing a cardinal role in promoting cross-over technical innovation.

In this high-tech age of the global village where the relationship between technology and humans and the environment is increasingly important, Yaskawa Electric believes that "technology must be refined and friendly to people". The company has proposed a slogan, "Quality and Beauty". On the policy, "Quality" is meant maintaining technological quality and reliability, and "Beauty" is meant the interface and relation between technology and our species, the company is striving to contribute to development of industries and the facilitation of people's living standard.

Since its establishment in 1915, Yaskawa Electric has sent electromagnetic motors and their applications to the world. Products range from mechatronics facilities to system electric appliances and even heavy electric equipment. The company is well known for starting production of industrial robots in 1970 as a pioneer in the field, and it coin the word "mechatronics."

2. R&D Themes

Research and development activities of Yaskawa Electric is primarily carried out in the development division of plants and in the Basic Research Center. Two hundred and eighty staff members are engaged in the center. In the Basic Research Center, the researche items are medical and welfare applications, remote-controlled virtual reality robots, and ultimate environment mechatronics for high-vacuum environments. In order to realize these advanced applications, fundamental technologies including motor technology, control technology, and new materials are also studied. At the Tsukuba Research Laboratory, human mechatronics and information communication have been studied as a part of the quest and research in mechatronics technologies. Researches on Intelligent Manufacturing System (IMS) and Micromachine Technology are also carried out, which are national projects.

3. Study on Micromachine Technology

The idea of a microfactory system is to "make small products with small machines," thereby conserving energy and space. To build a system with micromachines requires microactuator technology. The Tsukuba Research Laboratory has studied and developed such "neomechatronics" technologies.

Micro electric devices have been studied under sub-contract to the Micromachine Center. In this theme, special efforts are being made in R&D of rotary microactuators. There are electrostatic and electromagnetic types of rotary actuators. It had been accepted that, to decrease the device size, the force produced by the electrostatic type becomes relatively greater than that by the electromagnetic type. But at exactly what point the electrostatic surpasses the electromagnetic has remained unknown, in part because there have been no microtorque measurement instruments.

Until now, fundamental technologies were studied to increase output torque of both actuators. The improvement efforts were successful to realize their torque-size relation by experiment and analysis. The microtorque measurement instrument was specially developed which has a resolution of 10^{-8} Nm. These results are used to determine which type of microactuators should be used for a given application. The laboratory is now working to enhance performance of microactuators and improve the elegance of their motion.

We are impressed that micromachine fundamental technologies are progressing step by step towards system integration.

Yokogawa Electric Corporation

1. Introduction

Yokogawa Electric Corporation was established in 1915 in Tokyo as a research institute for electric instruments. Since then, the company has extended its operations to include the measurement, control, and information technology fields and it remains a leading manufacturer in the field. Monitoring the status of a constantly varying system to control it using the monitor information, and to send out that information to other systems over a network is a basic and indispensable technology for society and industries. Based on this technology, Yokogawa Electric is extending into new fields such as system solutions that offer optimum solutions to customers, highly reliable tests & measurements, and components through which the high technology of the company is provided to the market.

2. R&D Organizations

These technologies were created by the research and development divisions of the company that have always worked at the cutting edge of the times. The results have been highly successful. At present, the Central Research Institute runs four laboratories and one development center: the Electronics Laboratory, Optoelectronics Laboratory, Sensors Laboratory, Information System Laboratory, and Communication Equipment Development Center. The organizations are carrying out advanced long-term research as we near the 21st century.

The Micromachine Group is held under the Sensors Laboratory. True to its name, the group is engaged in research and development of high acurate, highly integrated sensors and actuators using micromachine technologies. For intensive and efficient R&D, the group was located at Inadani, in central Nagano Prefecture, in the spring of 1993. Facing the Southern Japan Alps and backed by famous Mt. Komagatake and other mountains of the Central Japan Alps, the group enjoys beautiful scenery.

3. Study on Micromachine Technology

Yokogawa Electric's first micromachining technology was the creation of semiconductor differential pressure sensors. The differential pressure sensor is an important component for measurement and control in the process industry. It is commonly used for measurement of flow, level, and density of fluid. As the process industry has grown more sophisticated, requiring higher precision in recent years, sensors of greater precision and durability are needed. Under the circumstances, the form of the differential pressure sensor has changed from the initial dynamic balance type with a metal diaphragm, to a differential capacitive type, to using a piezo-electric resistor or capacitive sensor on a silicon crystal diaphragm.

