MMC MICROMACHINE

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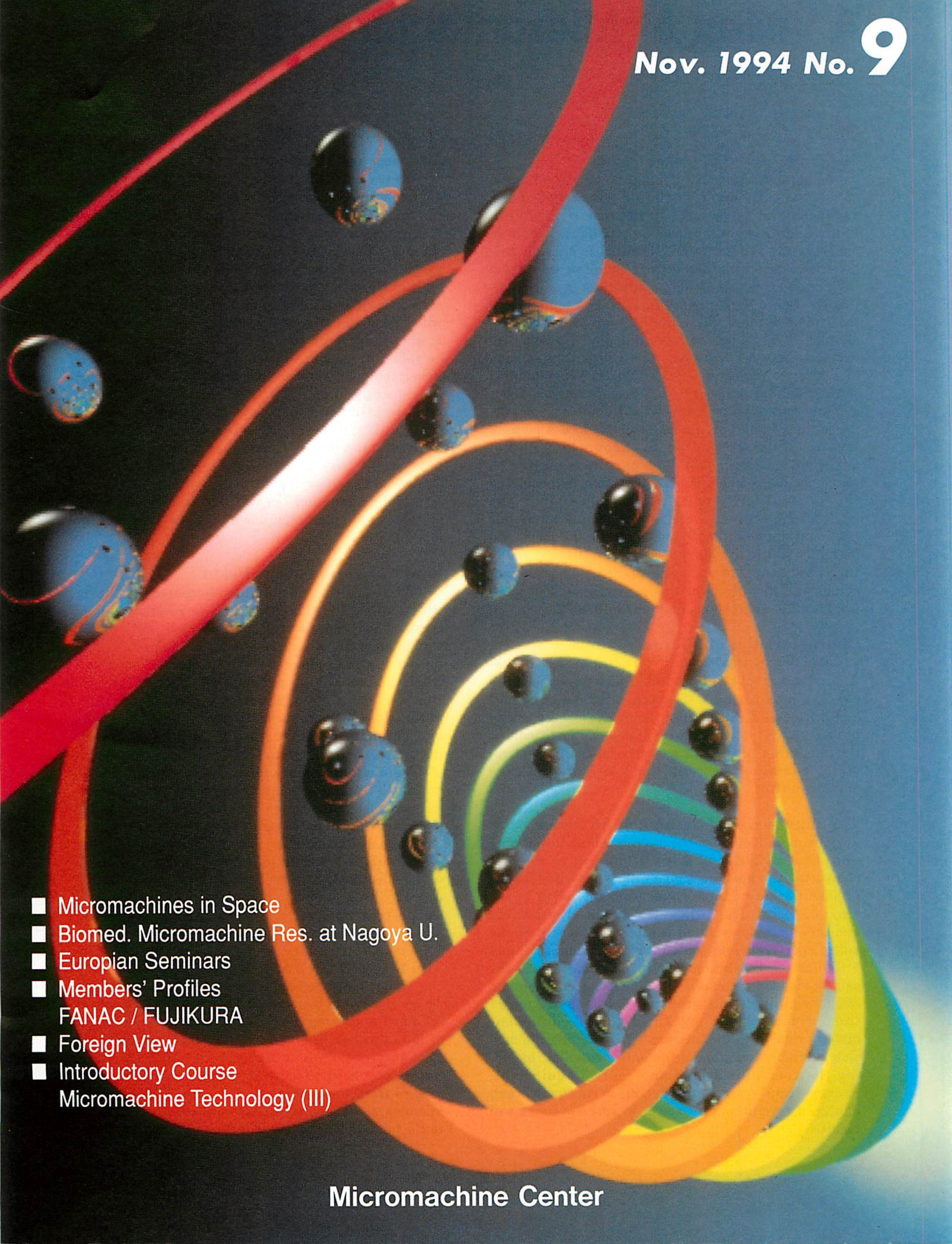


Micromachine Center

A Vision of Micromachines in Space

Kohtaro Matsumoto
National Aerospace Laboratory

The Downsizing of Outer Space

Japan is making steady progress in several major space projects, such as the development of the Japanese first large-scale rocket, the H-II Launch Vehicle, and the Japanese Experimental Module (JEM) of the space station. Parallel to these activities, however, is the miniaturization of space-related research as a result of recent advances in microelectronics. Space R&D miniaturization is a big affair in the United States, where by the year 2000 or thereabouts NASA hopes to have developed a satellite weighing only 5 kilograms. The United States have already put together a 16-kilogram experimental satellite, and a project of exploring Pluto with about 110-kilogram satellite has been initiated.

In this essay I would like to introduce a piece of technology discussed at the Moon and Planet Development Association's subcommittee meeting on Micromachine Utilization in Space, that is considered the ultimate in space R&D downsizing: the Micromachine Rover, a device containing numerous micromachines as a means of exploring the moon and Mars. I will use the Micromachine Rover to exemplify the expectations of space research using micromachines and the effects of this research, as well as to present related problems and possibilities.

Characteristics of Micromachines

The four primary characteristics of the mechatronics and robotics incorporated into micromachines are (1) miniaturization, (2) coordinated use of numerous devices, (3) autonomy (from the use of a tiny brain), and (4) harmony with humans. Additionally, the integration of the four characteristics into a micromachine can itself be considered a significant feature of these devices.

The Lightweight Micromachine Rover

The main feature of the Micromachine Rover is its ultra-light weight, and this will make it as the best choice for the space exploration, where the flights require huge amounts of fuel from the earth to the moon or Mars. The ratio of the weight of measuring and other mission-related equipments to that of the entire spacecraft and contents is a maximum of only 1:150 for the geostationary-orbit mission. Thus, the satellite loaded onto an H-II Launch Vehicle weighing 260 tons at liftoff must itself weigh less than 2 ton; of this, somewhat less one third can be equipment directly related to the mission. If lightening the mission equipment can make the entire satellite (including the communications and control equipment, energy supply, and supporting structure) much lighter, a revolutionary concept of space systems will result.

