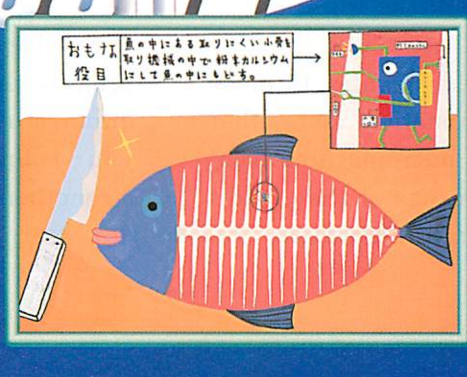
Micromachine
マイクロマシン

Oct. 1997

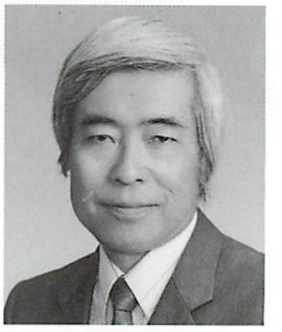


No. 21

MICROMACHINE CENTER

Essay

The Future of Micromachine Technology



Dr. Takeo Sato
Director-General
Agency of Industrial Science and Technology
Ministry of International Trade and Industry

Recognizing the role that micromachine technology plays in advancements in the field of mechanical engineering, the Agency of Industrial Science and Technology is currently implementing a ten-year project "Micromachine Technology" as part of the Industrial Science and Technology Frontier Program. Phase I of this program encompassed the years 1991-1995, Phase II the years 1996-2000.

We are grateful to the Micromachine Center for its invaluable cooperation in expediting the micromachine technology R&D project.

In response to the changing structure of Japan's science and technology, from a structure emphasizing catching up to one that strives at being a front runner, the Japanese government enacted the Science and Technology Basic Law in November 1995 to promote Japan's evolution into a nation that creates original science and technology. In May 1997, Japan's Cabinet passed the Action Plan for Economic Structural Reform and Creativity, recognizing the importance of creating new industries in order to achieve structural reform in the Japanese economy and to assure sufficient levels of economic growth in Japan in the face of the world economy's globalization.

This Action Plan, which designates 15 fields of technology for priority promotion, states that steady, continuous R&D on micromachine technology shall be pursued because of that field's contributions to the creation of innovative, creative technologies that will lead to new industries. Thus, high expectations are being placed on micromachine technology as a way of creating an industrial structure that suits society's needs.

At the same time, the Agency of Industrial Science and Technology, in keeping with its role in developing next-generation technologies, has held conferences to discuss R&D trends in each field, and has designated priority fields in R&D strategies. With regards to the field of mechanical engineering, we believe that the two trends of intelligent technology and micro-technology should continue to be pursued.

Furthermore, in order to promote the project more effectively and efficiently, we implemented in 1996 an institutional reform of the Industrial Science and Technology Frontier Program, including reevaluation of the project management structure and establishment of a rigorous evaluation structure.

It is increasingly important for scientific research and development in Japan not just to respond and adapt to the major political and social trends affecting Japan as a member of the world economy, but also to lead and shape those trends. The Agency of Industrial Science and Technology, for its part, will continue to promote projects that contribute to the revitalization of Japan's overall industrial base, and asks for your cooperation in further expanding and strengthening these efforts.

Shoji Laboratory of Waseda University

Shuichi Shoji
Professor, School of Science and Technology, Waseda University

1. Introduction

We are studying micromachining technologies, especially with silicon, and its application to devices, for development of micro-sensor and micromachines that meet the needs of the 21st century. Along with the development of single micro-devices, we will also aim on constructing a micro-system that will integrate all those single micro-devices. The theme we are focusing at present is micro-sensing systems for medical use, industrial measurement, or environmental measurement. We are also developing sensing systems making use of the multi-media communication network, which, we expect, is a field where the micromachine technology will widely contribute to the society.

2. Theme of Research

2.1 Micromachining basic technology

Micro-devices including micro-sensor are basically fabricated by bulk silicon etching, selective etching using highly boron diffused layer, etc. The recent global trend of integrated systems as micro-sensor and circuit, actuator and circuit requires micromachining also considering consistency with the micro-structure and integrated circuit manufacturing process. So, we are making research on low temperature and less damaging micromachining using electrochemical reaction as porous Si anodization and metal electro-plating. Along with the substrate bonding technology which are important technologies in the micro-system assembly, we are conducting systematic research on bonding technology, as anodic bonding using crystallized glass and room temperature bonding. This technology is also being noted as a key technology for micro-sensor packaging.