In 1984, the company began studying monolithic construction of a unique differential pressure sensor using micromachining technologies. The sensor consists of a resonator in which the frequency varies with applied pressure, and a micro vacuum chamber where the resonator is housed. In 1986 they succeeded in fabricating miniature resonator on diaphragms, with excellent reproducibility and stability. Sensors manufactured by this process were used as the key device of a differential pressure transmitter that debuted in the market as "DPharp." It was the first application of a 3-dimensional micromachining sensor to industrial process applications. The high precision and high characteristic stability of the sensor outdid conventional products and was awarded the Ohkhochi Memorial Prize in 1995.

Yokogawa Electric hopes to contribute to the success of MITI's Industrial Science and Technology Frontier Program "Micromachine Technology" by developing its accumulated technologies in various sensors and actuators. The company believes that micromachine technology will drive future product concepts for the better and will reduce costs as well, thereby contributing to the society of the coming century.

Micromachine Technology (IX)

Microsensors

Micromachine technologies, especially silicon process-related technologies enable unification of a sensor with the connecting circuit, along with drastic size reduction of the sensor and significant cost saving by batch processing. At present, sensors are the largest hope of applying micromachine technology. Sensors manufactured by micromachine technology have already been brought to market. This issue reports on the acceleration sensor, angular velocity sensor, pressure sensor, and flow sensor as development examples.

1. Acceleration Sensor

Recently as the safety demands for automobiles increase, more cars have air bags installed. An acceleration sensor is used in the air bag system to detect collision of the car. Photo 1 shows the structure and top view of the acceleration sensor. The cantilever is formed on single-crystalline silicon by anisotropic etching. At the cantilever is placed a strain gage in which resistance varies with deflection of the lever. If acceleration is applied in the direction of the arrow, the weight is displaced, the cantilever deflects, resistance of the gage changes, and the acceleration is detected by the adjacent circuit. The sensor measures 8.3 mm × 3.55 mm.

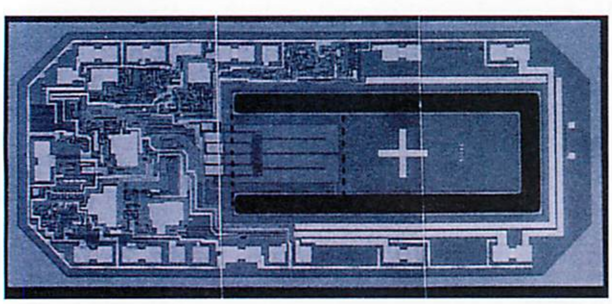


Photo 1 Acceleration Sensor [Nippondenso Co., Ltd.]

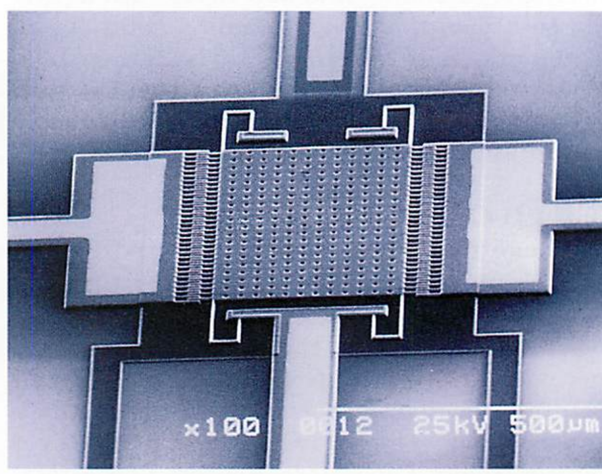


Photo 2 Angular Velocity Sensor [Murata Mfg. Co., Ltd.]

2. Angular Velocity Sensor

An angular velocity sensor measures rotational speed of an object. This sensor is important for offsetting unintentional movement of hand-held video cameras, robot control, and automobile navigation and control. Photo 2 shows an example of an angular velocity sensor that was developed. The principle of detection is as follows. The comb electrodes on the sides of the weight generate static electricity to drive the weight in a direction parallel to the board (in the horizontal direction in this figure). If angular velocity is produced in the vertical direction in the figure, Coriolis force applied to the weight drives the weight perpendicularly to the board. This displacement is detected as a change of capacitance between the weight and the board. This sensor is built by depositing the sacrificial layer and polycrystalline silicon on a silicon substrate after which, part of the sacrificial layer is removed by etching to make the polycrystalline silicon movable. Such processing technology, called surface micromachining technology, enables further size reduction from the processing of single-crystalline silicon used to make the acceleration sensor described above. The sensor structure shown in the figure measures 0.7 mm × 0.7 mm.

