2000 8

MICROMACHINE

MICROMACHINE CENTER

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No.32

For Development of Micromachine Technology

Koji Kajimura
Director-General,
Agency of Industrial Science and Technology,
Ministry of International Trade and Industry

The Agency of Industrial Science and Technology has promoted an R&D project related with "micromachine technology" in cooperation with the Micromachine Center (MMC, a juridical foundation), relevant companies, and research institutes under the Industrial Science and Technology Frontier Program. This particular project started in 1991 with the aim of meeting social and technological needs such as conversion to an environmentally-friendly society through energy-conservation and resource-conservation, and promotion of mechanical microtechnology. During almost a decade since then, a number of brilliant achievements have been resulted, which include manufacture of the world's smallest (14-mm dia.) wireless mobile machine to run through piping systems as well as the trial manufacture of a "micro- factory" which may be referred to as the world's smallest machining and assembling factory. In the technological evaluation of the project conducted by external experts last year, the project was highly evaluated as being a success. Through the process of the development of the project, technologies that may be utilized in various industries were obtained. These globally recognized achievements in micromachine technology have been resulted from the substantial efforts and support rendered and extended by all the people concerned in the Micromachine Project. We would like to express our sincerest gratitude to all the individuals and institutes concerned. This fiscal year is the last year of the project. We are determined to further pursue the improvements in related technology with the aim of yielding meaningful results that may codify the project and of passing the technological achievements on to society as a whole.

In "The National Strategies for Industrial Technology" established with industrial-academic-government cooperation in April 2000, it is suggested that we should convert the concept of the technological development attitude from so-called "catching up with the advanced technology" to "pioneer-spirited development of technological frontiers." Micromachine technology in particular is expected to continuously play one of the most important roles in the manufacturing industries of Japan. In other words, it is anticipated that micromachine technology, an important technological task which will lead to the cultivation of new demand in mechanical industries, will be utilized in the fields of "information & communications" and "medical & welfare" which are expected to become more advanced in the future. Super precision machining and micromachining technologies as well as the system design technology developed in the past will be the basis for realizing such devices as a custom-made wearable information device, etc., which is much smaller in size and renders it easier to access information sources than those devices currently available.

Almost coincidentally, the "Industrial Technology Reinforcement Act" was enforced in April this fiscal year to prepare the environment required for the joint industrial-academic-government efforts toward strengthening of industrial technology. For example, the regulation on the faculty members (professors or teachers) of national and public universities and colleges in connection with simultaneously work as executives of private industries has been alleviated in order to promote the transfer of technology to private sectors. The Agency of Industrial Science and Technology is also ready to ensure the role of a promoter of industrial technology R&D projects for our nation's advancement in technological innovation systems. We would like to ask for your continued cooperation and understanding in connection with our programs.

A Nano-device for Drug Delivery: Macromolecular Micelle Effectiveness and Potential

Professor Kazunori Kataoka
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1. Introduction

The multimolecular self-association of block copolymers, composed of hydrophilic and hydrophobic macromolecular chains, is promoted by various driving forces in an aqueous medium. Via this process, core-shell type macromolecular micelles of very narrow distribution within the mesoscopic size range (approximately 20 - 100 nm) are created. The shell of a macromolecular micelle has a structure that is characterized by crowding of tens of or hundreds of hydrophilic free terminal chains. Because of the steric repulsion based on hydrophilic property and entropic elasticity, the shell demonstrates properties to effectively inhibit the nonspecific interaction with vital components such as plasma protein and cells in addition to excellent dispersion stability. The core characterized by the marked ability of aggregation is expected to contribute to the stabilization of micellar structure and assume the role of a microreservoir of physiologically active substances including drugs. A macromolecular micelle with high biocompatibility and remarkable drug retaining ability is expected to be of a size that can permeate smoothly through tissues. Its advantage consists in its function as a carrier to deliver drugs including anticancer drugs and genes for gene therapy to the specified organs and cells. Ligands can be quantitatively attached to the free terminals of the linkages that make up the micellar shell (refer to Fig. 1). The application of this system to targeting therapeutic devices for the delivery of the micellar contents to specified cells (artificial virus), and diagnostic devices for the detection of pathogens (supramolecular probe) is anticipated. This research team is energetically studying these macromolecular micelles with unique functions.

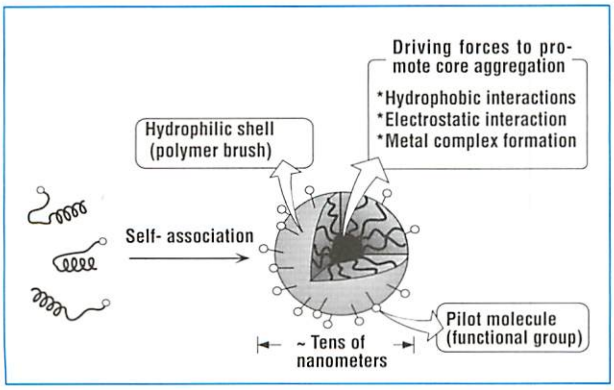

Fig. 1 Formation of a macromolecular micelle using various driving forces

2. Designing the structure of block copolymer micelles with the drug delivery function and introducing the new drug delivery system into target cancer treatment

During the process of designing the structure of block copolymer micelles with drug delivery functions, we selected polyethylene glycol (PEG) as a substance for the linkages comprising the micellar shell because PEG is a water-soluble substance of hydrophilicity and has a flexible nature, which may induce remarkable steric repulsion. As for the substance for the linkages comprising the micellar core, we considered biodegradability and selected polyaspartic acid (PAsp). We incorporated adriamycin (ADR), an anticancer drug that is hydrophobic toward side chain carboxyl groups and showed enhanced self-association, by amide bonding in order to increase the stability of the micellar structure. Furthermore we attempted to increase the amount of ADR that was to be physically entrapped in the micellar core (Fig. 2). ADR containing macromolecular micelles (PEG-

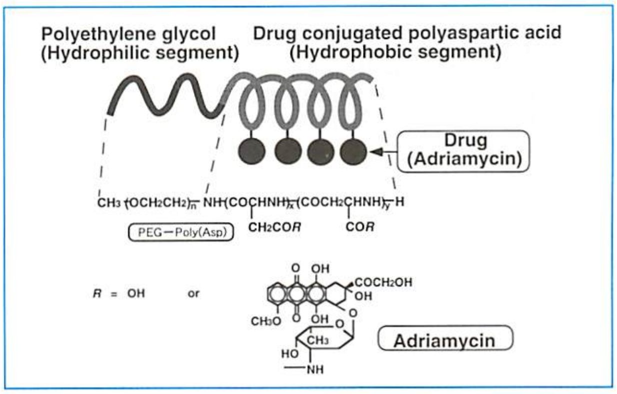

Fig. 2 Block copolymer conjugated with Adriamycin, an anticancer drug

PAsp(ADR) micelle), having this functional design, shows significantly higher blood retention than ADR itself because of its remarkable structural stability and marked biocompatibility. As demonstrated in Fig. 3, in an experiment using mice, PEG-PAsp(ADR) micelle completely cured the subcutaneously implanted solid tumor. This experimental system is now being used to conduct preclinical tests at the National Cancer Center in Japan. We directed special attention to a new complexing reaction that could be utilized as a driving force for the

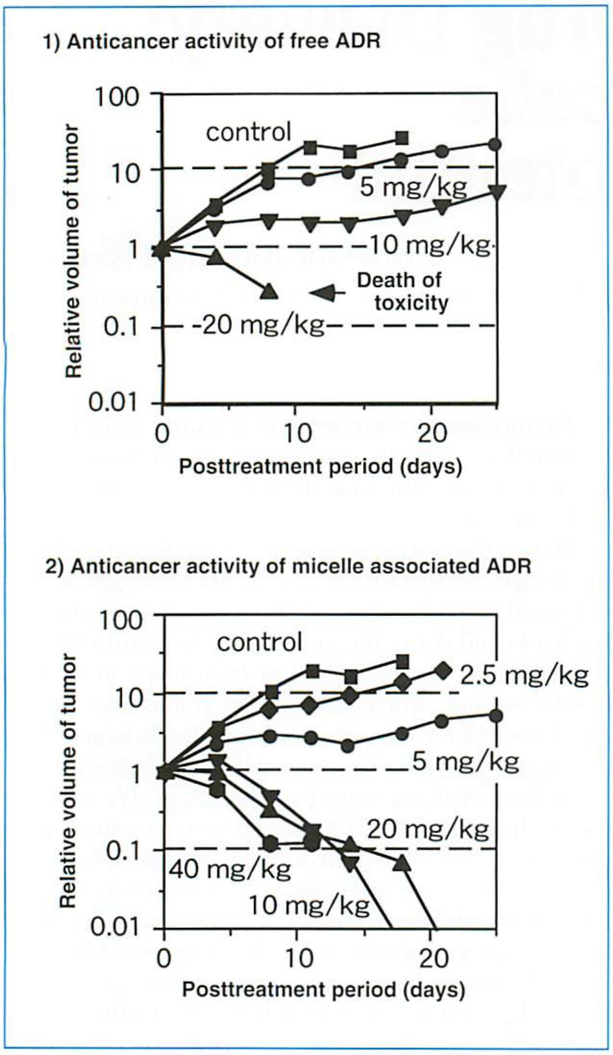

Fig. 3 In vivo anticancer activity toward colon cancer (Colon 26)
Chemically bound ADR in the micelle: 48 mol % of aspartic acid residues (weight %: 23%)
Physically adsorbed ADR in the micelle: 18 mol%

core formation process and enclosed cisplatin, a platinum complex anticancer drug, in the micelle. Experimental results demonstrated that cisplatin containing micelle also demonstrated marked stability in the blood and significantly promoted the accumulation of solid cancer. The possibility was suggested that the drug containing macromolecular micelles might control pharmacokinetics in the living body. It has been revealed that this treatment can be applied in various medical fields.

3. Development of a new macromolecular micelles using electrostatic interaction and evaluation of its functions

When differently charged macromolecular electrolytes are mixed in water, an insoluble association, polyion complex (PIC), is usually formed. In the case of block copolymers, however, we recently discovered that PIC, which formed the core, was surrounded by the spontaneously formed PIC micelles, a narrowly distributed multimolecular association which was covered with a hydrophilic shell and had a diameter of tens of nanometers.

PIC micelles containing biomacromolecules such as enzymes and DNA can be used as effective biofunctional materials in various ways. The micellization contributes significantly to the improvement of the resistance of plasmid DNA and antisense DNA to nucleases and the enhancement of gene expression. In this experimental system, it is anticipated that the PIC micelle will replace a natural virus and act as a gene vector.

4. Synthesis of a new block copolymer with functional groups at the free terminals and formation of a reactive macromolecular micelle

When we develop a new drug delivery system using macromolecular micelles, it is crucial to confer the ability to recognize molecules on these micelles. To this end, we should establish a method to design the structure of reactive macromolecular micelles with many functional groups at their external margins. In the present study, we developed a general synthetic procedure which could be applied in various medical fields. In the procedure, protected functional groups were incorporated into metal alkoxide which was used as an initiator. In this way Anionic ring-opening polymerization of ethylene oxide and d, l-lactide was conducted in successive manner to obtain block copolymers with various functional groups at their terminals. The macromolecular micelles derived from these block copolymers have many functional groups at their external margins and various ligands can be incorporated therein. These micelles can be used as organ specific drug carriers in a wide range of medical fields. In fact, micelles installed with lactose definitely demonstrated a high binding specificity to lectin.