A Numerous Micromachines

Another important characteristic of the Micromachine Rover is the possibility of using numerous rovers simultaneously because of their small size. The usual way for the space exploration is to entrust the entire mission to one or two large rovers, owing to weight considerations. Double or triple redundancy is built into each of the functions of the rovers, so that in case of malfunctions, the mission can still continue with one of the alternate systems. The use of micromachines, however, should allow numerous rovers to be taken on a space mission. Each Micromachine Rover could, on its own, perform the entire mission; consequently, if one of them should fail, the mission could be taken over and completed by any of the others. Further, if several dozen or even several hundred Micromachine Rovers could be employed on a single mission, the basic philosophy of completion of a mission would change from "all or nothing" to one of "graceful degradation," in which Micromachine Rover systems gradually break down over the course of the mission.

Miniaturization of the Brain

What are the merits of a Micromachine Rover with a miniaturized brain? First, we need to think in terms of two aspects of miniaturization. The miniaturization of the physical elements of the brain is simply one aspect of the miniaturization of the rover as a whole and so has no particular impact of its own. However, the miniaturization of the brain's intellectual functions — of the software that provides control and autonomous functioning — will have a major impact on the rover concept. For example, inclusion of advanced autonomous functionalities in the rover's brain will be indispensable to the completion of a mission when communication between earth and mission equipment is curtailed or lost temporary. Although the possibilities for the realization of the Micromachine Rover have been increased as a result of the effectiveness of the reactive control theory, proposed by Prof. R. Brooks, MIT, the miniaturization of sample-collection, analysis, and other functions necessary to the rover depends on future research.

The Size of Space Micromachines

The original definition of a micromachine was a device that could be measured in centimeters down to millimeters or even microns. Will the lower extreme of miniaturization be possible in space exploration? Probably not. For a Mars probe, Micromachine Rovers will need to move in a radius of at least 100 meters from the landing craft — preferably several kilometers — take rock samples, and carry these back to the lander. The rovers will thus have to have a certain degree of strength and durability, which will place limits on how small they can be made. I would estimate that their dimensions would have to be on the order of 10 centimeters.

NASA's Efforts toward Miniaturization

Here I will introduce the pathfinder Mars Rover, being developed by NASA's JPL. Working on the basis of Brooks' proposal for a lightweight, breakdown-resistant probing rover system that uses multiple miniature insect-shaped rovers, each with a simple function, the JPL has moved away from the concept of a large-scale Mars rover to research on ultrasmall ones. This switch from the "traditional" method of developing highly reliable functions and put them together in a single large probing system is a major shift for NASA and is worth noting. The Mars Environmental Survey (MESUR) mission, scheduled for launching in December 1996, will use a small landing craft and a single small-sized rover based on the Rockey 3/4 rover, weighing 7–9 kilograms and measuring 65 centimeters in length. The rover will be able to probe in an area surrounding the landing craft with a radius of 10–100 meters.

The Mother Micromachine

What is ultimately needed in lunar and planetary development is the elimination of dependence on the earth — that is, resource and energy self-sufficiency on the moon or planet itself. Beyond the ultraminiaturization of development, then, is the possibility of a self-reproductive micromachine system. One such concept, for lunar surface development, has already been proposed.

Self-reproduction of a large, complex space system is probably out of the forecast. However, it would seem that a self-reproduction or localized recycling system for simple-function micromachines with simple brains could be developed, particularly if micromachine manufacture using silicon circuit technology becomes possible. Such micromachines would have to be much smaller than the Micromachine Rovers mentioned previously — about the size of ants or other insects — and a large number of these devices would be required.

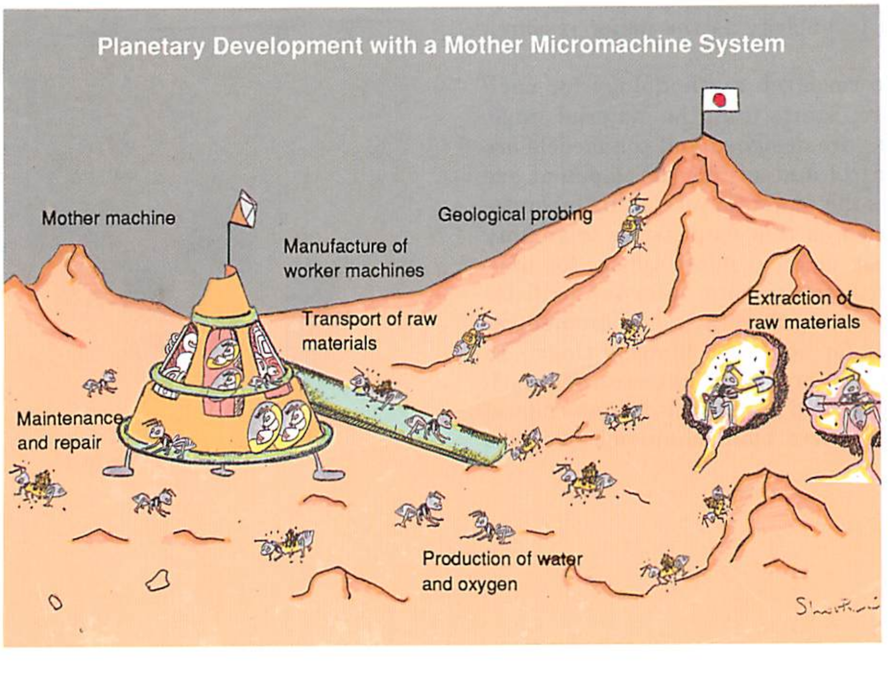
The ultimate step is the "mother machine" concept for the rebuilding of Mars and Venus. The mother machine concept, as currently envisioned, encompasses a very large scale, completely self-contained reproductive mother machine. The image of a mother machine on the micromachine scale, however, would involve ant-like "worker machines" diligently digging on the surface of Mars or Venus, producing oxygen and water from the rocks and releasing them into the atmosphere, and feeding the residue to the queen machine (the mother micromachine), thus producing more worker machines. At first, a large number of queen machines would have to be sent from earth, and in the midterm field reproduction would take place. One or two hundred years later, the improved Martian or Venusian atmosphere resulting from the work of the micromachines would result in an environment hospitable to human beings.