2.2 Health information measurement micro-system

In Japan, with the acceleration of the aging population, individual health management and prevention of disease have become ever important. The information communication network currently being completed will help us construct a new medical system that sends individual health information to doctors in the hospital and returns the diagnosis (see Figure 1). For this purpose, the development of the health information measurement micro-system (see Figure 2) comprising the micro-sensor and telemeter, which acts as the human-network interface is indispensable. We have designed a system that collects the information from all the sensor systems attached to the body, sends the information to the relay transmitter, and records or transmits them outside. Research will be done on its sensor unit, telemeter unit, and communication protocol. Body surface mount micro-system for cardiograph driven by thin film battery, and oral micro-capsule using multi-micro-system for mea-

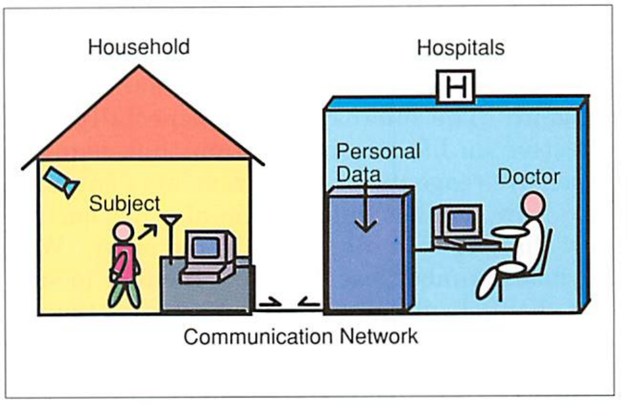


Fig. 1 Schematic of Health Information Monitoring System using Communication Network

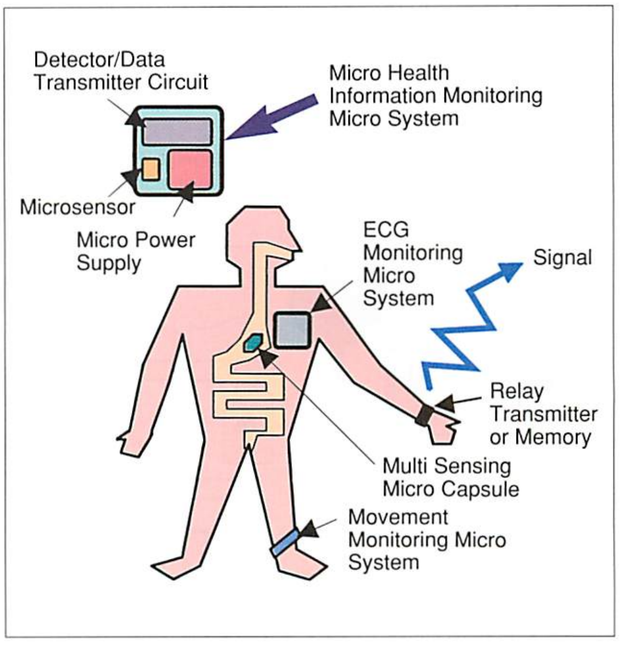


Fig. 2 Examples of Multi Health Information Monitoring Micro System

surement of pressure, temperature, and pH within the alimentary canal are currently under development. The micro-capsule is intended for development of the basic technology for the next-generation endoscope.

2.3 Micro Total Analysis System, Microbiosystem

The micromachining technology is used to fabricate a Micro Total Analysis System (μTAS) that accommodates a compact chemical analysis system on a board. This new system has allowed shorter analysis time with less sample and reagent. The microsystem is especially cost-effective on bio-sensing system that requires expensive reagents for measurement of enzymes, etc. Now, smaller fluid system also has smaller flow channel with dimension in μm order. With Reynolds number less than 100, the flow in such fine channel will be seriously affected by the viscosity. We have to study a special devise to solve this issue.

The combination of mechanical micro-valves and micro-pump (shown in Figure 3) is the system we are proposing for medical application. This system, by automatically collecting and sending small amount of sample, good fits analysis of blood, because it keeps the pump, valve and detector more cleaner. In the chemical analysis system field, we are studying systems using mechanical elements (micro-valve, micro-pump), and system using electric phenomenon (electroendosmosis) for flow control, to develop analysis systems that take full advantage of their benefits. Basic research is also conducted not only on analysis, but also on biochemistry experimental microbench performed for synthesis of protein, etc. The micro total analysis system has potential for a wide range of applications, not only in the medical field, but also for the environmental sensing system that detects chemical substances in the environment. A link with the information communication network can even allow configuration of a wide-area environmental monitoring system.