5. Conclusion

As described above, it has been revealed that a macromolecular micelle formed by the self-association of block copolymers is a useful nano-device of viral size that plays roles as a carrier of various drugs and genes in the drug delivery system. This new drug delivery system can be regarded as a molecular device developed via a chemical approach. When the capacity of the target recognition function and the function of responding to stimulation are given, it is anticipated that this macromolecular micelle will act as an effective chemical nano-machine that can accomplish the particular mission at the specified site on the specified occasion.

References

1) Kataoka K., Gene Medicine 2000 4(I), 156-161.
2) Harada A., Kataoka K., Protein Nucleic Acid Enzyme 2000 45(7), 1265-1272

The Activities of Micromachine Center in Fiscal 1999

I. Investigations and Research on Micromachines

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

The Industrial Science and Technology Frontier Program of MITI's Agency of Industrial Science and Technology (AIST) has entered the forth year of its second phase. To achieve the goal of the basic plan for the R&D (Phase II), the R&D system was further improved and research delegated to MMC was actively promoted. The final evaluation of this project was conducted preliminarily by the AIST.

(1) Development of Advanced Maintenance Technologies for Power Plants

① R&D of systematization technology (Experimental wireless micromachine for inspection on inner surface of tubes)

R&D of systematization technology was conducted through production of an experimental system for a wireless self-locomotive micromachine (experimental micromachine for inspection on inner surface of tubes, and systematization of a microvisual device and an optical energy transmission device, etc.). In metal tubes with curved sections, this system is able to move forward, backward, horizontally and vertically, stop optionally, and recognize its surroundings as well as detect defects of tubes.

② R&D of systematization technology (Experimental chain-type micromachine for inspection on outer surface of tubes)

R&D of systematization technology was conducted through production of an experimental micromachine system (experimental chain-type micromachine for inspection on outer surface of tubes, and systematization of reduction and traveling devices and a microconnector, etc.). This system is composed of a group of machines capable of combining or separating according to the form of the object to be inspected.

③ R&D of systematization technology (Experimental catheter-type micromachine for repair in narrow complex areas)

R&D of systematization technology was conducted through production of an experimental micromachine system (experimental catheter-type micromachine for repair in narrow complex areas, and systematization of a position detection device and a monitoring device, etc.). This system is able to enter the equipment of various structures and perform measurements or repair minute internal flaws.

④ R&D of functional device technologies

R&D was 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 (artificial muscle, microjoint, low-friction suspension device, microbattery, optically driven free joint device, etc.).

⑤ R&D of common basic technologies

R&D was conducted on common basic technologies such as technologies for control, measurement, design, and evaluation necessary for realizing micromachine systems (pattern forming technology for a group of distributed micromachines, hierarchical group control technology, measuring technology for weak power, torque etc.).

⑥ Comprehensive investigation and research

Comprehensive investigation and research required for the conceptual design of maintenance micromachines necessary for maintaining future power plants was conducted.

(2) Development of Micro-Factory Technology

① R&D of experimental micro processing and assembly system

R&D was conducted on systematization technology by producing an experimental system for processing and assembling. This system is able to manufacture models of small parts by integrating processing, assembly, conveyance, and inspection machines in a limited narrow space (micro processing technology, micro assembling technology, micro-fluidics technology, micro optical driving technology, micro electric driving technology, micro conveyance technology, and micro inspection technology).

② Comprehensive investigation and research

Investigation and research on the influence of micro-factories due to such problems as electromagnetic interference by integrating or concentrating various devices in a small space were conducted. In addition, MMC conducted the analysis of the economical effect of micro-factories, jointly with AIST's Mechanical Engineering Laboratory, and research on enhancing the performance of micro-electron guns for beam processing jointly with AIST's Electrotechnical Laboratory.

(3) R & D on Micromachine Technology

① Research on micromachine systems

In the medical field, R&D on miniaturization and multi-functionality of micro-laser catheters and micro-tactile sensor catheters were conducted. These catheters are the major functional components of a micro-catheter for diagnosis and treatment of cerebral blood vessels, an intraluminal diagnostic, and therapeutic system. Also R&D was conducted on the system of sampling and mixing of small amount of liquid, on micro gas analysis device, and on micro multi reactor required for the realization of medical micro system for analyzing and reacting a small amount of liquid which is used for screening substances that may be used for drugs. In addition, R&D on micro scanning imaging unit was also conducted.

② Comprehensive investigation and research

Investigation and research on micromachine technology was carried out on the future advanced applications of micromachine system to the medical field. With AIST's Mechanical Engineering Laboratory, MMC also conducted research on micromachine basic design and manufacturing technologies.

2. Investigation on R&D Trend of Micro-fluidics etc. on Creating New Industries (delegated to MMC by the New Energy and Industrial Technology Development Organization (NEDO))

MMC conducted investigation on R&D trend of micro-fluidics, patent research, manufacturing technologies and collected the relevant literature and analyzed them, and technical issues for developing the seeds were clarified.

3. R&D of Micromachine Materials (Joint research with the Mechanical Engineering Laboratory of AIST)

Jointly with the Mechanical Engineering Laboratory of AIST, MMC conducted (1) research on the operating environments for micro functional elements, (2) research on micromachine materials, and (3) feasibility studies on micromachine materials.

4. Research on the Applicability of Emerging Technology in Other Fields to Micromachine Technology (Aid activities from the Japan Motorcycle Racing Organization)

MMC pursued joint efforts among government, academia and industry to search out emerging technology in other necessary fields in order to promote the diversification and practical use of micromachine technology, and to verify its applicability and fusion.

5. Study of Overseas Applications of Micromachine Technology (delegated to MMC by The Japan Machinery Federation)

For creating new industries by micromachine technology from the viewpoint of considering what kinds of developments may lead to what kinds of utilization systems, MMC conducted study of concrete application samples of micromachine technologies and of their road maps for their practical applications.

6. Investigation and Research on Potential Health and Medical Applications for Micromachines in 21st Century Society (delegated to MMC by Mechanical Social Systems Foundation)

MMC conducted investigation on the needs for potential applications for the micromachine technologies from the viewpoint of health and medical use, and based on the technical seeds needed the investigation on the new systems meeting them was conducted.

7. Investigation on R&D Trends of Micromachine Technology in Japan and Abroad

For the purpose of enhanced and convenient data base construction, contents and trends of international conferences and academic meetings were investigated.

8. Study of Future Element Technologies of Micromachine Systems

Based on the accumulated data, the conceptions of element technologies needed for future micromachine technologies were systematically clarified and investigation for defining the future conceptions of systems was carried out.

II. Collection and Provision of Micromachine Information

① MMC has collected and sorted periodical journal, documents, and other materials on micromachines. ② Major materials were provided to those concerned, in our periodic "Micromachine Index." ③ Starting last year MMC has been providing public relations magazines in English and micromachine technology related event information in addition to introduction of MMC in Japanese on the Internet.

III. Exchange and Cooperation with Worldwide Organizations Involved with Micromachines

1. Research Grants for Micromachine Technology

MMC has solicited applicants for Micromachine Technology Research Grant in fiscal 1999 (7th) and has provided Research Grants for 13 themes, including seven new themes and six carried over at universities for R&D on basic micromachine technology. This was also meant as a contribution to the development of micromachine technology as well as promotion of exchange between industry and academia.

2. Participation in International Symposiums and Dispatching Missions

① Dispatch of a mission to English universities and enterprises in April 1999
② Participation in ICEE '99 (International Conference of Electrical Engineering '99) held in Hong Kong in August 1999 and a technical presentation on "Development of Advanced Micromachine Maintenance Technologies for Power Plants"
③ Dispatch of a mission in September 1999 to Netherlands, Switzerland and Germany for the investigation of application trends of micromachine technologies
④ Participation in SPIE ÅiMicromachining and MicrofabricationÅjheld at Santa Clara, US in September 1999
⑤ Participation in ME '99Åi1999 International Mechanical Engineering Congress & ExpositionÅjheld at Nashville, US in November 1999
⑥ Participation in IARPÅiInternational Advanced Robotics ProgramÅjheld at Moscow in November 1999 and a technical presentation centered on the assembling technology of micro-factory
⑦ Participation in Photonics West held at San Jose, US in January 2000 by SPIE
⑧ Participation in MEMS 2000 (13th MEMS International Conference) held by IEEE and cosponsored by MMC in January 2000 at Miyazaki
⑨ Dispatch of a mission in February 2000 for the investigation of the micromachine technology for maintenance micromachine in Germany and Switzerland and for standardization trend in Europe
⑩ Dispatch of a mission in February 2000 to US for the investigation of quality characteristic measurement technology and its standardization trends of the materials for micro devices composing micro-factories

3. Participation in the 5th Micromachine Summit

MMC participated in the "5th Micromachine Summit" held At Glasgow, Scotland, U.K., in April 1999.

4. The 5th International Micromachine Symposium

The 5th International Micromachine Symposium was held in October 1999 at Tokyo Science Hall, jointly sponsored by the MMC and Japan Industrial Technology Association.

5. Overseas Seminars

In June 1999 MMC held the European Seminars in France, Italy and Spain jointly with the relevant local organizations there. In November 1999 MMC held the North American Seminar at Cleveland, US jointly with the relevant local organizations there.

IV. Standardization of Micromachine

1. International Standardization Program for Assisting New Industries "Standardization of Quality Characteristic Measurement Evaluation for Micromachine Materials" (delegated to MMC by the New Energy and Industrial Technology Development Organization (NEDO))

A comprehensive investigation on the technology development trends both at home and abroad, formation of policies to be proceeded, selection of items and conditions appropriate for standardization were conducted. For the themes to be promoted, a standardized tensile test method, and toward the Round Robin Test to be conducted in the second year, the processes for selecting the materials for thin film test pieces and forming them as free as possible from quality variation were studied.

2. R&D on Standardization

Following the work conducted last year, studies were carried out as follows.

① The past studies were systematically reorganized toward the issue of "MMC Technical Report on Measurement Evaluation Method of Micromachine"
② As the first working item of the "Micromachine International Standardization Forum", established 15, November 1998 composed of 12 countries/regions the issue of standardization of technical terms was internationally discussed.

V. Dissemination of Information and Education about Micromachine

1. Public Relations Magazines

MMC published four public relations magazines, respectively in English and Japanese.

2. Micromachine Drawing Contest

MMC held the "6th Micromachine Drawing Contest" with the assistance of MMC's supporting members and Science Museum. 34 elementary schools and junior high schools sent us 3,215 pictures. MMC selected 30 pictures for awards.

3. Presentations of the research results on Fundamental Micromachine Technology in fiscal 1998

Presentations of the research results on Fundamental Micromachine Technology in fiscal 1998 as an aid activity from the Japan Motorcycle Racing Organization were held on two occasions, July 1999 and January 2000, in Tokyo.