Micromachine Issues

Solving the following three issues will be crucial to the realization of the Micromachine Rover and other ultrasmall space systems (as well as of micromachines in general):

1. Making machines that have a strong power relative to their small size
2. Making machines that can work together in a unified fashion to get a task done
3. Making machines that could reproduce itself

In addition to pursuing the possibilities of ultrasmall machines, we also need to solve the somewhat different issues associated with the practical use of these machines, especially in outer space.



Aiming at Development of Biomedical Micromachines

Koji Ikuta
Professor, Biomedical Micro Mechatronics and Systems Laboratory,
Department of Micro System Engineering,
School of Engineering, Nagoya University

1. New Department for Micromachine

The "Department of Micro System Engineering" refers to the first graduate course newly established at the Nagoya University in April 1994 for the purposes of comprehensive research and education of new science and engineering in a micro/nano scale. This Department, consisting of six laboratories, each year accepts 30 graduate students in the master's program and 12 in the doctorate program. In addition, according to the graduate school emphasis, working people in company as well as foreign students are also definitely accepted in the special doctorate program.

In this Department, "micromachine" is the most significant research subject. Development of a wide range of research topics from materials to medical applications has been initiated, even though the method of selecting research themes and the research approaches vary according to the laboratory.

2. Laboratory for Biomedical Micro Mechatronics

As indicated in the name, "Biomedical Micro Mechatronics and Systems Laboratory", the Ikuta Laboratory has been studying advanced medical micromachines and micro mechatronics for biotechnology that are difficult to realize by drawing upon existing industrial technology as the major research themes.

Regarding the research methodology for each theme, basic research starts from the material stage, then micromachines are designed and the models are developed, and control and system development are carried out. This is the major feature in his laboratory. In practice, research that emphasizes originality is promoted such as medical micro robots for non-invasive/low-invasive treatments, internal artificial organs, and basic research relating to biomedical micro mechatronics for advanced biotechnology. In addition, to understand organisms themselves, which comprise the effective field of medical micromachines, research regarding micro biomechanisms has also been started.

3. Research Themes

In practice, themes are established by developing major research themes that, in the past, were conducted at Ikuta Laboratory, such as new principle actuator, active endoscope, and three-dimensional micro fabrication.

1) Development of new principle micro actuators based on new materials such as a shape memory alloy (SMA) and piezoelectric elements, and application of the actuator to medical and welfare fields

Recently, thin-film SMA has been produced for the first time by laser ablation. Dedicated CAD, called "SMA-CAD", was also developed to facilitate the application of SMA. Research in the new control method of an SMA servo actuator for long term operation is also in progress.

2) Research of a multi-joint active endoscope (hyper endoscope), active catheter, and remote micro surgery system

To replace the world's first active endoscope of the SMA actuator driving type that was proposed and developed by Koji Ikuta and Shigeo Hirose ten years

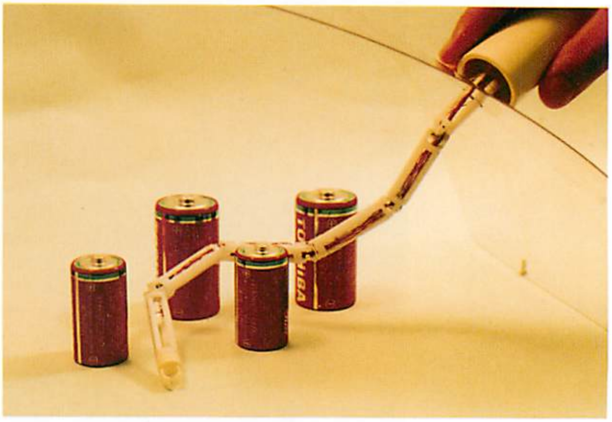


Photo 1

ago, we developed a "Hyper Active Endoscope" (ultra multi-degrees of freedom) for abdominal surgery for which the degrees of freedom were increased using cybernetic actuators of piezo-electric driving type (Photo 1). In addition, we are carrying out research of a master slave system with ultra-compact force sensation that will be required for remote surgery in the near future.

3) Research of the IH process

We are developing a three-dimensional micro fabrication process (IH process) that can produce coils (Photo 2) and pipes of 100 µm or less within one hour by improving drastically the stereo lithography, and through experimental and theoretical analysis of the photosolidification process. We have also developed a conductive UV-polymer and succeeded in manufacturing and driving an electrostatic micro actuator. As a result, both micro three-dimensional structures and also a micro actuator can be constructed concurrently, leading to high expectations for micronization of chemical analysis devices and medical biodevices.

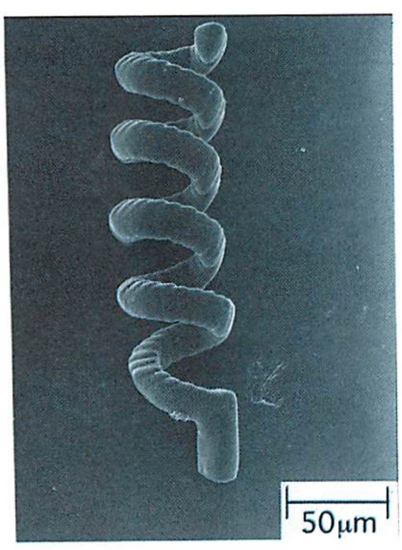


Photo 2 Micro coil spring (50 µm in diam.) fabricated by stereo lithography (IH process)

4. Call for Students

Research regarding micromachines and medical mechatronics has just started in the world and there are many subjects to be solved. We would like to have your support and cooperation to attract as many young people as possible who wish to tackle the interdisciplinary research fields covering the mechanical, electrical, instrumentation/control, material, chemical, and medical fields.

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Reports of European Seminars

The International Committee of the Micromachine Center (MMC) in 1993 established basic guidelines for the promotion of R&D through international exchange and to further the development and dissemination of micromachine technology. Activities will be undertaken with four "pillars" in mind: the first is that they incorporate technology and personnel exchange; the second is that they provide an arena for technical discussion; the third is that they include exchanges of basic studies at universities and other research institutions; and the fourth is that they enlighten and disseminate information to a broad range of people including the general public. Details will be determined in the course of implementation of each activity, but initial steps decided on are the holding of summits and overseas seminars and periodic technical exchanges.

To carry out projects planned in 1993, MMC held recent seminars in UK (London), Belgium (Brussels) and Switzerland (Crans Montana), with support provided by the Japan External Trade Organization (JETRO). Lectures were given by speakers from Japan at each seminar.