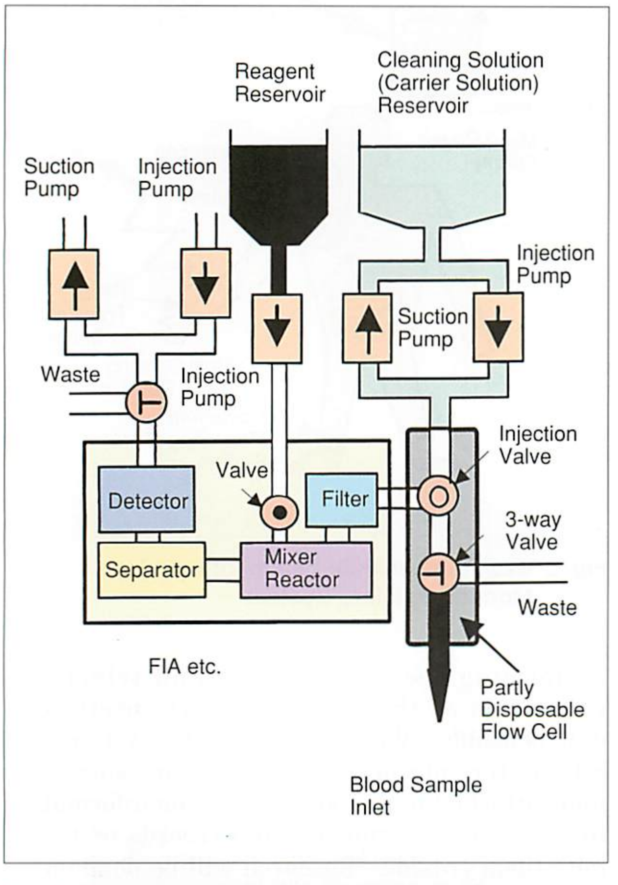


Fig. 3 Schematic of Micro Total Analysis System including Disposable Sampling Part

2.4 Microsensors using Micro-structure

Our research also includes micro-sensors using micro-structure silicon fabricated by highly boron diffused layer selective etching, for development of low flow velocity thermal type flow sensors and high flow velocity gas airfoil micro-flow sensors. Another theme is the micro cosmic X-ray sensor to be loaded on artificial satellites made by absorbent of less heat capacity and highly sensitive thermal sensor.

3. Staff and Research Alliance

Our laboratory consists of 1 professor, 11 master-degree students (7 M1 students, 4 M2 students), and 9 undergraduate students (altogether 21). Each student with his or her own theme, belongs to one of the four groups (micromachining, ME, fluid system, micro-sensor), so that they can help each other in their studies.

As mentioned in Section 2, the microbiosystem and cosmic X-ray study groups are also collaborating with The Institute of Physical and Chemical Research and The Institute of Space and Astronautical Science. There are also themes that are under joint research with some corporations.

4. Summary

We are aiming at development of practical micro-sensors, microsensing systems, micromachines, using the micromachining technology. Research on the micro total analysis systems and biochemical experimental micro benches are themes of special emphasis, as Japan is somewhat behind the U.S. and Europe in this area. As we belong to the information communication department, research of the micro-system in connection with multimedia is also considered an important theme.

Research on Basic Micromachine Technology for Fiscal Year 1996 (Part I)

Since 1992, the Micromachine Center has taken up various seeds of technology as themes for joint research by academic, government, and industrial sectors, aiming to reinforce basic technologies by searching for technology seeds, especially in the scientific and technological fields, that are necessary to build various micro systems. In fiscal 1996, research has been carried out on seven themes. The following articles are summary reports on three themes among them.

Research on Materials for Biosensors

Satoshi Sasaki and Isao Karube
Research Center for Advanced Science and Technology
The University of Tokyo

The micromachine technology is considered to be a challenging method for constructing biosensors. The value of biosensors have become more and more prominent for the last 20 years, through wide range of application, including the medical, food manufacturing process, and environmental fields. Needless to say, the performance of biosensors has become higher along with the development of biochemical and electronics technologies. Biosensor is an analysis device that uses the high molecular recognition ability of materials such as enzymes and antibodies. For example, glucose sensors with glucose oxidase immobilized on the electrode surface have been widely developed. When the oxidation of glucose is catalyzed by enzymes, oxygen is consumed and hydrogen peroxide is produced. By measuring oxygen or hydrogen peroxide using the electrode, the change in the amount of oxygen or hydrogen peroxide according to the amount of glucose can be detected as current change using the electrode. Generally, a biosensor consists of two units; the molecular recognition element (enzyme, antibody) and transducer that converts the reaction into electric signal. By combining the two units according to the needs, biosensors with higher performance can be created[1].

An important requirement on analysis in the medical field is to allow analysis with as small pain to the patient as possible, while preventing infection and avoiding any effect on the symptom. Thus the sample volume should be small, leaving smallest scars on the patient. The sensor should also be disposable. Requirements for the analysis of food are; non-destructive process, less sample volume required, and evaluation of components such as taste and smell which are combinations of complex materials, not quantity of a single material. Requirements for the analysis in the environmental field are; no need for maintenance and more compact body. Biosensor using the micromachine technology must satisfy the above conditions.