4. Domestic Micromachine Seminars

MMC held "Domestic Micromachine Seminars" for people interested in R&D on micromachine technology, in September 1999 in Morioka (Iwate Prefecture), and February 2000 in Oita (Oita Prefecture).

5. MMC Activity Introduction and Promotional Videos

The video on the results of Industrial Science and Technology Frontier Program and an educational video for children were renewed.

6. Publication of Educational Brochure for Children

A brochure titled "What is Micromachine?" targeted for higher-class members of elementary schools, junior high school students and their teachers was published.

7. 10th Micromachine Exhibition

MMC held the "10th Micromachine Exhibition" in October 1999 at the Science Museum in Tokyo.

The Research Reports under the 6th Micromachine Technology Research Grant

Micromachine Center (MMC) is promoting the researches and developments of national project "Micromachine Technologies", one of the Industrial Science and Technology Frontier Program of Agency of Industrial Science and Technology (AIST), Ministry of International Trade and Industry (MITI), entrusted by New Energy and Industrial Technology Development Organization (NEDO). At the same time, MMC is conducting independent activities to promote R&D and its diffusion of micromachine technology.

The above mentioned research grant program started invitation in 1993 as a part of independent activities of MMC, intended to assist college and university staff engaged in basic research on micromachines, as well as to promote further development of micromachine technology and communication between academics and people in the industrial world.

Among themes selected for the sixth (1998) research grant, one 1-year research and five 2-year researches carried over from fiscal 1997 have been completed.

Turn the pages for the summary of the research results.

Subjects for the Micromachine Technology Research Grant

Research Project Selected for Fiscal 1998

Leader & Co-Worker	Affiliation	Subjects	Period
Assoc. Prof. Osamu Nakabeppu	Dept. of Mechano-Aerospace Engineering, Tokyo Institute of Technology	Development of dynamic valve type micro-pump driven by vapor bubble oscillation	1 Year

Carried-Over Projects Selected for Fiscal 1997

Leader & Co-Worker	Affiliation	Subjects	Period
Dr. Toshihiro Itoh	Assoc. Prof., Research Center for Advanced Science and Technology, The University of Tokyo	Plasma etching using scanning probe microscope	2 Years
Prof. Shuichi Shoji, Ph.D. Dr. Osamu Tabata	School of Science and Engineering, Waseda University Assoc. Prof., Faculty of Science and Engineering, Ritsumeikan University	Fundamental study on microchip for DNA analysis	2 Years
Prof. Katsutoshi Kuribayashi, Dr. Eng. Dr. Seiji Shimizu	Faculty of Engineering, Yamaguchi University Lecturer, Faculty of Engineering, Yamaguchi University	Development of pre-stretching method of SMA thin film actuator on Si wafer	2 Years
Prof. Tadashi Matsunaga, Dr. Eng.	Department of Biotechnology, Tokyo University of Agriculture and Technology	Development of a nano-probe for detection of a cell surface protein	2 Years
Dr. Kenji Suzuki	Lecturer, Graduate School, Faculty of Engineering, The University of Tokyo	Measurement and control of friction in micromachines	2 Years

Application Guidelines for the 8th (Fiscal 2000) Research Grant Themes on Micromachine Technology

1. Object of the research grant
Basic research on basic technology, functional element technology and systematization technology of micromachines

2. Research period
Theme A: April, 2001 - March 31, 2002, or
Theme B: April, 2001 - March 31, 2003

3. Application period, theme decision and fund grant date
Application period: July 1 - October 31, 2000
Theme decision: Middle of March 2001
Fund grant date: Late in March 2001

4. How to apply
Send a fax request for the application form to Micromachine Center, with your fax number specified.
Fax: +81-3-5294-7137

5. Qualification
College or university faculties (professors, associate professors, lecturers and research associates) who belong to the academic societies which are affiliated with Federation of Micromachine Technology

6. Others
(1) Total fund granted: about 15 million yen
(The limit for a single research is 2 million yen for theme A and 3 million yen for theme B.)
(2) We may ask the grant receivers to carry out the researches in cooperation with supporting member enterprises of the Micromachine Center after the grant is decided, since one of the objectives of this project is to encourage communication between enterprises and academies.
(3) Reference: Research Department, Micromachine Center (persons in charge: Hodono)

Development of Dynamic Valve Type Micro-Pumps Driven by Vapor Bubble Oscillation

Osamu Nakabeppu
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Tokyo Institute of Technology

1. Introduction

"A Dynamic Valve Pump" (DVP) drives fluid by the periodic pulsation in a liquid chamber provided with a couple of nozzle-diffuser-shaped inlet and outlet, and is suited for micronization due to its simple structure and freedom from trouble related to friction or leakage. It is now under research and development as a liquid-driven element for a micro-analysis system as well as for cooling the inside of next-generation CPUs.

The DVP is normally driven by piezoelectric effect for liquid chamber pressure pulsation. In this research, however, a DVP was developed to utilize the oscillation of vapor bubbles generated in the liquid chamber with the intention of both improving the life and reliability of a pump with movable parts removed and also developing a new pump that works thermally.

2. A Bubble-driven Micropump

Fig. 1 shows a typical asymmetrical channel shape and a trial manufactured micropump. The channel is formed by laser-drilling a stainless steel plate, 200 µm in thickness, with its throat part 200 µm width. A pump is structured by placing the channel on a glass plate with a 400 µm heater, and then sealing it with a metal flange from top and bottom. Water or ethanol is used as working fluids. When a square wave form voltage is applied at the predetermined frequency and voltage, a bubble is formed and its oscillation actuates the pump. The pump pressure and flow rate can then be measured by the changes in liquid level inside the glass tube installed at the outlet.

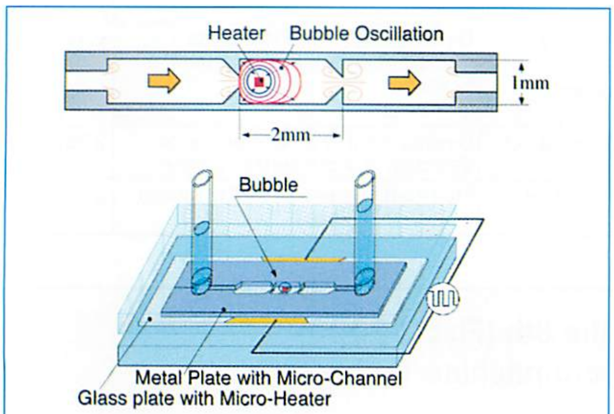

Fig. 1 Asymmetrical channel shape and bubble-driven micropump

3. Experiment Results

Fig. 2 shows how a bubble behaves when heated and when not heated. The bubble starts a volume oscillation at around a certain average diameter, pushing the fluid to the right by blocking the left channel when expanded and leading the liquid from both sides into the liquid chamber when shrunk. This movement is considered to generate a pump pressure.

The trial manufactured micropump attained a maximum pressure of 80 Pa and a maximum flow rate of 200 µl/min, which confirmed that an almost linear relationship exists between the generated pressure and the flow. In addition, Fig. 3 gives the findings of pump characteristics when frequencies were changed under definite heating conditions. The bubble-oscillated pump

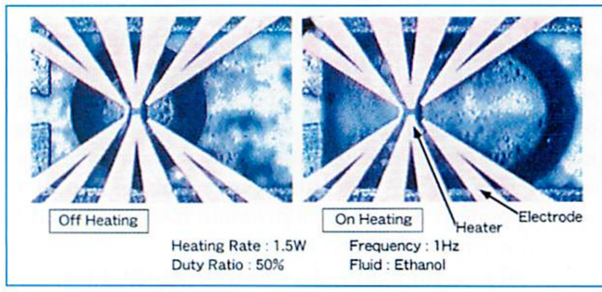

Fig. 2 Air bubble movement

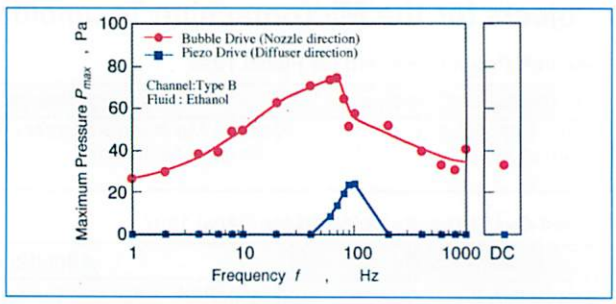

Fig. 3 Working characteristics of bubble-driven and piezo-driven micropumps

exhibits a pump action over a wide frequency range of 1 ~ 1000 Hz at which the experiment was carried out, and it performed best at around 100 Hz. This frequency can be considered as a kind of resonance frequency with bubble oscillation well-matched with fluid movement. On the other hand, when liquid chamber pressure was pulsated by piezoelectric effect in the same shape channel, pump effect was confirmed only in a frequency range of 40 to 200 Hz, with best results attained at around 100 Hz. The difference between the above two cases may be considered due to the difference in working principle as described below: Bubble type: A bubble is blocked from flowing in the direction of a narrower channel due to surface tension effect, and allowed to expand only in the direction of a wider channel. Piezo type: Pump pressure is generated from asymmetrical fluid movement in an asymmetrical channel. It is to be noted that pump pressure is generated even at a high frequency of 1000 Hz, a frequency impossible for a bubble oscillation movement to keep up with, because the bubble, when DC-heated, oscillates from self-excitation. This was confirmed by the experiment in which a bubble started to oscillate, even when the heater was DC-heated, to generate pressure.

4. Conclusion

The author confirmed that a vapor bubble, when formed and oscillated in a minute asymmetrical channel, acts as a micropump, and investigated the characteristics of the pump. In comparison with the piezo-driven DVP in the same shape channel, the bubble-driven one was confirmed not only to exhibit a pump effect over a wide frequency range, but also to work by the self-excited oscillation of the bubble even when DC-heated. The foregoing characteristics suggest to the author the possibility of a self-sustaining cooling system for the CPU cooling in which waste heat can be utilized directly for fluid driving.

Plasma Etching Using Scanning Probe Microscope

Itoh Toshihiro
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The University of Tokyo

1. Introduction

Minute surface processing using a micromachine probe can be expected to be applied to local lithography in nanometer order or a wafer probe card for the inspection of integrated circuits (IC). In this research, studies were made of the development of fundamental technology for plasma etching using a scanning probe microscope (scanning probe plasma etching), and the application to a probe card for IC test.

2. Scanning Probe Plasma Etching

Fig. 1 shows the schema of a scanning probe plasma etching system for which this research is intended. In this system, plasma processing is carried out by applying a DC bias to an oscillated probe, when a dynamic scanning force microscope (SFM) is operated in a reaction gas. Plans called for using a piezoelectric cantilever array as a probe to enable parallel operation particularly for the realization of simultaneous multiple-point processing. To this end, this research was devoted to the development of a micro-SFM to enable three-dimensional scanning with a probe alone as well as to the processing using a dynamic SFM.