Takayuki Hirano (Executive Director, MMC): ***"Future Prospects of Micromachine Technology"***

Tadashi Hattori (Assistant Director, Research Laboratories, NIPPONDENSO CO., LTD.): ***"Overview of R&D Activities in Japan"***

In Switzerland, additional lectures were given by seven speakers on their own research:

Tsuneji Yada (OMRON Corporation)
Kazuhisa Yanagisawa (OLYMPUS OPTICAL CO., LTD.)
Tatsuaki Ataka (Seiko Instruments Inc.)
Susumu Tanabe (TERUMO Corporation)
Takeo Sato (MATSUSHITA RESEARCH INSTITUTE TOKYO, INC.)
Takeshi Yoshioka (MITSUBISHI HEAVY INDUSTRIES, LTD.)
Yoshikazu Mikuriya (YASKAWA ELECTRIC CORPORATION)

Outlines of the respective seminars follow:

[UK]

Date: June 21, 1994; 9:30 to 12:30
Place: London
Supported by:
Department of Trade & Industry, Government of UK
Imperial College, UK
Speakers from the UK:
Dr. Ian Eddison (Department of Trade & Industry): ***"Outline of the Activities in UK"***
Dr. Steve Prosser (Lucas Advanced Engineering Center): ***"Microengineering Common Interest Group"***

Number of participants:
About 40 people from universities and businesses

Outline: Current research in UK is in the area of manufacturing technology of semiconductors, and mechanism-oriented research seems premature.
Technical details, applications and future industrial predictions were discussed during the question session.

[Belgium]

Date: June 23, 1994; 10:00 to 12:00
Place: Brussels
Supported by:
Federation of Belgian Industry
Number of participants:
About 20 people from businesses and the EU
Outline: The seminar was aimed at Belgian industry but EU people also participated.
Discussion during the question session centered around not only MMC activities and research trends but also the economic aspects of micromachines, particularly their future market scale, investment and returns for new industries, and the potential participation by medium and small businesses. This subject area may have been the focus because of many participants from industry who were present.

[Switzerland]

Date: June 28 to 29, 1994
Place: Crans Montana
Supported by:
Institute of Microtechnology, University of Neuchâtel
Swiss Foundation for Research in Microtechnology
Speakers from Switzerland:
N. de Rooij (University of Neuchâtel): ***"Future Prospects of the Micromachine Technologies"***
H. Ruegg (Microprogram Microdar AG): ***"Overview of R&D Activities in Switzerland"***
Five other individuals who spoke on technological subjects
Number of participants:
About 45 people from universities and businesses

Outline: Against the technological background of development of a precision industry based on watches, Switzerland entered MEMS research through microelectronics. Government-supported projects include the M2S2 program centered in the University of Neuchâtel and the LETIS program based at ETH Zürich. These two programs will be concluded at the end of 1995, and beginning in 1996 the integrated MINAST program is proposed.
General discussions were on the future scale of the industry and the difficulty of participation by medium and small businesses. In-depth discussions during the technological session revolved around the state of technological development in each country; the Japanese side presented principally a description of R&D based on mechanisms while the Swiss side described research pursuing semiconductor manufacturing technologies. At the conclusion of the seminar, the Swiss proposed to continue such exchanges, and it was decided that the next seminar would be held in Japan a year and a half later.

"Future Prospects of Micromachine Technology" (Outline)

Takayuki Hirano (Executive Director, MMC)

Technology trend (micronization)

Research on micronization is being done today throughout the world in numerous technological areas of biotechnology, materials, and electronics. Historically, however, the major efforts in the machine field were devoted to the creation of larger machines, and this has caused micronization in the machinery field to lag behind other areas.

Micronization of machinery

In our daily life, we need only consider the force of inertia in Newton's dynamics, ignoring the forces of viscosity and friction. In the world of micromachines, however, the forces of viscosity and friction are very influential. Although the future of micromachines does call for interdisciplinary technical knowledge, since the important machinery area is far behind the others, Japan places more emphasis on R&D of micromachines than do Europe and the U.S., which are focusing more on the microminiaturization using semiconductor IC manufacturing technologies.

Expectations for micromachines

Micromachine technology has immense potential: it can improve machinery and system functions through miniaturization and integration of components; it can be applied to broad areas of life, society and industry, and can be the rationale for the formation of new industries in the 21st century. There are thus high expectations being placed on the technology now being developed.

Promotion of micromachine technology and the Micromachine Center
(Omitted)

Overview of the Industrial Science and Technology Frontier (ISTF) Program by MITI's Agency of Industrial Science and Technology
(Omitted)

Industrial Science and Technology Frontier Program's Micromachine Project
(Omitted)

Overview of the micromachine industry in Japan

Generally speaking, micromachine technology is now in the typical R&D phase which any new field goes through. Much time will pass before an actual product appears on the market. We therefore refer to it as an industry of "the 21st century." While it is nearly impossible to predict the market for a completely new technology like micromachines, we have used a very bold approach to construct a prospective image of this future industry.

The present micromachine market is about ¥ 134 billion, and the overall market for replacement of existing products and for new products is estimated to be ¥ 530 billion to ¥ 1.5 trillion by 2005, and to be ¥ 1,300 billion to ¥ 1.9 trillion in 2010.

New paradigm of micromachine technology

The new paradigm of micromachine technology is analogous to the Mandala of Buddhism. The mandala illustrates the concept of Buddhism as a "system" drawing on a large number of Buddhas. At the center of the Mandala is the "Dainichi Nyorai (Great Sun)," which stands for the highest state according to the Buddhistic teachings. Around the Dainichi Nyorai, we find lesser "Nyorais" which indicate various teachings of Buddhism. The further we go from the center, the closer we are to the real world. Humans are placed furthest from the center and begin their understanding of the teachings of Buddha from a great distance, gradually working their way toward the highest state in the center. To aid them in their endeavor, Gautama Buddha (who actually existed) appears in the Mandala as a mediator between the highest state and the real world.

Micromachine technology aims at bringing together the "wisdom of a small world." The new paradigm is a completely new technology that relates to numerous aspects of human activities on the planet. It is the theory of a technology which cannot be realized even by a superhuman being, but which will be achieved by the united efforts of many wise men and women.