In micromachines, the small size of the sensor probe (sensor chip) requires less sample, and is less painful when inserted in the patient's body or makes less destruction on food when inserted. Micromachines are certainly portable. Integrated biosensors can measure various components at the same time. Potential of mass production will reduce the cost of each sensor chip and then becomes disposable. This also means that infection can be avoided[2], which is favorable for medical applications.

In spite of the above advantages of biosensors using the micromachine technology, there are also disadvantages. The small amount of sample always connotes the possibility of variation of composition or density. The response may also become small, to deteriorate the reliability of the measured data and lower limit of detection. Various efforts have been done to solve these problems[3),4)].

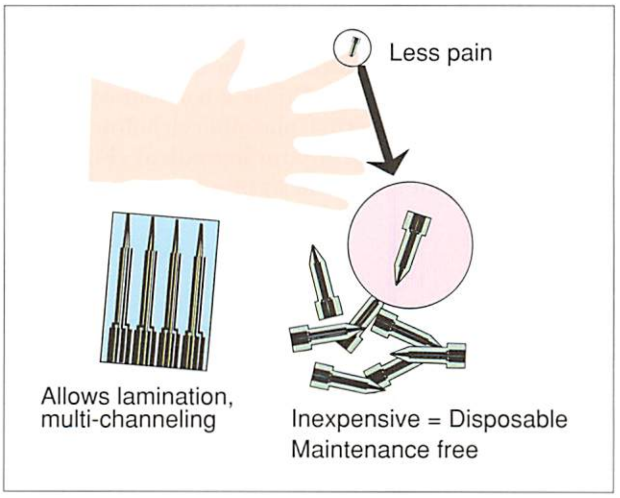


Figure Advantages of the micro biosensor

References

1) Isao Karube : Biosensor, Kyoritsu Shuppan (1986) 1
2) Isao Karube : Biotechnology in pictures, Nippon Jitsugyo Shuppan-sha (1992) 114
3) Kenji Yokoyama, Eiichi Tamiya and Isao Karube, Anal. Lett., Vol. 22, No. 15 (1989) 2949-2959
4) Kenji Yokoyama, Eiichi Tamiya and Isao Karube, J. Electroanal. Chem. Vol. 273, (1989) 107-117

Novel Polymer Materials for Development of the Medical Micromachine

Kazuhiko Ishihara
Institute for Medical and Dental Engineering
Tokyo Medical and Dental University

Secure and stable operation within the intravital environment, as well as innocuity against the living organism is essential when applying micromachines to medical use. The traditional focus of research in micromachines was how to make them smaller and how to make them operate better. Research still did not reach the stage for consideration to biocompatibility or blood compatibility. This research was conducted on this standpoint, to design, synthesize, and evaluate a new material at the molecule level for shaping a truly applicable medical micromachine. Special focus was placed on movement of the micromachine, through synthesis of biocompatible elastomer that can be applied on mobile parts of micromachines. Segmented polyurethane (SPU) is currently being used as medical elastomer, but is far from satisfactory concerning biocompatibility and blood compatibility, and strong demand exists for improvement. Now, the chemical modifications of the SPU are; (1) Surface modification aiming at selective adsorption of inert protein; (2) Surface modification aiming at prevention of adsorption and sticking of biological components; (3) Immobilization of biological active molecule; (4) Coating of blood compatible polymer; (5) Blending of amphipathic polymer.

Also to be noted is the synthesis of new blood compatible polymers, with attention to the surface structure of the biomembrane. This is a polymer composed of 2-methacryloyloxy ethyl phosphorylcholine (MPC) (with phospholipid polar group) ingredient (Figure 1). The MPC polymer may be applied as a polymeric additive to the SPU. It is generally considered that less amount of the MPC polymer as the additive is essential to maintain the mechanical strength of SPU. However, if blood compatibility is to develop, the MPC unit must exist on the surface to a certain composition. We have also to consider the environment where the SPU will be placed and used; dynamic deformation is inevitable, which may cause the MPC polymer to detach and elute. So, we have designed the molecule to control the interaction between the SPU and the MPC polymer, while concentrating the MPC polymer near the surface.

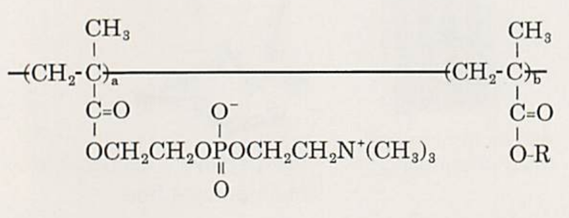


Figure 1. Chemical structure of MPC polymer which has the same polar group of phospholipid molecules constructed a biomembrane.