In the former case, a device was designed and manufactured as shown in Fig. 2(a) using a $Pb(ZrTi)O_3$ film prepared by the sol-gel process for the study of the working characteristics of the device. The probe shown in Fig. 2(b) enabled scanning a 1 μm zone, and was provided with a vertical resolution of around 1 nm under standard operation conditions. In the latter case, an Au conductive cantilever was used as a probe and CF_4 as a reaction gas so that a probe plasma etching device was structured based on the dynamic SFM to enable local processing of the Si surface at a base vacuum of less than 1×10^{-5} Torr, an operation pressure of 0.1 ~ 1.0 mTorr after gas introduction, and a bias voltage of less than 20 V.

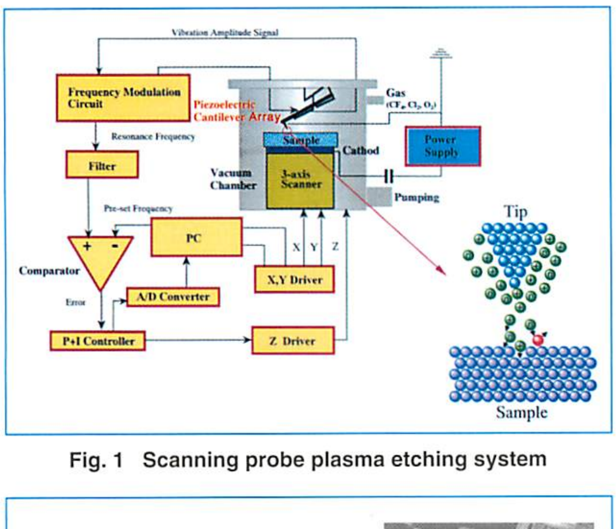

Fig. 1 Scanning probe plasma etching system

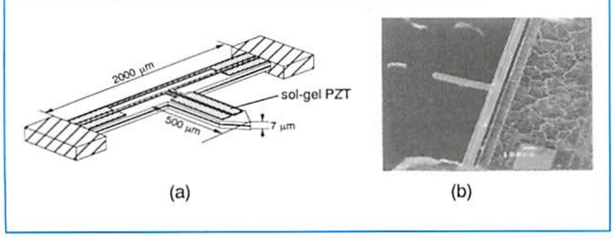

Fig. 2 Piezoelectric microscanning force microscope enabling three-dimensional scanning

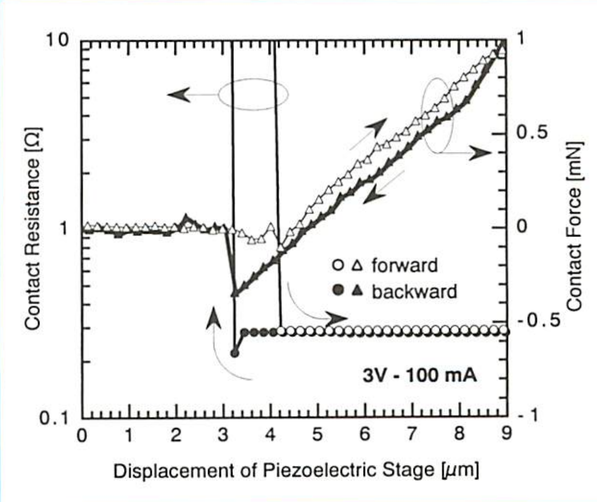

Fig. 3 Fritting characteristics of Au-plated probe

3. Micromachine Probe Cards

A probe card has usually been manufactured by manually mounting metal needle probes on a printed circuit board. It becomes possible, however, to test IC devices with a minute pad-size pitch, necessary for high-speed inspection, if a probe card can be batch-manufactured on a Si substrate by micromachining. In such a micromachine probe card, however, it becomes necessary to employ another oxide film removal method, because each probe fails to withstand the force so far required for removing an oxide film on the pad surface mechanically. This in turn has led this research to study "fritting", one of the methods of local probe processing, for application to those micromachine probe cards. After measuring a probe contact force and an adhesive force after contact, necessary for fritting, it was found that, in the case of Al film, an IC pad material, a low contact resistance of less than 0.3 Ω can be obtained without applying external force (contact force) by fritting with an Au-plated probe. It was further revealed that a micromachine active probe card enabling the direct change of contacts, can also be realized since the resulting adhesive force was around 0.3 mN.

4. Conclusion

As described above, this research has demonstrated the possibility of realizing a plasma etching system using a scanning probe microscope by developing the fundamental technology necessary for this system, along with the effectiveness of fritting, one of the methods of probe processing, by proposing a micromachine probe card for IC test as the application of probe etching.

Fundamental Studies on Microchip for DNA Analysis

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Osamu Tabata
Associate Professor, Faculty of Science and Engineering, Ritsumeikan University

1. Introduction

Micromachine technology is expected to greatly improve the accuracy and speed of processes ranging from extracting DNAs from organisms to determining the sequence of nucleic acids. When structuring a microsystem with which to realize this technology, it is necessary to research and develop the basic techniques, including the handling of micro-structures (DNAs) in a micro scale zone, the design of a microchannel based on micro-fluidics, and the high-sensitivity detection of DNAs in the multiple micro-structures. To achieve this objective, studies were made of micro-fluidic elements and microreaction systems for handling biological samples, and microchips for high-sensitivity DNA electrophoretic analysis. Specifically, micro-valves for introducing organism samples into multiple analytical cells, and micro-flow-cells for mixing and reacting samples and reagents were developed. In addition, microchips were designed and trial manufactured, provided with multiple electrophoretic microchannels with a high aspect-ratio structure that can be realized by the LIGA process.

2. Micro-fluidic Elements and Microreaction Systems for Biological Sample Handling

A pneumatic microvalve was fabricated by the method of forming a microchannel or a pressure chamber between silicon and silicon film or Teflon film in a low temperature (below 100 °C) process with a positive photoresist used as a sacrificial layer, and evaluated relative to its characteristics. A practical and disposable microvalve for introducing samples was realized by a structure in which a microchannel is separated from actuator parts. One-input-and-4-output valves of switching and flow types were fabricated for introducing samples into multiple analytical cells. A piezo-resistance diaphragm pressure sensor was integrated for controlling an actuator.

A mechanism becomes necessary for mixing two kinds of liquids since the liquids form a laminar flow in a microchannel. It also becomes important to control the temperature of a cell in which biochemical reaction takes place. A microflow cell for mixing/reaction was trial manufactured, the structure of which is given in Fig. 1. Since mixing in a laminar flow zone is forced by dispersing two kinds of liquids through their interface, a structure is designed so that the area of interfaces can be increased to as large as possible by inducing reagents from many micronozzles against the sample flow. A microstructure, made by forming a macroporous structure with silicon anodized, was employed to realize many micronozzles. Fig. 2 shows a photo micrograph in the vicinity of a sample inlet when a fluorescent material was used as a sample. The reaction part consists of a Ti-Pt film heater and a p-n junction temperature sensor, both of which are formed on the silicon substrate, and was confirmed to be capable of finishing the PCR reaction in about two minutes per cycle by PID temperature control.

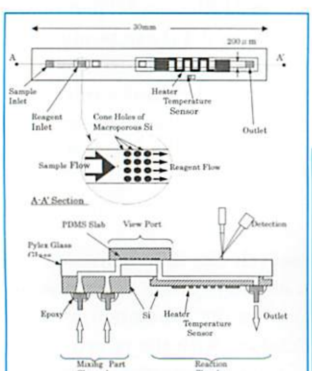

Fig. 1 Micro-flow-cell for biochemical reaction/mixing

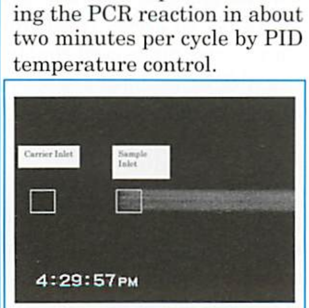

Fig. 2 Photomicrograph of the sample inlets part

3. Studies of Microchips for High-Sensitivity DNA Electrophoretic Analysis

As a biochip for analysis, a microcapillary-array electrophoretic chip (a μ-CAE chip) was devised, which uses laser-excited fluorescence for detection. Also proposed was a process involving a combination of the PMMA processing using moving mask deep X-ray lithography (M^2DXL), manufacture of a metal mold by plating, plastic molding by hot embossing, and junction using UV-curing adhesives. Experiments were then carried out to verify the possibility of realizing the biochip in question. Fig. 3 shows the concept of the microcapillary-array electrophoretic (μ-CAE) chip for DNA analysis. In the microchannel array on the chip, alternate channels are arranged in which DNA-containing samples and a buffer solution flow, respectively. The sample and buffer solution are supplied from an injecting hole provided at one end of the channel, and the DNA in the sample is separated during the electrophoresis of the sample from left to right on the chip. For detection laser-excited fluorescence is used. In the rear of a part where all the channels are formed in parallel (a parallel flow part) a fluorescence detection part is provided with partitions between the channels removed. The flow in the detection part should be the one with the sample separated not by the partition but by the buffer solution - a multi-sheath flow. The fluorescence excited in the channel improves its detection sensitivity when condensed in the microlens array. An inclined angle was found controllable in a range of 90° to 75° when a mask, 50 μm in channel width, is used in accordance with the M^2DXL method and when the diameter of gyration is changed in a range from 0 to 15 μm. This enables mass-production of μ-CAE chips, with many micro-capillaries densely arranged, at a lower cost by molding. In addition, a microlens array was molded experimentally using a PMMA die concaved according to the M^2DXL method, accompanied by the success in manufacturing a lens-like shape.

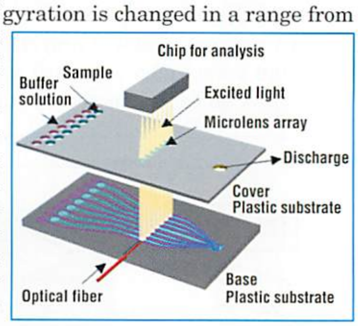

Fig. 3 Conceptual drawing of μ-CAE chip

4. Conclusion

This research was devoted to the study of practical micro-fluidic elements and microreaction systems for handling organism samples, resulting in the development of practical microvalves, improvement of the rate of mixing/reaction between biochemical substances and reagents, and acquisition of much expertise. Currently, to find solutions to problems related to damage, including the sticking to and the collision against the channel walls of organic substances, research is under way on micro-flow-cells for the realization of a complete sheath flow as well as on a microreaction cell array aiming at realizing various biochemical reactions simultaneously. The new concept of a μ-CAE chip was also proposed along with the studies of a processing technique in which are combined M^2DXL (moving mask deep lithography), plating, and hot embossing. And a possibility of realizing this processing process could be confirmed experimentally. In the future, studies will be made not only of realizing a μ-CAE chip with each processing technique integrated but also of a technique with which to manufacture a molecular sieve in a microchannel by combining the above processing techniques with another in the submicron order.

Development of Pre-Stretching Method of SMA Thin Film Actuator on Si Wafer

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Yamaguchi University

1. Introduction

A problem that arises when fabricating a shape memory alloy (SMA) microactuator on a Si wafer is how to develop a heat treatment process to automatically prestrain without human assistance. For this research a polyimide heat-shrinking material was used.