I feel that the effort of every individual nation toward creating micromachine technology should be seen as part of the Mandala. Japan has embarked on its research on micromachine technology focusing on mechanisms, while Europe and the U.S. have begun their research focusing on semiconductor manufacturing technology. All are heading toward the same goal: wisdom of a small world, the center of the micromachine technology paradigm, though they are coming from different directions in the larger Mandala.

Establishing the new paradigm

What is this central target of micromachine technology's wisdom of a small world? Where in the Mandala can we identify the approaches we are currently using? Are there other approaches we have not tried? International cooperation is vital to answer these questions. MMC is ready to serve as a catalyst or bonding agent in a cooperative international effort.

Conclusion

The machine technology that supported the industrial revolution in England in the 18th century is once more poised to support new age industry of the 21st century through the progress of micromachine technology. In this sense, the R&D activities for micromachines are a sign of an approaching "mechanical renaissance."

Overview of R&D Activities in Japan (Excerpt)

Tadashi Hattori (NIPPONDENSO CO., LTD.)

I would like to describe the present state and future prospects of micromachine technology R&D in Japan, using actual examples.

Micromachine technology is currently devoted primarily to research and development in the processing aspect of the fabrication of 3-D micro structures. One of the more remarkable recent achievements in this processing aspect is micro electrical discharge machining. Examples are micro drilling of a hole with a diameter of only 30 μm, and fabrication of a micro shaft with an end just 4.3 μm in diameter. In mechanical removal processing, it is now possible to drill a hole only 20 μm in diameter and to slice a thickness of 1 μm. PZT drilling to a depth of 100 μm with an excimer laser and the fabrication of a micro coil spring which has a diameter of 50 μm using a photoforming process have also been realized. The major achievements in processing technology done in the Industrial Science and Technology Frontier Program's "Micromachine Technology" project include the processing of a pit 6 μm in diameter in chemical solutions using SPM techniques and the processing of an array of 30 μm square PZT pillar produced by LIGA. The technology for directly bonding dissimilar materials like PZT and silicon has also been developed. Other advances include a micro coil spring 106 μm in O.D. made of a shape memory alloy of element wire 30 μm in diameter, formation of three joints in a tubular structure which is only 1 mm in O.D., a pre-assemble process to manufacture a wobble motor 1 mm in diameter, and an integrated micro photoelectric device which produces a voltage of 200 V.

Applications of micromachine technology are now being in various fields using a combination of micro fabrication and conventional technologies. In the next step, we hope that compounded and integrated micromachine subsystems with micro assembling techniques will be put to practical use for medical and instrumentation purposes.

The characteristics of micromachine technology R&D in Japan lie in the micronization of mechanics compounded with electronics. In the future, it will be increasingly important to adapt micromachine functions to a micro environment, rather than simple miniaturization of machinery. This means that it will become necessary not just to cram many parts into a small space but to select the most appropriate structure for a given purpose.

FANUC LTD

A bird's-eye view of the head office area

Introduction

This time we visited the headquarters of FANUC LTD located near the shore of Lake Yamanaka at the foot of Mt. Fuji. The head office, laboratories and factories were spread out in a wonderful natural environment backed by an extensive forest.

Fanuc has been in operation since 1956 and has developed CNC used in the automatization of machine tools as well as, in 1972, the first industrial robot. It is recognized as a company which has contributed to revolutionizing global manufacturing through its promotion of factory automation.

Fanuc's main products include its CNC systems and control motors for machine tool automatization, various industrial robots, plastic injection molding machines and wire-cut EDMs, which are generally referred to as robomachines because of their AI functions.

In the factories where these products are manufactured one can find many robots standing on the clean floor, all of them completely automated. The non-stop round-the-clock production of high quality items is truly impressive.

R&D activity

Fanuc views R&D as important as management and one-third of its employees, about 600, are involved in research and development.

There are six laboratories in the R&D section, all located in the headquarters area. The CNC Laboratory, Servo Laboratory, Laser Research Laboratory, Robot Laboratory, and Robomachine Laboratory is each engaged in the development of particular products, and each product is exceedingly competitive having been turned out under a banner of ***"high quality and high performance"*** and ***"high quality and low cost."***

The Basic Research Laboratory participates in the national micromachine project and the IMS project, and is involved in creating new products for the 21st century.

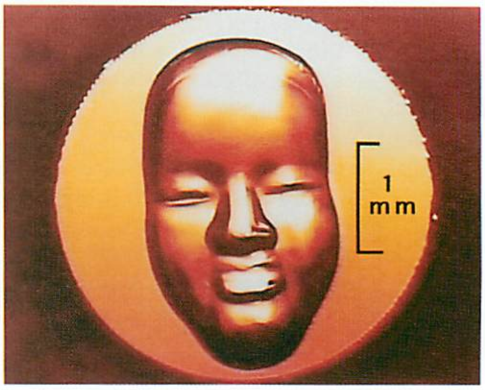
This emphasis on long-term studies and product development shows the company's attitude of cooperation with its customers in the automation of plants.

Tackling micromachine technology activity

Micromachine components, which are small in size, require exceedingly precise micromachining technology to assure relative accuracy. From early on Fanuc has been engaged in the study of 3-D ultra precision micromachining and with this as a basis, pursues its study of the machining of micromachine parts. A *Noh* mask shown in the photo was produced by engraving copper with a special tool called a "diamond end mill" which results in a surface smoother than a mirror.

We also saw a prototype linear actuator for micromachines. This new type actuator uses a piezoelectric element. Although still a prototype of a larger model, it is being microminiaturized after having proven its performance.

In the large forest near the Fanuc headquarters, social and recreational facilities for employees are provided, as well as company houses furnished with central heating. We felt that this wonderful environment was very conducive to the steady development of new technology by the young researchers.



A micro Noh mask 3 mm in size

FUJIKURA LTD.