3. Pressure Sensor

A pressure sensor typically used for measuring internal pressure of car manifolds has a diaphragm in which deformation is used to measure pressure. Photo 3 shows an example of a strain gage type pressure sensor that was developed. The point of this pressure sensor is the vacuum chamber seen in the cross section. An ordinary pressure sensor measures the difference between the pressures of the spaces partitioned by the diaphragm, which is a relative value. The sensor explained here measures absolute pressures as one side of the diaphragm is a vacuum chamber. The vacuum chamber is created by sealing the central hole in a vacuum after forming the diaphragm by sacrificial layer etching from the hole. The diaphragm measures only 0.1 mm in diameter.

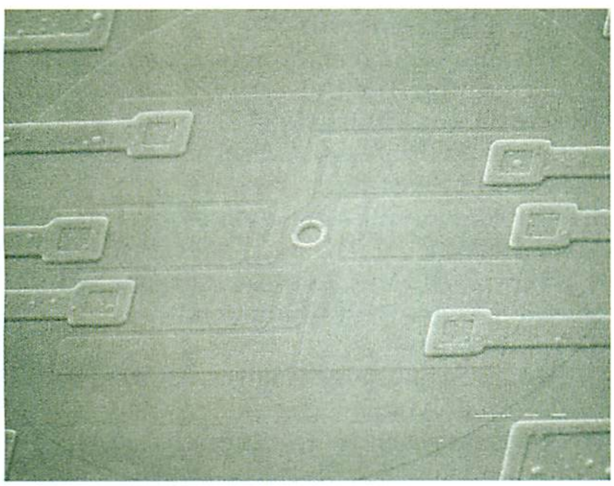


Photo 3 Pressure Sensor [Toyota Central R&D Laboratory, Inc.]

4. Flow Sensor

Since a flow sensor should be as small as possible so as to exert less effect upon the fluid, size reduction by micromachine technology is a great advantage. Photo 4 shows a thermal type flow sensor. The polysilicon bridge structure serves as the heater. As the flow changes, heat transmitted from the heater to the fluid also varies, which is measured. The substrate under the heater is removed by etching to improve thermal isolation which prevents sensitivity deterioration that can be caused by thermal loss if much heat transfers from the heater to the substrate. The heater measures 0.24 mm × 0.09 mm.

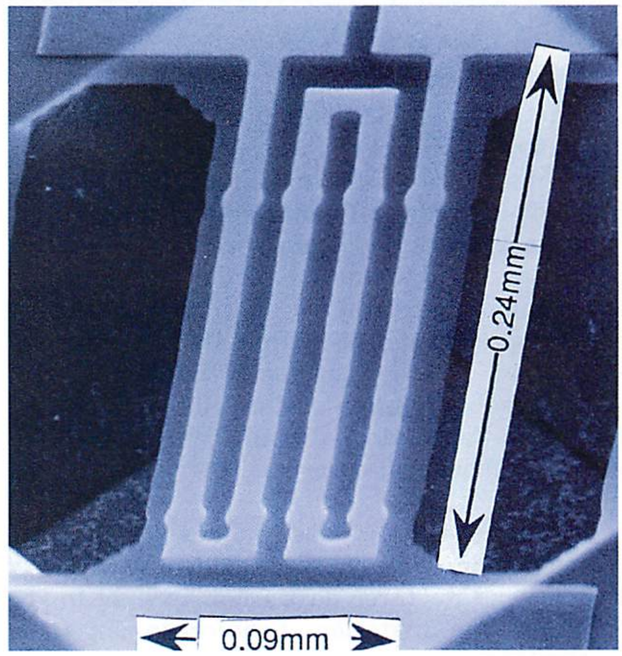


Photo 4 Flow Sensor [Tokyo Gas Co., Ltd.]

5. Future of Microsensors

Various microsensors have been developed by application of micromachine technologies. In the future, these sensors, it is predicted, will be more integrated and unified with actuators. For example, flow sensors and micropumps will be integrated into a flow controller system. Micromachine technologies will become more important for implementing high integration and high functionality.

Participation in the 2nd Micromachine Summit

MMC promotes international exchange activities to advance and disseminate micromachine technology. As part of these activities in March 1995, it sponsored the 1st Micromachine Summit in Kyoto. Twenty-eight leaders from micromachine-related universities, research institutes, and industries from 10 countries including Japan gathered and exchanged opinions on a range of aspects from R&D to commercialization. Another purpose of the meeting was to increase recognition of the value of micromachines in Japan and abroad. With an attendance of about 100 observers, the meeting bore good fruit.