2. Findings

Fig. 1 shows the method of fabricating an SMA actuator on a Si wafer, and a process of prestraining a curl-type SMA actuator. The procedure for this process is as follows:

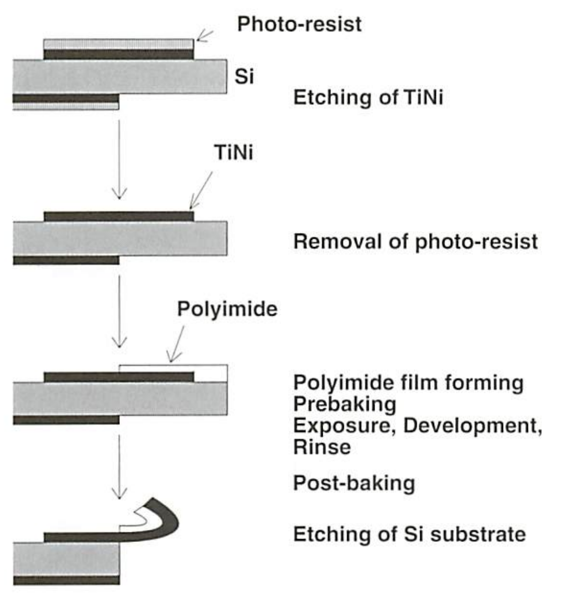

Fig. 1 A fabrication process of an SMA (TiNi) actuator using polyimide

Form a thin SMA (TiNi) film, about 5 μm thick, on both sides of the wafer by the sputtering method, and heat treat them so that the original flat shape is memorized. Coat a resist for photolithography on them. Then, etch them after making an actuator pattern on the surface and another pattern on the other side to partially remove a silicon wafer. Next, coat polyimide to a part of the SMA on the surface so that it shrinks by heat. Since polyimide acts as a bias spring after it shrinks, the polyimide-coated part turns flat with the recovery force of the SMA when heated, curling like a circular arc when cooled by the effect of a bias spring.

Fig. 2 is a photograph of the SMA microactuator formed. Six actuators are shown formed on a 20 mm × 15 mm silicon wafer. The white part shows the through hole of the silicon wafer, exposing paper underneath. In addition, Fig. 3 shows one of the actuator turned flat by electric heating and curled at room temperature. Fig. 4 shows that the actuator responded when dynamically actuated. The deformation of the SMA, actuated by applying voltages, 0 and 2 V, alternatively, is shown detected by the electromagnetic distance sensor.

Fig. 2 Side photograph of an SMA actuator fabricated (6 actuators en bloc)

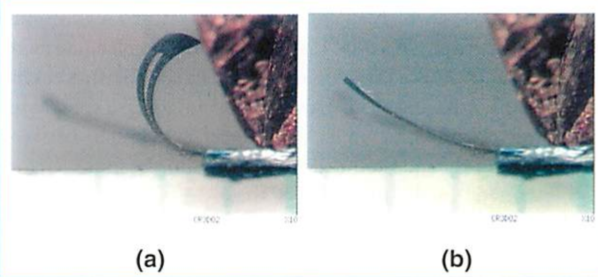

Fig. 3 SMA actuator deformed by electric heating
(a) Voltage = 0.0 V (b) Voltage = 1.5 V

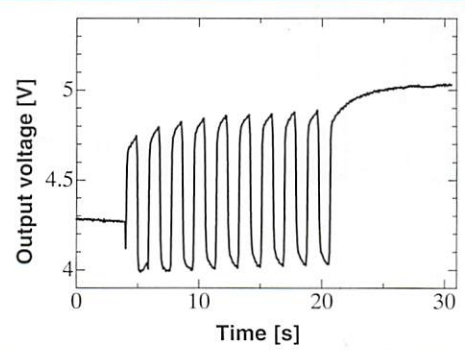

Fig. 4 Results of response of SMA actuator applied by alternating square wave form voltages, 0 and 2 V

3. Conclusion

A method of fabricating an SMA microactuator using polyimide for prestraining was developed and it was confirmed that the actuator made by this method works well.

Development of Nano-probe for Detection of a Cell Surface Protein

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Tokyo University of Agriculture and Technology

1. Introduction

The measurement of a force curve by the atomic force microscope (AFM) has already enabled the detection of the force of interaction between bio-molecules at the single molecular level. In this project, based on the expertise accumulated, a molecule-recognition protein is used as an AFM probe to investigate its applicability as a micro-detection system. Emphasis is placed particularly on the development of a new probe so that bacteria can be detected at the single cellular level by using anti-bacteria antibodies as biomolecule-recognition proteins.

2. Imaging of Antigen Antibody Reaction Using a Probe with Antibodies Inmobilized

With the measurement of a force curve by the AFM, the force of a specific bond between bovine serum albumin (BSA) and anti-BSA antibodies was confirmed to be 100 to 200 pN. Therefore, AFM imaging was done in an attempt to recognize the specific interaction using a probe with anti-BSA antibodies immobilized and a BSA substrate. For the substrate, a slide glass was used to which a gold nano-sized pattern was applied by bead lithography. An auto histogenetic monomolecular membrane of the BSA was formed on the gold surface with a chemical crosslinking agent (Fig. 1A). By AFM imaging a contrasted image was obtained, in which the difference in height between the surface of the gold nano-size pattern and the glass surface was enhanced in the presence of the BSA and the anti-BSA antibodies (Fig. 1B). The unevenness of an AFM image depends on the forces of interaction, including the molecular force between a probe and a sample surface. When a probe with antibodies immobilized was used, a difference in height of the image was considered a result of the force of adsorption to the BSA substrate. This suggested the possibility of recognizing an antigen antibody reaction of 100 to 200 pN by AFM imaging.

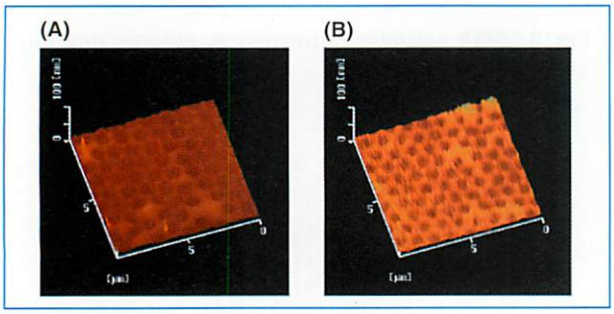

Fig. 1 (A) AFM image of BSA-patterned array using a non-treated probe.
(B) AFM image of BSA-patterned array using an antibody-conjugated probe.

3. Imaging of the Superficial Protein *E. coli* using a Probe with Antibodies Immobilized

E. coli (DH5α,JM109), prepared at a concentration of 1 × 10^9 cells/ml, was placed on a slide glass to air-dry and immobilize, and was used for the detection of a specific adsorption force by measuring a force curve using a probe with anti-*E. coli* antibodies immobilized. Even when a probe with no antibody immobilized was used, an adsorption force of below 600 pN was observed, suggesting that this interaction is a non-specific force working between the *E. coli* surface and the probe. On the other hand, when a probe with antibodies immobilized was used, a force of 600 to 2000 pN was observed. When *Pseudomonas aeruginosa* was immobilized as a control on a slide glass, its adsorption force was not detected as equal. This suggests that the resulting adsorption force is based on a bond derived from the antigen-antibody reaction.

Next, the imaging of one cell of *E. coli* was done using a probe with anti-*E. coli* antibodies immobilized. Then, the probe was allowed to approach the same position where an untreated probe was set for operation to observe the same *E. coli*. Image processing software was used to obtain a fault image so that the form and size of the *E. coli* observed could be compared (Fig. 2). No difference in fault image was observed between the two cases, confirming that the same *E. coli* was observed. On the other hand, the thickness of the *E. coli* was compared when the difference in height reached a maximum, and it was found to be 150 nm for the untreated probe and 250 nm for the treated one.

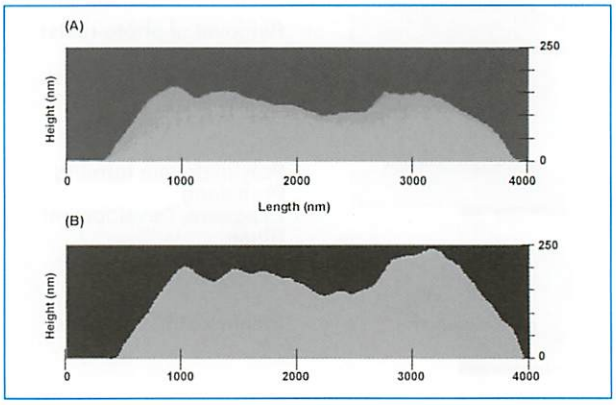

Fig. 2 Sectional view of *E. coil* using non-treated probe (A) and antibody immobilized on probe (B).

The findings in the 2 cases of image processing agreed, suggesting that the protein on the surface of *E. coli* can be recognized when anti-*E. coli* antibodies are used and that the AFM enables recognition of the interaction between the superficial protein and the antibodies.

4. Conclusion

As a result of this research, it was possible to recognize the antigen antibody on the single molecule level with identical results obtained, even on the surface of the live cell. The technique of imaging the interaction of one bio-molecule is expected to enable the structuring of a super-high-sensitivity sensor.

Measurement and Control of Friction in Micromachines

Kenji Suzuki
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The University of Tokyo

1. Introduction

On the sliding surface of a micromachine, the influence of several different forces working between the two surfaces relatively increases, including the van der Waals force, electrostatic force, and meniscus force of water adhered to the surface, in proportion as the vertical load decreases extremely, thus wielding a great influence on friction. In this research, a frictional force and an interfacial force under microload conditions were measured with the intention of both clarifying the phenomena of friction peculiar to a microzone and also to control actively the frictional force by changing the properties of the surface.

2. Measurement of Frictional Force

A friction tester, as shown in Fig. 1, was developed for the measurement of frictional force and interfacial force under microload conditions. This tester is structured so that a flat sample is pressed against a pin, and moved in the directions of the load and friction so as to be able to measure the load, frictional force, and pull-off force working on the pin end. For detecting microforce, two sets of parallel leaf springs crossing at right angles were used. The forces in the directions of x and z were obtained by measuring the deflection of the spring with the capacitance displacement gauge. The resolving power of the frictional force is 1.93 μN. This tester was put in a constant humidity cell that enabled setting relative humidity at any optional value between 20 to 90%. A silicon wafer and a diamond probe with a tip radius of 10 μm were used as a flat sample and a pin, respectively. A wafer coated with PFPE lubricant, which is widely used for magnetic recording applications, was also measured relative to the effect of the lubricant.