Today we visited the Advanced Technology R&D Center of the Tokyo R&D Center of FUJIKURA LTD. in Kiba, Koto-ku, Tokyo, which was completed in September 1993. Fujikura is a long-established cable manufacturer having a history of more than 100 years since its founding in 1885. Fujikura has four plants in Japan: at Sakura and Futtsu (Chiba Prefect.), Numazu (Shizuoka Prefect.) and Suzuka (Mie Prefect.), and based on its in-house developed technologies, the company has established its own production systems using the latest equipment. There are also five laboratories: Materials Research Laboratory, Advanced Technology R&D Center, Opto Electronics Laboratory, Energy System R&D Laboratory, and the Fujikura Technology America Corp., and a Research & Development Division which has eleven departments. Product development and manufacturing techniques as well as basic research on technological development are seen as assuring the future of Fujikura.

Three of the laboratories, Materials Research Laboratory, Advanced Technology R&D Center, and Energy System R&D Laboratory, are located in the Kiba area where the head office is. The Materials Research Laboratory develops and evaluates metallic and oxide superconducting materials, metals, polymers, and composite materials. The Energy System R&D Laboratory is engaged in the development of highly reliable, large capacity, extra-high voltage cable as a main artery for society and industry, construction and maintenance of electric lines, and technology for use in automation and energy saving in power distribution. Supported by these power cable-related methods, it is also actively advancing the development of energy systems for the new age.

At the Opto Electronics Laboratory located in Sakura (Chiba Prefect.), optical fibers for use as transmission lines, components such as couplers and connectors, and equipment and such systems as optical fiber fusion connection systems, optical measurement instruments, and LAN are studied. The large contribution made by Fujikura in reducing transmission loss of optical fiber is highly valued both at home and abroad.

The Fujikura Technology America Corp. is located in California and is a base for the gathering of information for Fujikura's international operations.

In addition to its R&D activities, the company established the ***"Fujikura Global Environment Charter"*** in March 1992, a "first" in the industrial world. Strongly recognizing that its business activity is closely related to the global environment, Fujikura has developed products furthering environmental protection and energy saving. Examples are heat pipes which utilize waste heat and far infrared ray radiating materials.

On October 1, 1992, Fujikura Ltd. changed its Japanese name from **"Fujikura Densen"** (literally translated as "Fujikura Cable") to **"Fujikura"** and renewed its determination to become a future-oriented business promoting harmony between humans and their environment, with major objectives placed on diversification, improved effectiveness, and internationalization.

Tokyo R&D Center

The Advanced Technology R&D Center we visited is involved in the development of $BaTiO_3$ optical single crystal, high purity copper, semiconductor lasers, optical switches, semiconductor pressure sensors, and ceramic oxygen sensors. All of this is in preparation for the expansion and advancement of key technology and its leap to the next generation, and is based on the concept that technologies applicable to crystal growth, high-purification, the semiconductor process, and those which are optics- and ceramic-related are essential.

For the distributed feedback semiconductor laser Fujikura has established a means of forming submicron diffraction gratings into a part of an element. For semiconductor pressure sensors and semiconductor acceleration sensors they have established a unique micromachining technology used to manufacture various kinds of microscopic structures by etching the silicon wafer itself. Crystal growth is done in bulk and thin film formation, while vacuum deposition, spattering and CVD techniques are employed for film formation of metals and dielectrics. We were actually able to observe various types of bonding techniques already in use to bond dissimilar sensor materials together.

We saw clearly that a bonding technology appropriate for micromachines will emerge with the further development of micromachining, reduction of the strain caused by bonding, and the devising of a low-temperature bonding technique. We feel sure these technologies will be used in various kinds of sensors in the future.

At the conclusion of our visit, we felt reassured that Fujikura, which began its business with cable-related products, had — with foresight — expanded its operations into optical fiber and peripheral products, and into the areas of advanced energy and electronics, and would successfully make the leap into the 21st century. We left Kiba confident that the company would make a positive contribution to the development of micromachines.

Current Situation and Future of Micromachine Development in Switzerland

Dr. N. F. de Rooij, who is the authority of the micromachine science in Switzerland, and also a professor at the University of Neuchâtel, has arrived in Japan and Visited the Micromachine Center on the afternoon of September 14. Although he has a very busy schedule, we had an opportunity to interview him and could listen to his informed opinion regarding the current situation and the future of micromachine in Switzerland.

Q: *Last June's Swiss-Japanese seminar on microsystems is highly evaluated in Japan. How is the evaluation in Switzerland?*

A: It is equally evaluated in Switzerland. We have got very positive comments from the Swiss delegates who participated. I think that it was a very good occasion for the Swiss delegates to learn the details about Japanese programs on micromachines.

Q: *What are the plans for the next Swiss-Japanese meeting?*

A: We plan to hold the next meeting in Feb. 1996, and it will be organized in Japan.

Q: *What do you think of the difference in point of view of microsystems between Swiss and Japan?*

A: There are distinct differences between Swiss and Japanese programs. Most of the programs in Switzerland are rather short or midterm; that means about 3-4 years. In general, the programs are defined in a bottom-up way. It starts with discussions between researchers and the company and/or university management. Then the project is defined. There are also important collaborations between industrial and university members in such programs. As far as Japanese programs are concerned, my understanding is that they are more mid to long-term, 5- to 10-year, programs. Their characteristics seem to be top-down oriented so that at higher levels certain decisions are taken which then spread to companies and universities where the programs are set.

Q: *We have heard that several research projects on microsystems are going on in Switzerland now. Would you introduce the outline of these programs?*

A: Currently 4-5 major projects related to microsystems are running in Switzerland. They are defined to promote microsensors and microactuators as well as interface electronics. Most of them will be completed by 1996. Then there are plans to start a large program called MINAST. MINAST is the abbreviation for Micro and Nanosystem Technologies. This rather large program can be considered as a combination and continuation of the current small programs. MINAST is planned for 4 years and will start in January 1996 and end in December 1999. In total we plan a budget of about 250 Million SFr for a period of 4 years. We have 13 universities or research institutions and about 100 company participants. The program deals with the design and the fabrication of the microsystems and their assembly. It also focuses on the applications of microsystems in a large variety of consumer articles and the application in industrial environments or in medical fields.