As a result of its success, the 2nd Micromachine Summit was held in Montreux, Switzerland for three days from April 24 to 26, 1996. At the invitation of the organizing committee consisting of representatives from six European countries, the five-member delegation shown below and 13 observers attended the Summit from Japan.

Chief Delegate:
Naomasa Nakajima, Professor, Faculty of Engineering, The University of Tokyo

Delegates:
Toshiro Shimoyama, Chairman, Olympus Optical Co., Ltd.
Tsuneo Ishimaru, President, Nippondenso Co., Ltd.
Sadao Moritomo, Vice-President, Seiko Instruments Inc.
Takayuki Hirano, Executive Director, MMC

Ten countries listed below participated in the 2nd Micromachine Summit.

After the presentation of micromachine-related country reviews by chief delegates from the participating countries, following seven topics were discussed.

(1) Scope of micromachine
(2) Standardization
(3) Research and education
(4) R&D programmes and role of governments
(5) Social & industrial impacts of micromachines
(6) Needs expressed by the industries
(7) Markets

On each topic, two to five Japanese, American, and European specialists designated by the organizing committee gave presentations. The following people were designated as presenters from Japan.

"Scope of Micromachine"
Naomasa Nakajima, Professor, Faculty of Engineering, The University of Tokyo

"Research and Education"
Koji Ikuta, Professor, School of Engineering, Nagoya University

"R&D Programmes and Role of Governments"
Takayuki Hirano, Executive Director, MMC

"Social & Industrial Impacts of Micromachines"
Toshiro Shimoyama, Chairman, Olympus Optical Co., Ltd.

"Needs Expressed by the Industries"
Tsuneo Ishimaru, President, Nippondenso Co., Ltd.

"Markets"
Sadao Moritomo, Vice President, Seiko Instruments Inc.

The details of the Summit will be appeared in the next issue.

The chief delegates of participating countries

Country	Chief Delegate	Institution
Japan	Prof. N. Nakajima	The University of Tokyo
Australia	Prof. I. Bates	Royal Melbourne Institute of Technology
Canada	Prof. G. Guild	President, Micromachine Technology Center Ltd., Simon-Fraser University
France	Prof. D. Hauden	Director, CNRS L'institut des Micro-techniques des Franche-comite (IMFC)
Germany	Prof. W. Menz	Albert-Ludwig University
Italy	Prof. A. D'Amico	Universita di Roma "Tor Vergata"
Netherlands	Prof. J. H. Fluitman	University of Twente
Switzerland	Prof. N. F. de Rooij	University of Neuchâtel
U.K.	Prof. H. Dorey	Chairman, UK Microengineering Common Interest Group, Imperial College
U.S.A.	Prof. R. S. Muller	University of California, Berkeley

Fukuoka and Yamaguchi Micromachine Seminars

For those interested in micromachine technology R&D, evening seminars by authorities on fundamental technologies are held once a month at MMC in Kanda, Tokyo. To further disseminate and promote micromachine technologies, seminars are also held at locations other than Tokyo in cooperation with local organizations.

In January this year, seminars were held in Kita-Kyushu City in Fukuoka Prefecture and Ube City in Yamaguchi Prefecture.

•Fukuoka Micromachine Seminar

Cosponsored by Fukuoka Industrial Technology Center and MMC, this seminar was held at the multipurpose hall in the Kita-Kyushu Technology Center in Kita-Kyushu City on the afternoon of January 11.

Lectures were as follows:

"Regional Activities in Innovative Technologies"
Yoshitaka Tatsue, Director of Fukuoka Industrial Technology Center

"National Policies on Industrial Technologies Research and Development"
Masayuki Kondo, Director for Machining and Aerospace R&D, AIST (Agency of Industrial Science and Technology)

"Activities of MMC"
Takayuki Hirano, Executive Director, MMC

"Outline of Micromachine Technology"
Yuichi Ishikawa, Mechanical Engineering Laboratory, AIST.

In addition, the following research results of the ISTF program were presented.

"Tube-Type Micromanipulators with Multidegrees of Freedom"
Kazuhisa Yanagisawa, Research Department, Olympus Optical Co., Ltd.

"Microgenerators"
Hiromu Narumiya, Advanced Technology R&D Center, Mitsubishi Electric Corp.

"Micro Photovoltaic Devices"
Hiroaki Izu, New Material Laboratory, Sanyo Electric Co., Ltd.