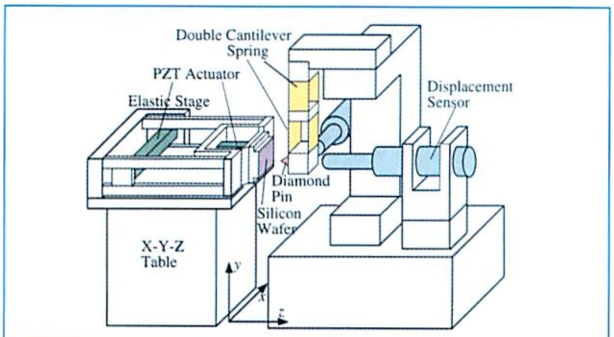

Fig. 1 Friction tester

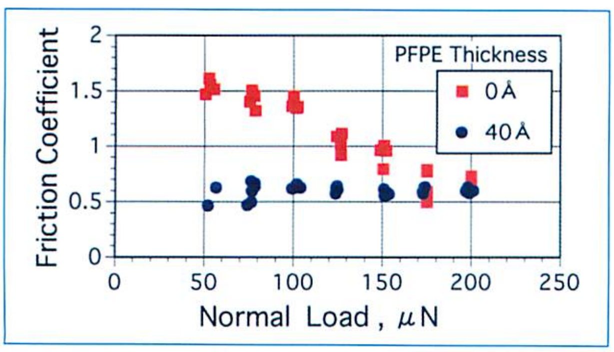

Fig. 2 Relationship between load and coefficient of friction

Fig. 2 shows the results of measuring the load and the coefficient of friction at a humidity of 80%. When no lubricant was applied, the coefficient of friction increased in proportion as the load became smaller. This is considered due to the suction force (meniscus force) of water adsorbed onto the surface in addition to the load as a thrusting force. On the other hand, when a lubricant is applied, the coefficient of friction does not depend on the load. This is considered due to the hydrophobicity of the lubricant, which makes it harder for water to be adsorbed onto the surface.

3. Control of Frictional Force

In this research, control by means of vibration of the friction surface was used as a method for controlling frictional force. As Fig. 1 shows, a piezoelectric element is mounted on the back of the stand of a silicon wafer sample so as to be able to shake the wafer surface in the directions of x, y, and z. With a load of 120 μN and a sliding velocity of 4.12 μm/s frequency and amplitude of the oscillation were changed to check the changes in frictional force. The natural frequency of the parallel leaf spring being 51 Hz, the frictional force measured by the spring is "an apparent force" with the changes in force averaged in terms of time. In other words, an apparent frictional force is controlled in this research by changing the directions of sliding and the loads with the high frequency. Fig. 3 gives the relationship between the frequency and the coefficient of friction when vibration amplitudes of 0.05, 0.15, and 0.25 μm were applied in the direction of y. The coefficient of friction μ is normalized by μ_0, the coefficient of friction when no vibration is applied. The coefficient of friction decreases as the amplitude or frequency increases. It can be seen that the coefficient of friction changes over a wide range from μ_0 to 0. This shows that a frictional force can be controlled by changing the frequency and amplitude of vibration. It was also confirmed that the value calculated for the coefficient of friction agrees well with the empirical value.

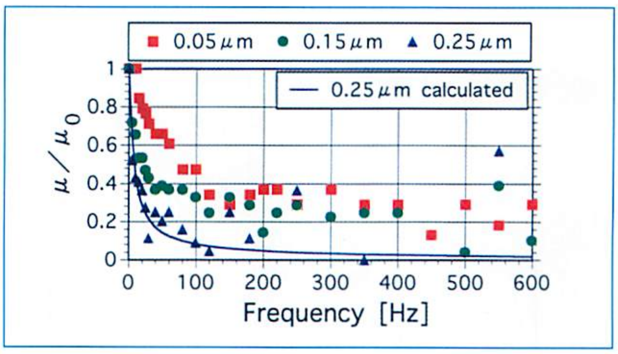

Fig. 3 Changes in coefficient of friction by oscillation

4. Conclusion

The influence of an interfacial force on a frictional force was investigated by carrying out friction tests under microload conditions. In addition, it was demonstrated that an apparent frictional force can be controlled by shaking the surface. The writer is considering the development of a micromachine by utilizing the above-described phenomena in the future.

OLYMPUS OPTICAL CO., LTD.

Atsushi Yusa
Director-General, The Basic Technology Research Institute

1. The Challenge of Micromachine Technology

Micromachine technology has been positioned as a technology to support miniaturization and the high performance of our company's products in the fields of medicine and industry is to be the core of a new project. In order to acquire the technology that may be called the lifeline of our company, we have participated in "Micromachine Technology," Industrial Science Technology Frontier (ISTF) Program incorporating advanced R&D activities.

2. Development of Micromachine Technology

In the ISTF Program, our company has researched a micromachine entering a complex structure, such as a complicated machine, the inside of a human body, etc., and performing inspections or repair operations.

In the technology development of an industrial micromachine, our corporation has been in charge of the development of an experimental system for internal work in an appliance and have developed a technology by which repair work can be performed inside a small space, as well as the technology in which functional devices are densely assembled three-dimensionally. As to a module for a repair work, we have experimentally produced a shape memory alloy (SMA) manipulator onto which a microlaser welding device is mounted, and have confirmed that welding work can be executed to the degree of positional accuracy 0.5 mm or less.

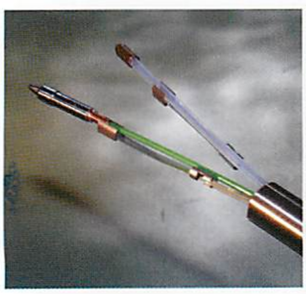

Fig. 1 Module for repair

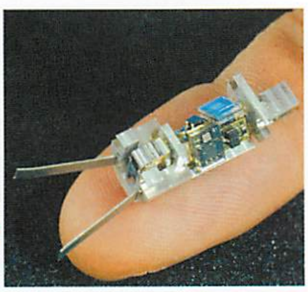

Fig. 2 Module of the head part electric equipment system

It is necessary to install a large number of the measuring devices necessary for the welding work in the head of the experimental system. We have thus developed a three-dimensional mounting technique employing a multifunctional integration film (MIF) technology wherein a large number of functions are internally equipped in thin films. In the experimentally produced head part electric equipment system module, a SMA manipulator, an attitude detecting device (manufactured by MURATA MANUFACTURING CO., LTD.), a monitoring device (manufactured by OMRON Corporation), and an IC for driving them are densely assembled three-dimensionally.

In this module, the functions of individual functional devices have been confirmed.

In the technology development of a micromachine for medical use, a bending function by an SMA wire is placed in a catheter with a diameter of 1.5 mm, and three micro contact force sensors composed of Si gauge sensors having a thickness of several microns are arranged in the tip. Active bending has been realized wherein the contact pressure with a blood vessel wall at the time the catheter is inserted is detected and the sensors and the bending function act so that the tip of the catheter is automatically bended in an evasional direction. Furthermore, we have developed a micro tactile sensor (1.5 mm) by which viscoelasticity information of an object, such as biological tissue, can be detected, employing a piezoelectric transducer.

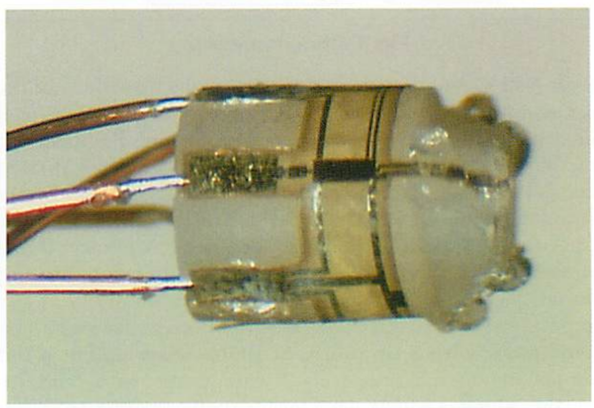

Fig. 3 The micro contact force sensor

3. Future Stance

Via the research into these micromachine projects, accumulation of micromachine element technologies, such as sensors and modules to which a micromachining technique has been applied and a new mounting technique, has progressed steadily. Hereafter, there are plans to improve these element technologies so as to expand existing projects including an endoscope-related project, and to develop the element technologies of the technique to be the core of a new project.

KAWASAKI HEAVY INDUSTRIES, LTD.

Osamu Miki
Associate Director, Electronic & Control Technology Development Center

1. The Challenge of Micromachine Technology

As a heavy industries manufacturer, our company has tackled these technological developments by taking relatively large objects, such as marine vessels, vehicles, and aircraft. However, hereafter, we plan to acquire new technology by executing technological research using small objects, and attempt to fuse a technology in which both large and small objects are handled so as to develop new business. In micromachine research, we have developed a technology by which maximum performance can be realized under restricted environments, including those in which there are limitations in size, power consumption, computer capacity, etc. By utilizing such technology it is believed that a technology developed by means of a micromachine can be utilized in a restricted environment, such as, for example, outer space.

2. Development of Micromachine Technology

A micromachine can easily enter a small spaces due to its size, and the technology utilizing this characteristic is expected to be an element technology in which a new style of maintenance and inspection is realized wherein the shutdown of operation in a power generation facility, etc., becomes unnecessary. However, a micromachine that is fully miniaturized is restricted in its function, so it is difficult to realize high functional work with just one machine. Thus, a method may be considered wherein a large number of micromachines are cooperatively operated so as to achieve the end purpose, and our company has executed R&D related to a control system through which an optional work pattern can be formed by plural micromachines. Although points of similarity exist between cooperative operation by plural micromachines and conventional group robots research, a different approach should be adopted due to specific limitations originated in the structure of a micromachine. In the present research, the limitations in the control of group micromachines have been rearranged assuming that all micromachines are uniform and a self-position can only be recognized in a relative manner, etc.; under these limitations a control algorithm has been proposed in which an optional pattern can be formed. In the present technique, each micromachine acts autonomously and forms an optional pattern while cooperating with other micromachines. With respect to the validity of the present technique, tests have been performed employing a simulator constructed on a computer (Fig. 1) and a small mobile robots (Fig. 2).

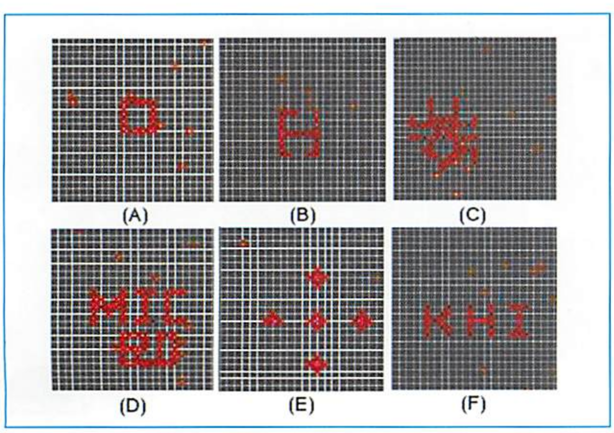

Fig. 1 Screen images of the motion simulator

Fig. 2 Experiment sight using small mobile robots

3. Future Stance

In the future, further leaps are expected in micromachine technologies, and there is little doubt that the areas of application will also expand commensurately. Based on the research results we have obtained so far our company plans to seek greater degrees of practicality, reliability and generalized applicability.

The 6th Micromachine Summit

The 6th Micromachine Summit was held over the three days from April 10 to 12 at the International Conference Center Hiroshima. It was the second conference to be held in Japan, after a gap of 5 years from the 1st Micromachine Summit held in Kyoto in 1995. The MMC International Committee acted as the organizing committee. Good weather conditions and beautiful cherry blossoms in full bloom contributed to the successful atmosphere throughout the events.