We have thus, synthesized the MPC polymer which is created by copolymerization of the MPC with 2-ethylhexyl methacrylate and cyclohexyl methacrylate, considering the solubility with the common solvent with the SPU, as well as the affinity of the MPC polymer with soft and hard segments of SPU. SPU and MPC polymer were dissolved in the mixed solvent of methylene chloride and ethanol mixed, the solvent removed, and formed into a film. The mixing ratio by weight of the MPC polymer against the SPU is 5 to 20%. The obtained film had extremely good form and flexibility. The result of surface analysis of the SPU/MPC polymer blend film confirmed the phospholipid polar group on the SPU/MPC polymer blend film. The blend film showed the same mechanical properties as the SPU film. In short, blending of the MPC polymer has no adverse effect on the mechanical properties of the SPU as elastomer.

As the platelet in blood has an important role in the formation of the thrombus, studying its adhesion and activation is effective in evaluating the blood compatibility. When the SPU film contacted with blood, many platelets adhered on the surface, activated, and deformed. The SPU/MPC polymer blend film effectively suppressed the platelet adhesion. It must also be noted that any platelets adhered on the SPU/MPC polymer blend film showed no activation or deformation. The SPU is used on mobile parts and parts subject to dynamic stress of the medical devices. Therefore, the blood compatibility must be evaluated under such conditions. We used our prototype distortion load unit to evaluate the platelet adhesion under dynamic conditions. Compared to static conditions, the SPU film caused activation of the more adhered platelets with prominent formation of pseudopodium. The SPU/MPC polymer blend film showed suppression of activation and formation of pseudopodium of the platelets, even under dynamic conditions.

It is now clear that, blood compatibility can be obtained while maintaining the mechanical properties by blending the MPC polymer to the SPU. This material can also be used to form a approx. 100μm-diameter hollow fiber. This hollow fiber technology, we believe, is an extremely significant technology that can directly lead to the development of catheter and sensors that can even reach the brain capillary.

Research on Application of Intelligent Materials to Micromachines (Part I)

Definition of Intelligent Materials and their Examples

Seizo Miyata
Dean, Professor, Graduate School of Bio-Applications and Systems Engineering
Tokyo University of Agriculture and Technology

1. Foreword

With the 21st century just around the corner, a new industry that will support the next century is strongly awaited, calling for the research and development of a new material and application based on a new concept as one of the most important tasks.

The newly suggested concept of a new material, or intelligent material, including sensor function, processor function and actuator function has now become a hot R&D theme. If we succeed in creating such materials, many conventional parts and units as well as controlling computers will be needless, resulting in great benefit to resource and energy conservation. In the ever changing needs of the society, development of machines that move in special environments, narrow space, health and welfare of human will also be an important subjects. Research and development of micromachines is being conducted with such background. If we want to promote the development, introduction of new material and new function will be an urging must. This research studies the potential of intelligent materials for the applicability to micromachines.

2. Example of intelligent material

Micromachines that operate in closed space as within the organism cannot be repaired easily once embedded. This is why we conducted this research on how we can introduce intelligence as destruction sensing function and self recovery, to the material itself.

An example of self recovery in metals can be observed in the 18-8 type stainless steel. Accretion of cerium removes the sulfur, and addition of titanium fixes the remaining sulfur as oxide including titanium. Thus, this type of steel self-recovers by thermal treatment even when the surface changed.

There is also the example of application of the thin filmed shape memory alloy as micro-actuator function such as driving micro-valve, and mirror.

Ceramic material such as zirconia is known to have destruction sensing function, high destruction resistance characteristics, and self recovery function. The whisker reinforced silicon nitride is also effective.

Semiconductor materials are used for VLSI devices, with application of its superfine machining technology creating the first micromachine. Now, the intelligence of the material has become target an important piece of research. When voltage is applied to both ends of gallium arsenide single crystal, the current starts vibration at a certain voltage (gun effect). Deep energy level can be applied to this crystal to observe non-linear current-voltage characteristics. It is believed that such phenomenon can be used to create micromachines with a new sensing function.

Among the various organic materials, the polypeptide is a good example. Gel created by polypeptide recognizes a specific molecule and changes the volume or detects the blood sugar value and releases insulin. It can even sense heat and release antipyretics. In other words, the material senses the exterior condition, and exhibits the proper actuating function to sustain the environment.

We have also conducted research on organic material. The calmodulin/phosphodiesterase super molecules that changes the form of molecule by changing calcium ions, and the TOL plasmid that lights against atmospheric pollutant are such examples. The above examples are all protein. It is very likely that suitable structuring of protein can create new types of micromachines.