Q: *Institute of Microtechnology, University of Neuchâtel has published a lot of results for various field. On what fields are you currently concentrating most at the IMT?*

A: Currently we are designing and fabricating individual components like microsensors (for instance: gyroscopes) and optical components like mirrors and optical switches in view of their application in microsystems. We also have a strong interest in various types of actuators, both linear moving and rotating type actuators based on piezoelectric as well as electrostatic drives. As for systems, we are developing small chemical analysis systems and miniature dosing systems for the medical fields. We are also developing microsystem based instruments for space research. Finally we are focusing on microfabricated tools for nanoscience and nanotechnology, like STM/AFM tips. We also have a project on bioelectronics.

Q: *You have introduced a small dosing and sampling system at the Swiss-Japanese seminar. Would you show us what kind of background produced the idea?*

A: First of all the idea was originated by the micromachine program of Japan. So I would say that this is based on the concept developed by the micromachine program. At the same time this system incorporates a number of developments from the IMT Neuchâtel, such as a dosing system, a chemical analysis system and the actuators for moving or displacements. So in a way, this is also an integration of device developments and an excellent demonstration of future microsystems or micromachine technologies.

Q: *Both sensors and actuators are main targets of microsystem development, but from the point of view of industrialization, there are few actuator products in comparison with sensors. What do you think of probable applications for actuators?*

A: Microactuators are still in an early stage of research and development, but many applications are expected. Let us look at the various kinds of actuators and their principles of functions. Using magnetic forces we can imagine many kinds of actuators, for instance in printers where they can be activated to get extremely high dot density. Using actuators based on thermal effects, liquid control valves have been recently introduced in the market by a US company. Using electrostatic principles we can build displacement actuators for optical applications, such as small mirrors or optical switches. We can also think about piezoelectric driven actuators, small micromotors and switches. Then if we talk about micropumps, we can use piezoelectric or electrostatic or thermal principles. And we will have to search for the actuators that are needed to deal with the manipulation of extremely small particles on the nanometer scale. Thus, if we are thinking about applications of small actuators I predict many applications in the future.

Micromachine Technology (III)

Fundamental Technologies

Machining technology

1. LIGA process

As described earlier, the silicon process has advantages such as the possibility of micro processing, simple assembly, and compatibility to a semiconductor circuit. The silicon process plays a major role in micromachine processing technology. However, as shown in Fig. 1, this process has some disadvantages. The products are thin, weak, and cabled. The diameter of a common motor that is made by silicon process is about the diameter of a hair, but the thickness is about 1/100 of the diameter. As a result, it is difficult to obtain a comparatively large force or to extract the force. "Cabled" indicates that even if the rotating part of such a motor is small, the size of the connection cables to the power supply and control circuit are about a hundred times or thousand times larger, so independence is impossible for micromachine at this moment.

Promising methods for solving the problems of thinness and weakness include the LIGA process, micro electro-discharge machining, photoforming, and conventional machining. This article introduces the first two methods.

The LIGA (Lithographie-Galvanoformung-Abformung) process is a technology developed by the Kernforshungszentrum Karlsruhe GmbH (KfK) in Germany. Originally, the process was developed to produce a radioisotope separation nozzle. This method is often considered to be a sophisticated and advanced technology since it requires an outstanding facility such as synchrotron radiation (SR). However, the principle is as simple as that of the silicon process and is basically equivalent to a printing technology.

To produce a thick structure, photosensitive resin (polymethyl methacrylate, PMMA, is often used) applied at a thickness of several hundred microns is baked with bright light. The light requires brightness and parallelism, and radiation (X-rays) emitted from an electron circulating at high speed is utilized. When the resin is developed, a very small but thick resin structure is produced. The ratio of horizontal dimension to height is called the aspect ratio. This method allows a high aspect ratio micro structure to be produced.

A replica of the structure is then produced. A reverse replica is produced by nickel electroplating (electroforming, Galvanoformung), rather than by clay or plaster molding. If required, processing (Abformung) such as resin injection molding is followed using this reverse replica as the mold. Figure 2 shows a shaver(?) for ants produced by this method.

Beside the possibility of making a high aspect ratio structure, LIGA has advantages of low materials restriction and mass production capability with molding. The disadvantage is that SR requires a large facility and is too expensive. In addition, completely free three-dimensional shapes cannot be produced. For the advantages, practical optical elements, filters, printer nozzles, and acceleration sensors have been developed.