This Summit was attended by participants from a total of 15 countries and regions around the world (a total of 20 countries and regions have now been registered as members) including Korea and Singapore as new members.

The table below shows the breakdown of the numbers of participants.

	Overseas	Japan	Total
Delegates	50	4	54
Observers	13	26	39
Total	63	30	93

The 15 countries and regions that participated in the conference and their chief delegates are as follows:

Australia (Ian Bates)
Benelux (Albert van den Berg)
Canada (Dan Gale)
China (Zhaoying Zhou)
France (Daniel Hauden)
Germany (Wolfgang Menz)
Japan (Naomasa Nakajima)
Korea (Young-Ho Cho)
Mediterranean (Paolo Dario)
Nordic (Jan-Ake Schweitz)
Singapore (L. C. Lee)

Photo 1 The 6th Micromachine Summit at Hiroshima

Switzerland (Nico de Rooij)
Taiwan (Min-Shong Lin)
UK (Geoff Beardmore)
USA (Albert Pisano)

The Japanese delegates were represented by Dr. Naomasa Nakajima (chief representative), professor at The University of Tokyo, Dr. Tsuneo Ishimaru, Chairman of DENSO CORPORATION, Mr. Toshiro Shimoyama, Chairman of OLYMPUS OPTICAL CO., LTD., and Mr. Takayuki Hirano, Executive Director of MMC. Professor Nakajima chaired the conference, as the chief representative of the host country.

The conference was divided into eight sessions, each of which comprised a leading speech and short comments. The topics discussed in the conference were selected from among the various themes related to the development of micromachine technology, concentrating on the fundamental concepts ad-

Photo 2 The participants

dressed at the very beginning of the Micromachine Summit. The overview of the speeches and topics of discussion at respective sessions are described below.

"Country / region review"

Chief representatives of each country / region reported on their own current circumstances. Generally speaking the research activities have become increasingly active, with R&D projects related to microfluidics reported as a new enthusiastically-promoted field.

"Government policy"

Natural or Forced Collaboration? / Nordic
EU 5th Framework Programme & EUREKA / EU
The French Actual Position Compared with the Expected Ones Five Year Ago / France
Expectations to Government Policy from Industry / Japan

The importance of the roles of governments was discussed, including the roles of governments in a cooperative relationship between two nations with different industrial backgrounds, government assistance for micromachine technology that carries high risks in terms of commercialization, and the role of the government with respect to micromachine technology.

"Education"

The Use of Multimedia in Microsystem Education / Switzerland
MEMS / Micromachine Education in Tsinghua University / China
Schoolchildren and Micromachines / Japan

The topics included the importance of international cooperation in promoting educational programs that cover not only children but also professional engineers and the importance of education to acquire the knowledge and skills necessary to support the development micromachine technology. Due to their significance, the topics were designated for further discussion at the next Micromachine Summit.

"Standardization"

Standardization for Microsystems / Germany
Short Comments for Standardization / Japan
Standardization - the Aerospace Perspective / UK

The standardization of microsystems has been demanded, however, to date no concrete steps have been taken. The session focused on the necessity of re-examination of the purposes and targets of standardization, the necessary prerequisite procedures for commercialization, and the standardization of research procedures. A proposal was made for the creation of a study forum on the Web.

"Technology transfer"

MEMS Technology Transfer and Associated Problems / UK
MEMS Research in Nanyang Technological University / Singapore
Taiwan's Approach to MEMS Technology Transfer / Taiwan
Technology Transfers at Photonics Research Ontario / Canada

"Industrial infrastructure"

EU Scenario / Mediterranean
Toward the Industrialization of MEMS / Korea

Photo 3 Dinner tour to Miyajima Island

MEMS Commercialization: Taiwan's Foundry Role / Taiwan

In the "Technology transfer" and "Infrastructure" sessions, energetic activities were reported.

"Exploiting of application"

Microfluidics: Technology, Applications and Opportunities / Canada
The Unique Options Offered by Australian Cooperative Research Centre Model / Australia
Social Industrial Impact / China
Marketing Evaluation of the French R and D and Industry in Microtechnologies / France
Status of Fluidic MEMS in USA / USA
Wearable Micromachine / Japan
MEMS Activities in Singapore / Singapore
Micromachine Technology for Korea Industry / Korea
MEMS for Magnetic Disk Drives / USA

Various applications of fluidics, wearable devices, and hard disk drives were introduced. In addition, efforts to identify more applications were taken up as the subject of discussion.

"Prospects for the future"

Microfluidics in USA / USA
Micro Chemical Systems: A Paradigm Shift in the Chemical Industry / Benelux
NEXUS - Market Forecast & Road Map / NEXUS
Can Micromachines Fulfill our Dreams and Desires? / UK
Strategies for the 21st Century / Japan

The scenario of the future of micromachine technology was discussed. In particular, the paradigm shifts in the biotechnics and chemical industries that utilize micro-fluidics were examined. Further, the feasibility of micromachines meeting human needs in the future was positively evaluated and the necessity for efforts toward realizing these dreams was clarified.

At the end of the conference, the Chairman's Summary (introduced on the MMC Web site) was adopted. Decisions on the venues for the next summit conferences were made, with Germany selected for 2001 and Benelux countries for 2002.

After the conference programs, a dinner tour to Miyajima Island took place on April 12; a technical tour to MITSUBISHI ELECTRIC CORPORATION on April 13 and another tour to DENSO CORPORATION on April 14 were also well attended.

Latest Micromachining Technology — Part 2

Thin Film 3D Structures — Surface Micromachining

Professor Kazuo Sato
Graduate School of Engineering, Nagoya University

The previous issue explained the Bulk Micromachining that forms micro 3D structures on a silicon substrate using an etching technique. The Surface Micromachining in this issue refers to a technology that creates a complicated 3D structure by layering thin films over the surface of a silicon substrate, in sharp contrast to the techniques used in Bulk Micromachining.

1. Forming a structure with polycrystalline silicon thin film

The micro mechanical components and electrostatic micromotors developed by the University of California, Berkeley and MIT in the latter half of the 1980s which move on silicon substrate had a major impact on the researches of micromachine technology throughout the world. Those achievements were resulted from surface micromachining technology.

Figure 1 shows a SEM photo of the electrostatically driven micromotor developed by MIT. A star-shaped rotor, whose diameter is smaller than 0.1 mm, is enclosed with a stator which extends radially. In the center of the rotor, a shaft that holds the rotor in a fixed position is fixed to the substrate. All three of these elements are made of a poly-crystalline silicon thin film having a thickness of about 1 μm (0.001 mm). An electrostatic attraction force is generated in the gap between the rotor and the stator as voltage is applied. Where the edge of the rotor is dislocated from the edge of the stator circumferentially, the circumferential component of the force works on the rotor, which is then rotated.

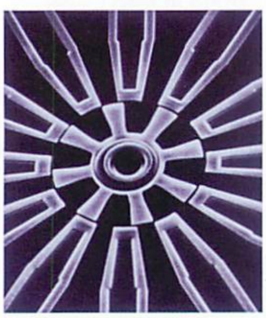

Fig. 1 Electrostatically driven micromotor made of poly-crystalline silicon film (Courtesy of Prof. M. Mehregany, Case Western Reserve Univ. USA)

Figure 2 shows the fabrication process of an electrostatic micromotor. The structural material poly-crystalline silicon thin film and the gap-creating material silicon oxide film are laminated alternately while being patterned by photolithography and etched. The stator and the shaft are fixed to the substrate, however, the rotor must be rotated freely with respect to the substrate. For that particular purpose, the surface of the rotor is covered entirely with the laminated silicon oxide film in the fabrication process. Finally, the whole structure is submerged in the etching solution (hydrofluoric acid solution) that selectively dissolves silicon oxide film only. As a result, the rotor is completely released from the substrate to become freely to rotate. It should be noted that the thin film that helps a structure to be independent as it dissolves away, as with the silicon oxide film mentioned above, is called a "sacrificial layer".

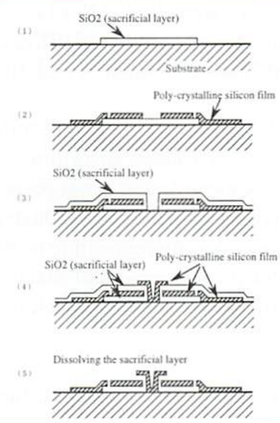

Fig. 2 Fabrication process steps of electrostatic micromotor

Unfortunately, the rotary type electrostatic motor has never been used in any practical applications. This is because the mechanical output from the low-torque and high-speed rotor is difficult to utilize and the bearings used in the system are easily degraded. However, surface micromachining technology has introduced a new product to the world in a different form. For example, Analog Devices Inc., U.S.A., has developed an acceleration sensor for automobiles as shown in Fig. 3. The H-shaped mass is floated about 1 μm above the substrate surface, except for the four ends of the legs which are fixed to the substrate surface. If acceleration is applied to the substrate

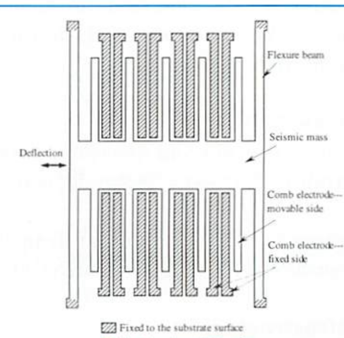

Fig. 3 Top view of poly-crystalline acceleration sensor structure

surface in the left/right direction in the figure, the four legs of the H-shaped mass are deflected and the central cross bar is displaced sideways. This displacement is detected as a variation in the gap between the electrodes which are engaged in the forms of combs. Furthermore, an electrostatic force is applied between the comb-shaped electrodes to cancel the displacement for servo control. The realization of this system in which electronic circuits such as servo circuits and amplifiers, and mechanical structures are integrated on a single chip has clearly demonstrated a model micromachine system, and is highly evaluated as a successful joint project in the US in the fields of industry and academia, and by the government.

2. Metal surface micromachining

Surface micromachining can be applied not only to the poly-crystalline silicon mentioned in the above paragraph but also to devices consisting of metal-based structures. By selecting good combinations of structural materials and sacrificial layers, thin film 3D structures can be formed just in the same manner as with the foregoing paragraph.

The digital light processing (DLP) device developed by Texas Instruments Inc., U.S.A., is another example of a successful project of surface micromachining. Figure 4 shows the principle of a video projector using the DLP device. About one million micro reflecting mirrors are laid over the surface of the DLP device. The mirrors are supported respectively with spring structures which swing the mirrors for a range of ± 10° in angle.

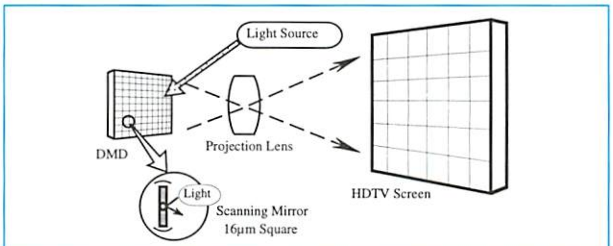

Fig. 4 Principle of the video projection system using digital micro-mirror device

The mirrors and springs are made of a thin aluminum film, while the sacrificial layer is polymer substance. The mirrors swing as they are driven electrostatically. The motion of each mirror is individually controlled by the transistor formed on the silicon substrate. The light from the source is reflected on the surface of the device to be projected onto the wall. This application has already been widely accepted as one type of video projector system, along with liquid crystal devices.