3. Micromanipulation and energy supply

Microparts must be trapped and assembled to create micromachines. The laser trapping method is one such technology. The parallel rays of the laser is converged by the objective lens, and the micropart is placed at the position where the laser will start diverging again. Trapping is done by the change of the momentum. The greatest feature is the superior energy effect, as all the used laser beam is used for the trapping. The program can also be changed to change the pattern by software.

Another big problem is how to supply energy to the micromachine. Batteries using polymers as the ionic conductor and electrode is one promising solution.

So, the above defines the problems on the intelligent functions, its production technique, and energy issue of micromachine materials.

Research on Application of Intelligent Materials to Micromachines (Part II)

Polymer Networks as Intelligent Materials and Micromachines

Masayoshi Watanabe
Associate Professor, Faculty of Engineering
Yokohama National University

Materials for sensors that convert chemical information is an essential intelligent material for the micromachine. Conventional chemical information conversion materials often include biopolymers such as enzyme, antigen, and antibody. However, biopolymers have limited resistance and choose the operation environment. Chemical information conversion elements using network polymers may open new possibility to form intelligent sensors.

Network polymers with low cross-linking density and sufficiently swollen by solvents are often referred to gels. The degree of swelling changes largely according to minute change of composition, pH, ionic species, ionic strength, temperature, light, electric field, and concentration of chemicals in the external solutions. These characteristic make gels promising as new intelligent materials. In this research, we have shown that intelligent gels chemically fixed on a microelectrode have chemical information conversion function, that allows the change in the degree of swelling caused by change of the external environment, to be converted into a change in electric current.

Now, it has also been demonstrated that cross-linked resins having highly specific adsorption (molecular recognition capability) can be synthesized by molecular imprinting technique. This technique is based on 3-dimensional polymerization of functional monomers in the presence of guest molecules (template molecules) which can interact with the monomers, followed by removing the guest molecules from highly cross-linked imprint polymers. This method creates imprint polymers that act as a complementary mold of the template molecule. It is shown that the network polymer obtained by this molecular imprinting method can be used to design field effective capacitors, amperometric sensors, and optical fiber sensors that selectively respond to the template molecule.

The above shows examples of sensing function applications of intelligent materials using network polymers. We also tried to realize the network polymers with functions other than the sensing function, including the processing and actuator functions. In fact, we attempted to establish a methodology to design gels that induce macroscopic change in their volume by molecular recognition. Such gels with low cross-linking density have been successfully synthesized under the condition in which gelation proceeds in the presence of guest molecule, while the phase separation progresses during the gelation. This intelligent gel not only has the molecular recognition capability, but also the molecular selectivity.

Toyama Micromachine Seminar

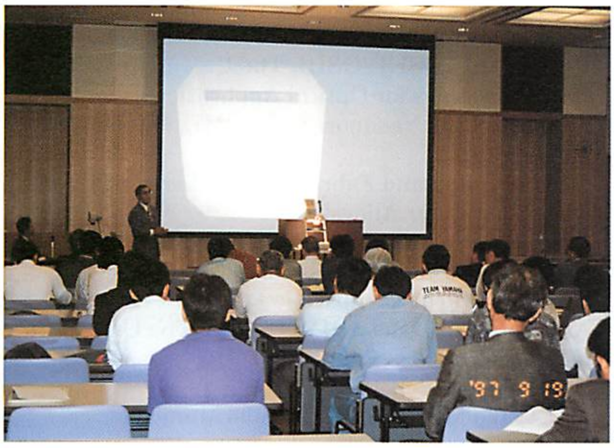
The Toyama Micromachine Seminar was held at the Toyama Municipal Hall in Toyama City on the afternoon of September 19th, 1997 under the auspices of Micromachine Center, Toyama prefecture, and the Toyama Foundation for Development of Technology, with the support of the Toyama Prefectural Machinery Association, Electronic and Electrical Industries Association of Toyama and the Toyama Technology Exchange Club.

The seminar began with an introductory speech on recent micromachine technology, which was followed by a report on four specific examples from the Industrial Science and Technology Frontier Program's development of Micromachine Technology, led by the Micromachine Center. During an intermission, a portable micromachine technology exhibit "lady-bird shaped actuator with photovoltaic device" made by Sanyo Electric Co., Ltd. was exhibited and Dr. Hisaki Tarui explained the details. It was a good opportunity for the participants to understand the outline of the micromachine technology.

In the lectures, MMC Secretary General Mr. Hajime Arai, and Dr. Yuichi Ishikawa, Chief of the Mechanical Engineering Laboratory, AIST, spoke on "MMC's activities" and the "Current status of and problems concerning micromachine design," respectively. In addition, the results of the following projects from the Industrial Science and Technology Frontier Program were presented.