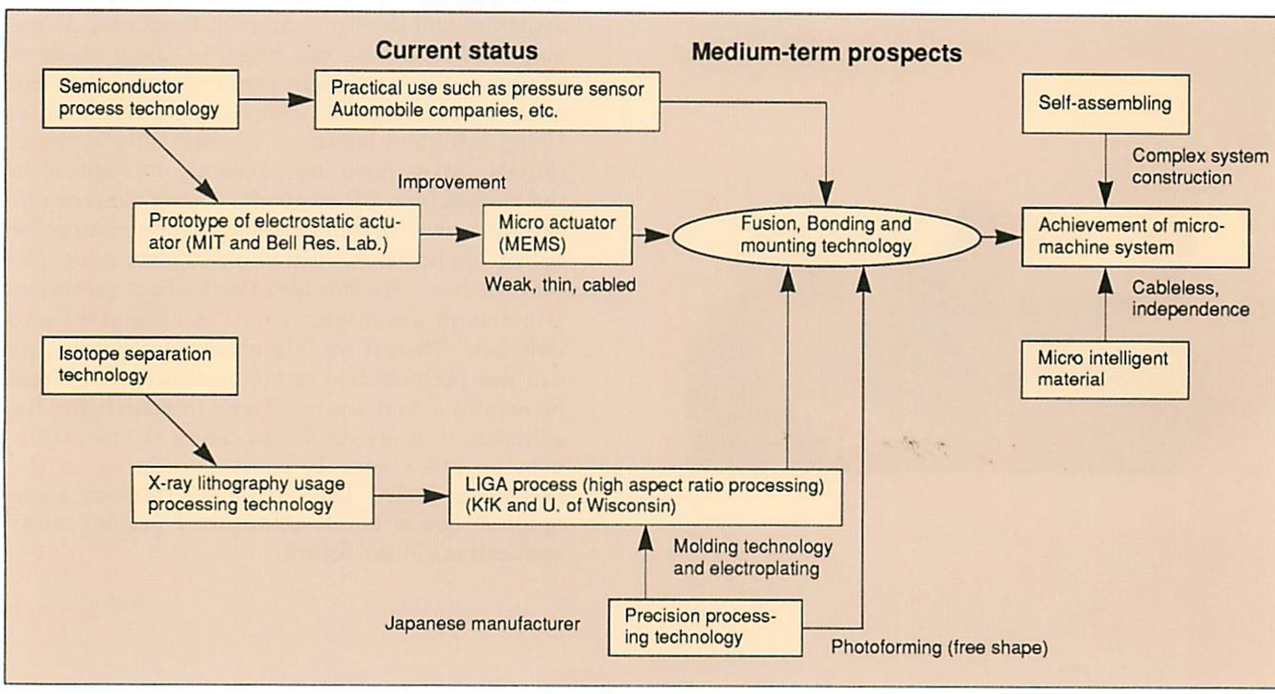


Fig. 1 Current status and future of each processing technology

Fig. 2 Shaver(?) for ants
(Presented by KfK)

2. Micro electro-discharge machining

Principle of electro-discharge machining and objects to be machined

Electro-discharge machining is a processing method that melts and splashes the section of the work opposite the tool by sparking between the work and electrode tool. Normally, both the work and the tool are immersed in an insulating liquid such as deionized water or kerosene. When the dielectric breaks down or sparking occurs, this melts the work and at the same time vaporizes the liquid rapidly, and the molten section is splashed instantly. Stating it very simply, very small thunderbolts scrape the material.

The disadvantage of this process is that basically only conductive materials can be processed; however, semiconductors such as Si can be processed depending on the conductivity. The advantage of this process is that it is a non-contact machining method; no large force is applied between the work and the tool, so that fine or thin work or tools can be used.

Micro electro-discharge machining

In comparison to conventional electro-discharge machining, micro electro-discharge machining reduces the amount removed in one discharge. Consequently, discharge energy per time must be minimized. Since a certain amount of voltage is required to produce dielectric breakdown, discharge current of short pulse width (1 ns to 1 µs) is used. Since it is difficult to satisfy this condition in the present pulse technology using semiconductor devices, charging and discharging of a capacitor is used. Such a circuit has a floating capacity other than that of the capacitor in the charging circuit. To minimize discharging energy, it is important to minimize the floating capacity. In a micro electro-discharge machine, more ceramic components are used, thus reducing the metallic components to minimize the floating capacity.

Micro electro-discharge machining was developed by Professor Takahisa Masuzawa and others in the Institute of Industrial Science, The University of Tokyo. A shape is created by machining an object by rotating the work and feeding in the z-axis direction; the electrode is a metallic wire that runs along a guide. A running wire is used so that there is less influence from electrode wear and a complex shape can be machined by numerical control (NC).

Micro-holes can be produced by using the micro-shaft that was manufactured by the WEDG (wire electro-discharge grinding) process as the tool. The micro electro-discharge machine that was developed by the Matsushita Research Institute Tokyo, Inc. can produce a hole 5 to 300 µm in diameter, with a depth 3 to 5 times the diameter, and at a precision of plus or minus 0.5 µm circularity, and plus or minus 0.1 µm surface roughness. Micro-holes can be used for nozzles for ink-jet printers, flow control orifices, and pin holes for X-ray measurements.

Slit and through hole machining is also enabled by overlapping micro-hole machining. A three-dimensional shape can also be produced by using a micro-electrode as the end mill of a milling cutter. The micro air turbine rotor shown in Fig. 3 cannot be created easily by the LIGA process. Microblanking is attempted by creating punch and die by this method.

Comparison with LIGA process

The electro-discharge machining can process conductive objects to a certain degree of fineness for which the aspect ratio of 5 and surface roughness of 0.1 µm. The processing efficiency is generally lower than that of a silicon process because batch processing is not possible. However, since the electro-discharge machining is first used for machining of metallic molds, the economics may be enhanced by combining it with plastic working or injection molding. This process is not suitable for production of high aspect ratio structure or honeycomb structure which are produced by LIGA process. It is, however, suitable for producing metallic dies for single item micro-components used in OA devices. In addition, as described above, this process has a higher degree of processing freedom than does the LIGA process, which is originally 2.5-dimensional processing.

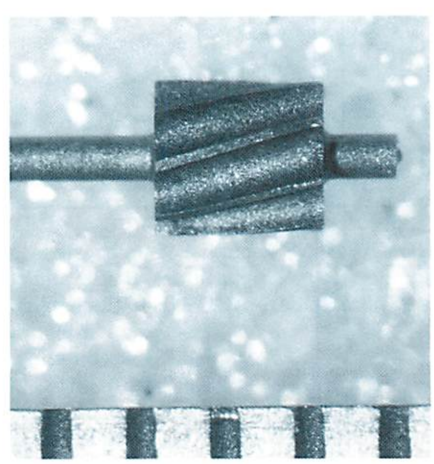


Fig. 3 Micro air turbine rotor
(Presented by Matsushita Res. Inst. Tokyo, Inc.)

Invitation to Join the General Supporting Membership

Micromachines are minute devices capable of performing complex, microscopic operations, despite being composed of functional elements less than a few millimeters in size. It is believed micromachines have strong potential use across many industrial spectra, particularly in areas requiring sophisticated, advanced maintenance technology in response to increasingly complex and precise machine systems and in medical services where sensitive, advanced medical technology is required, but with minimal discomfort to patients.

The Micromachine Center (MMC) was established on January 24, 1992, with the approval of the Minister of International Trade and Industry. Its objective is to promote the dissemination of micromachine technology in Japan, and contribute to the development of Japan's industry, economy, and the advancement of international communities.

MMC promotes research and development work under the Industrial Science and Technology Frontier Program "Micromachine Technology," a 25-billion-yen mega-project begun in 1991, delegated by the Ministry of International Trade and Industry's Agency of Industrial Science and Technology.

The center will also engage in independent research, promote cooperative research involving industry, government, and academia, and organize international symposia on micromachine research and development.

MMC would like to invite your interest and support for its projects and activities—and call for your direct support through membership in MMC itself.

Membership privileges include:

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Membership requires an initial payment of ¥ 4 million and annual dues of ¥ 2 million.

For further information, please contact the General Affairs Department of the Micromachine Center.

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