3. Advantages and disadvantages of surface micromachining

Comparing the advantages and disadvantages of surface micromachining using thin film materials for their structures with bulk micromachining, the advantages can be summarized by the following two points.

(1) Mechanical structures together with electronic circuits are formed into an electronic and mechanical integrated system.

(2) The size of a structure formed by surface micromachining technology is smaller than that of a structure formed by bulk micromachining technology in which etching is made for a depth beyond the thickness of the silicon substrate.

On the other hand, the disadvantages of surface micromachining are listed below.

(1) Compared to bulk micromachining, it is more difficult to control the physical characteristics of the thin film which is the material for structures.

(2) The thin film structures sometimes adhere to the substrate during the drying process after etching of the sacrificial layer.

(3) The rigidity of thin film structure is low.

4. Technological trends

4.1 Fusion of surface micromachining and bulk micromachining commences.

The disadvantages of surface micromachining mentioned in the foregoing paragraph have gradually been overcome by recent improvements in the technology. In connection to the particular problem with the low rigidity of thin film structures in the film thickness direction, the following solutions have been introduced.

The University of Michigan reported on the manufacturing of a thin-film structure having a T-shaped cross-section separated from the substrate by performing micromachining on the surface of a silicon substrate, which had been machined to have a deep, narrow ditch using the dry etching technology, as shown in Fig. 5. A thin film having a T-shaped cross-section

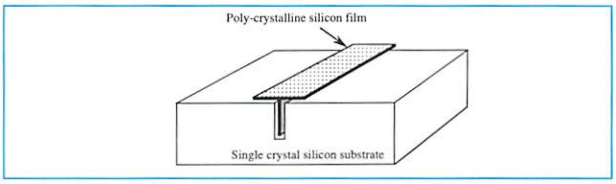

Fig. 5 Rigid thin-film structure having a T-shaped cross-sction

is applied as a fixed electrode plate for an acceleration sensor. It must be noted that this achievement results from the availability of the groove machining with a high aspect ratio based on the dry etching technology introduced in the previous issue as well as the film deposited deep internal grooves with an equal film thickness. So it is no exaggeration to say that further improvement of 3D machining depends on the fusion or combination of bulk micromachining and thin-film micromachining.

4.2 Combination of surface micromachining technology and device packaging technology is anticipated.

Another point worthy of remark is that surface micromachining can encompass the capsule sealing step that is required for the device packaging within the device fabricating process. When a moving part is formed on the surface of a silicon substrate using the surface micromachining method with poly-crystalline silicon, any dust contained in the atmosphere must not be allowed to enter the gap between the moving part and the substrate. However, it is extremely difficult to cut out and mount a device from a silicon substrate without trapping any dust in the packaging. In fact, it is often the case that the cost of the packaging is higher than the cost of manufacturing the device itself. In one of the recently developed methods, the surface of a device is covered with a poly-crystalline silicon film, which is also the capsule material, before sacrificial layer etching; the sacrificial layer is then etched through micro holes in the capsule material to separate the moving part from the substrate. In this way, the packaging process itself is included in the machining process of the silicon device. At the same time this method remarkably reduces the chances of dust entering the package during the sacrificial layer etching process and the following packaging process.

THE SIXTH INTERNATIONAL MICROMACHINE SYMPOSIUM

Foundation of Industrial Technology in the 21st Century

Date: November 9-10, 2000
Venue: Science Museum, Tokyo
Organizers: Micromachine Center / Japan Industrial Technology Association
Supporters (Expected): Ministry of International Trade and Industry (MITI) / Agency of Industrial Science and Technology (AIST) / New Energy and Industrial Technology Development Organization (NEDO)
Cooperators (Expected): The Federation of Micromachine Technology / Micromachine Society / Research Committee on Micromechatronics / Japan Power Engineering and Inspection Corporation / Japan Robot Association / Japan Machinery Federation
Registration Fee: ¥15,000 (Including proceedings and reception party)
Application: Complete the symposium registration form and FAX to Micromachine Center by Oct. 27, 2000
Contact: Micromachine Center
(TEL +81-3-5294-7131 FAX +81-3-5294-7137)

PROGRAM (Tentative, as of July 14, 2000)

November 9, 2000

9:00 ~	Registration	
Session 1: Opening		**Chairman: Mr. T. HIRANO**
9:30	Opening Declaration	Mr. Takayuki HIRANO, Executive Director, Micromachine Center
9:30 ~ 9:35	Opening Remarks	Dr. Tsuneo ISHIMARU, Chairman, Micromachine Center
9:35 ~ 9:43	Guest Speech (Expected)	Mr. Shinichirou OOTA, Director-General,Machinery and Information Industries Bureau, MITI
9:43 ~ 9:51	Guest Speech (Expected)	Dr. Koji KAJIMURA, Director-General, AIST, MITI
9:51 ~ 10:00	Guest Speech (Expected)	Mr. Hideyuki MATSUI, Chairman, NEDO
10:00 ~ 10:40	Special Guest Speech: Micromachines and Artificial Organs (tentative)	Prof. Shinichi NITTA, Tohoku University
Session 2: The Path to New Industries in The 21st Century		**Chairman: Prof. I. SHIMOYAMA**
10:40 ~ 11:00	International Cooperation in MEMS (tentative)	Prof. Dominique COLLARD, IEMN
11:00 ~ 11:25	MEMS Standardization Course (tentative)	Dr. Michael GAITAN, NIST
11:25 ~ 11:45	Problems to be Solved for MEMS Commercialization (tentative)	Prof. Kyoichi IKEDA, Tokyo University of Agriculture & Technology
11:45 ~ 12:10	MEMS Opportunities in Photonic Communication Netwoks (tentative)	Prof. Ming C. WU, UCLA
12:10 ~ 13:15	Lunch	
Session 3: Thinking of Micromachines — Health Care & Micromachine —		**Chairman: Prof. H. MIURA**
13:15 ~ 13:35	Gene Diagnosis/Therapy (tentative)	
13:35 ~ 14:00	Tele Health Care (tentative)	Prof. Masako MIYAZAKI, University of Alberta
14:00 ~ 14:20	Robot Surgery (tentative)	Prof. Makoto HASHIZUME, Kyushu University
14:20 ~ 14:40	Break	
Session 4: Overseas Activities		**Chairman: Prof. K. IKUTA**
14:40 ~ 15:00	Recent Activities in Germany (tentative)	Prof. Hermann SANDMAIER, IMIT
15:00 ~ 15:20	Recent Activities in Italy (tentative)	Prof. Paolo DARIO, Sscuola Superiore San't Annna
15:20 ~ 15:40	Recent Activities in Canada (tentative)	Mr. Dan GALE, Canadian Microelectronics Corporation
15:40 ~ 16:00	Recent Activities in Korea (tentative)	Dr. Young-Ho CHO, KAIST
Session 5: Innovative R&D		**Chairman: Prof. H. FUJITA**
16:00 ~ 16:20	Power MEMS (tentative)	Prof. Shuji TANAKA, Tohoku University
16:20 ~ 16:45	Nano Technology (tentative)	
16:45 ~ 17:05	Micro Chemistry (tentative)	Prof. Teruo FUJII, University of Tokyo
18:00 ~ 20:00	Reception Party at KKR Hotel Tokyo	

November 10, 2000

9:00 ~	Registration	
Session 6: Current Status of Micromachine Technology Project in ISTF Program		**Chairman: Mr. K. HOMMA**
9:30 ~ 9:45	Overview of ISTF Program	Mr. Yoshikazu YAMAGUCHI, Director for Machinery and Aerospace R&D, AIST, MITI
Researches and Future Prospects on Micromachine Technology in National Research Laboratories		**Chairman: Mr. K. HOMMA**
9:45 ~ 10:00	Research and Development on Micromachines at Mechanical Engineering Laboratory	Dr. Shigeru KOKAJI, Mechanical Engineering Laboratory, AIST, MITI
10:00 ~ 10:15	Research on Micromachine Technology at Electrotechnical Laboratory	Dr. Shigeoki HIRAI, Electrotechnical Laboratory, AIST, MITI
10:15 ~ 10:30	Precision Measurement Standards & Micromachine	Dr. Mitsuru TANAKA, National Research Laboratory of Metrology, AIST, MITI
10:30 ~ 10:40	Break	
R&D in Micromachine Center		**Chairman: Mr. K. HOMMA**
10:40 ~ 11:10	The Outline of the Micromachine Project	Mr. Tatsuaki ATAKA, R&D Committee, Micromachine Center
● Systems		**Chairman: Mr. K. HOMMA**
11:10 ~ 11:30	Experimental Wireless Micromachine for Inspection on Inner Surface of Tubes	Dr. Nobuaki KAWAHARA, Micromachine Center
11:30 ~ 11:50	Experimental Chain-type Micromachine for Inspection on Outer Surface of Tubes	Mr. Munehisa TAKEDA, Micromachine Center
11:50 ~ 12:10	Experimental Catheter-type Micromachine for Repair in Narrow Complex Areas	Mr. Ryo OHTA, Micromachine Center
12:10 ~ 12:30	Experimental Processing and Assembling System (Microfactory)	Mr. Kazuyoshi FURUTA, Micromachine Center
12:30 ~ 13:30	Lunch	
● Elements		**Chairman: Mr. T. ATAKA**
13:30 ~ 13:50	Development of Micro Coating Device	Koichi IRISA, Aisin Cosmos R&D Co., Ltd.
13:50 ~ 14:10	Development of a Microconnector Utilizing Deep X-ray Lithography Technique	Tomohiko KANIE, Sumitomo Electric Industries, Ltd.
14:10 ~ 14:30	Wafer level Three-dimensional Integration Technology for MEMS	Akinobu SATOH, Fujikura Ltd.
14:30 ~ 14:50	Micro Force/Torque Measurement for Micromachines	Yasushi ONOE, Yokogawa Electric Corp.
14:50 ~ 15:00	Break	
15:00 ~ 15:20	Development of a Microfine Active Bending Catheter	Hideyuki ADACHI, Olympus Optical Co.,Ltd.
15:20 ~ 15:50	Ultra-high Precision Machining Technology of Micro Structure	Hiroya TERASHIMA, Fanuc Ltd.
15:50 ~ 16:10	The Micro-parts Conveyance Unit with Coil Module	Yasumasa WATANABE, Fuji Electric Corp. R&D, Ltd.
Session 7: Closing		**Chairman: Mr. T. HIRANO**
16:10 ~ 16:20	Closing Address (Expected)	Mr. Hikaru HAYASHI, Managing Executive Director, Japan Industrial Technology Association

Pictures on the cover: *Winning artworks in the Micromachine Drawing Contests*
Water cleaner for home use, with compost maker, Anti-arteriosclerosis machine, Vacuum-and-burn type anti-virus MCM, MCM cleaner (from top to bottom)

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