- Group control of holonic mechanisms: Mr. Tomoyoshi Ibe, Mitsubishi Heavy Industries, Ltd. (Takasago R&D Center)
- Block technology self package application: Mr. Akinobu Satoh, Fujikura Ltd. (Advanced Technology R&D Center)
- CCD micro-cameras: Mr. Akihiro Koga, Toshiba Corp. (Energy & Mechanical Research Center)
- Micro-photovoltaic devices: Dr. Hisaki Tarui, Sanyo Electric Co., Ltd. (New Materials Research Center)

As part of its industrial and regional policy for fiscal 1997, Toyama prefecture, in addition to working for the cultivation of vital small and medium-sized enterprises, will support the entry of such small and medium-sized enterprises into new fields, the creation of new industry, as well as the advanced technology researches by the enterprises within the prefecture jointly done with universities and public research institutes. In Toyama prefecture, there are many companies that have the technology to apply to micromachines and micromechanisms such as micromachining technology, precision dies technology, and lithography in semiconductor manufacture. There are also many related industries that deal with organic and other materials used in the manufacture of micromachines. With the awareness that ever more precise, sophisticated and complex component parts are required in daily production activities in order to achieve future prosperity and development, these precision machine engineering and precision electronic engineering-related firms within the prefecture are understandably interested in acquiring precision processing technology that exceeds current limitations. For this reason, there has been great interest in this seminar, with 161 participants in total (37 from precision machine engineering and precision electronic engineering-related 20 firms within the prefecture; 124 from Toyama University, Toyama Prefectural University, Toyama National College of Technology, and Machinery and Electronics Laboratory of Toyama Industrial Technology Center). The lectures prompted lively question-and-answer sessions, and the result was a very meaningful and informative seminar for all involved.



Scenes from the seminar at Toyama Municipal Hall

A portable micromachine technology exhibit

Third International Micromachine Symposium Coming Soon!

The Micromachine Center has been encouraging international exchange activity for promotion of the micromachine technology. As a part of this activity, we have hosted the International Micromachine Symposium annually, ever since 1995.

The Micromachine Symposium has been jointly held by MMC and the Micromachine Society (Chairman: Professor Iwao Fujimasa, Saitama University). The symposium was named International Micromachine Symposium aiming on promotion of international exchange of information and human resource. Lecturers will also be invited from Europe and the U.S., and participants worldwide. Simultaneous interpretation is adopted for convenience of our international participants. The first Symposium recorded 505 participants, the second 430 participants, with very high appraisal.

Last year's symposium had the honor of participation of the Research Mission of the French National Research Institutes. This year, we expect the participation of the British Department of Trade and Industry's OSTEMS Program, headed by Professor Dorey, who will also act as an invited lecturer. This is a British governmental program to inspect foreign scientific technology, consisting of six British micromachine experts.

This Symposium was planned by the Organizing Committee (Chairman : Professor Naomasa Nakajima, The University of Tokyo), while the invited lecturers were selected by the Program Committee (Chairman : Professor Tomomasa Sato, The University of Tokyo). An advisory board was also installed by eight chief delegates of Western participants of the third Micromachine Summit held this April in Vancouver, Canada. The Symposium will be held on October 30 and 31, at the Science Hall of the Science Museum (Kitanomaru Park, Tokyo).

The first day is reserved for lectures by invited lecturers. The opening session will be honored by guests from MITI, AIST, and the New Energy and Industrial Technology Development Organization. Then a special lecture will be given by Professor Isao Karube, The University of Tokyo on Application of the Biotechnology on Micromachines. We have high expectations on this lecture given by a highly renown researcher linking micromachine technology with biotechnology.

We will have four invited lecturers from overseas this year, including the chairman of the NEXUS Executive Board, EC, who will lecture on the role of research and development of the EC's MEMS/MST. This will be another lecturer from the EC, following last year's Mr. Forster of DGIII, which shows EC's special interest in this Symposium. An American lecturer, the actual head of the industrial technology program of the NSF, will give a lecture on a overview of the microfabrication research in the U.S., and the current NSF initiative. The following are our overseas invited lecturers and their themes.

- Mr. Gaëtan MENOZZI / Chairman of NEXUS, European Commission
  "Role and Action of NEXUS within the European MEMS/MST R&D Structure and Programmes"
- Dr. Jay LEE/ National Science Foundation, U.S.A.
  "Overview and Perspectives on Microfabrication Engineering Research and Education in the United States"
- Prof. Howard DOREY / Imperial College, U.K.
  "Microengineering in the U.K."
- Prof. Roberto HOROWITZ / University of California at Berkeley, U.S.A.
  "MEMS for Ultra-high Density Hard Disk Drives"

We have also invited ten Japanese lecturers, who are specialists of various fields, including DNA chips, global environment, standardization, material, etc. Unique lectures are expected. This year will have a special session on "Thinking of Micromachines", with lectures given by an elementary school teacher, a specialist in sociology and a cultural anthropologist. It will surely give a new flavor to your conventional view on micromachines.