"Micro Inspection Machines"
Koji Idogaki, Research Laboratories, Nippondenso Co., Ltd.

This seminar was attended by approximately 100 people including those engaged in R&D, and manufacturing technologies at companies pursuing micromachine technologies in Fukuoka Prefecture as well as participants from universities and research laboratories. Many participants showed a strong interest in micromachine technologies, and enthusiastic questions and answers were exchanged after the lectures.

Seminar in Fukuoka

•High-Tech Symposium Yamaguchi '95

Sponsored by the Faculty of Engineering, Yamaguchi University and supported by MMC, a two-day micromachine symposium (chairman of executive committee: Katsutoshi Kuribayashi, Professor, Faculty of Engineering, Yamaguchi University) was held on the afternoon of January 12. This seminar focused on the ISTF micromachine technology program, and lectures were presented under the themes of "Policies on Industrial Science and Technology," "Activities of MMC" and "Present Status of Research and Development of Micromachine Technologies." The seminar was held at Tokiwa Kosui Hall overlooking Lake Tokiwa in Ube City, Yamaguchi Prefecture. Many students of Yamaguchi University attended the seminar, and questions and answers were actively exchanged. This seminar detailed the wide range of MMC activities and results of the ISTF program, and emphasized the importance of this type of symposia. Lecturers and their subjects were as follows:

"Direction of Policies on Industrial Science and Technology and Micromachine Technologies"
Masayuki Kondo, Director for Machining and Aerospace R&D, AIST

"Activities of MMC and Technological Promotion by MMC"
Takayuki Hirano, Executive Director, MMC

"Micro Photovoltaic Devices"
Hiroaki Izu, New Material Laboratory, Sanyo Electric Co., Ltd.

"Microgenerators"
Hiromu Narumiya, Advanced Technology R&D Center, Mitsubishi Electric Corp.

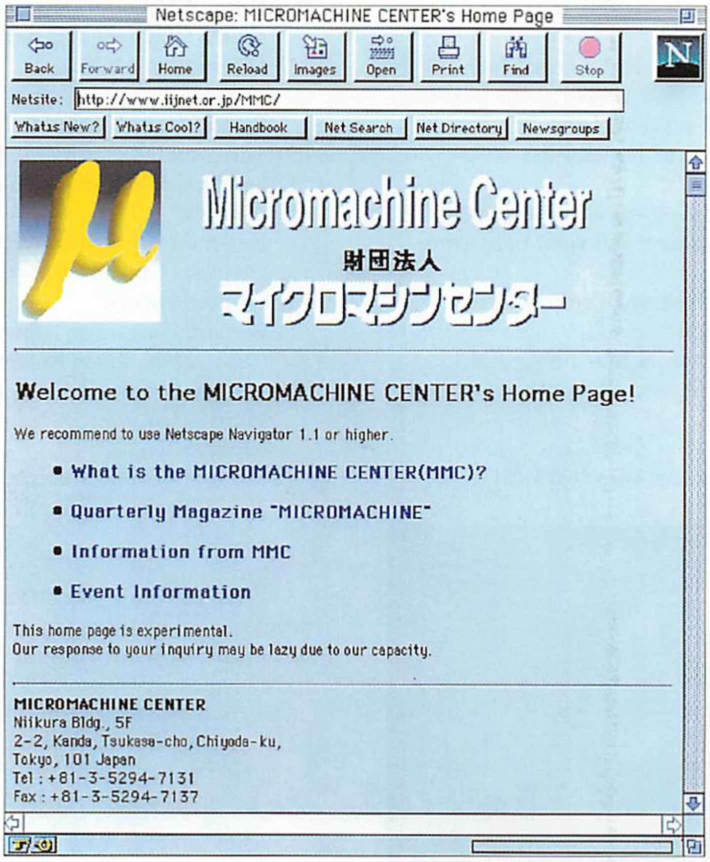
"Tube Type Micromanipulators with Multidegrees of Freedom"
Kazuhisa Yanagisawa, Research Laboratories, Olympus Optical Co., Ltd.

"Micro Inspection Machines"
Koji Idogaki, Project Manager, Nippondenso Co., Ltd.

Visit Our Internet Homepage

Since last October, the Micromachine Center (MMC) has started its homepage on the Internet WWW server to disseminate information overseas. This homepage gives an overview of the Center, introduces our activities, and provides information on events that concern micromachines. Please visit our homepage. The address is given below.

http://www.iijnet.or.jp/MMC/



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