The following are lecturers and their themes.

- Associate Prof. Akira SUYAMA, The University of Tokyo
  "DNA Chip – Integrated Chemical Circuit for DNA Diagnosis and DNA Computer"
- Dr. Hiroaki TAO, National Institute for Resources and Environment
  "Expectation to Micromachine Technology for Global Environment Protection"
- Prof. Kimiyuki MITSUI, Keio University
  "Standardization of Metrology in Micromachine Technology"
- Dr. Hiroshi TOSHIYOSHI, The University of Tokyo
  "Micromachines for Optical Applications"
- Associate Prof. Yasunori SAOTOME, Gunma University
  "Microforming and Fabrication of Micromachines with Amorphous Alloys"
- Associate Prof. Nobuhiko YUI, Japan Advanced Institute of Science and Technology
  "Design of Blood Compatible Polymeric Surfaces"
- Associate Prof. Isao SHIMOYAMA, The University of Tokyo
  "Micro-Insect Robots"
- Ms. Ayako MOCHIZUKI, Okubo Municipal Elementary School, Narashino
  "School Children's Idea of Micromachines"
- Dr. Masaki UKAI, Kyoto Bunkyo University

"Micromachine as a Culture"

- Associate Prof. Shin-ichi TAKEMURA, Tohoku University of Art and Design
  "Socio-Cultural Implication of Micromachine Technology"

The second day is dedicated to presentations on the progress of the R&D of the Micromachine Technology of the Industrial Science and Technology Frontier Program of MITI's Agency of Industrial Science and Technology. Mr. Makoto OKAZAKI, Director for Machining and Aerospace R&D, AIST, MITI will give an overview, followed by introductions of researches conducted in the three national institutes (Mechanical Engineering Laboratory, Electrotechnical Laboratory, and National Research Laboratory of Metrology). Then comes a presentation on progress of the second phase of the micromachine technology project by the chairman of Research Committee and chiefs of Systematization Committee of the Micromachine Center. This will be followed by presentation of the newest research by researchers of MMC's supporting member companies. The following are the lecturers (other than Mr. Okazaki) and their themes.

- Dr. Yasuhisa ANDO, Mechanical Engineering Laboratory, AIST, MITI
  "Tribology for Micromachine"
- Dr. Shigeoki HIRAI, Electrotechnical Laboratory, AIST, MITI
  "Research on Micromachine Technology at Electrotechnical Laboratory"
- Dr. Akira UMEDA, National Research Laboratory of Metrology, AIST, MITI
  "Technique Developed at NRLM for Microdevices and Micromaterials"
- Mr. Kazuhisa YANAGISAWA, Research Committee, Micromachine Center
  "R&D Plan for the Second Phase of the Project Micromachine Technology"
- Dr. Nobuaki KAWAHARA, Micromachine Center
  "Experimental Wireless Micromachine for Inspection on Inner Surface of Tubes"
- Mr. Hiromu NARUMIYA, Micromachine Center
  "Experimental Chain-Type Micromachine for Inspection on Outer Surface of Tubes"
- Mr. Ryo OHTA, Micromachine Center
  "Experimental Catheter-Type Micromachine for Repair in Narrow Complex Areas"
- Mr. Tatsuaki ATAKA, Micromachine Center
  "Experimental Processing and Assembling System (Microfactory)"
- Mr. Tomohiko KAWAI, FANUC LTD
  "Super Precision Machining of Micro V Shaped Gratings"
- Mr. Akinobu SATOH, FUJIKURA LTD.
  "Application of Block Technology for the Self-Package"
- Mr. Haruo NAKAZAWA, Fuji Electric Co., Ltd.
  "Development of a 2-Dimensional Micro Conveyor"
- Dr. Ronald B. ZMOOD, Royal Melbourne Institute of Technology, Australia
  "Micro Magnetic Bearings and Suspension Mechanisms"
- Mr. Takeo TANAAMI, Yokogawa Electric Corporation
  "High Speed Shape Measurement Technology for Micromachines"
- Mr. Yasuo OHTSUKI, KAWASAKI HEAVY INDUSTRIES, LTD.
  "A Study for Pattern Generation of Micromachine Group"
- Mr. Tomoyoshi IBE, MITSUBISHI HEAVY INDUSTRIES, LTD.
  "Formchanging Control and Behavior control for Holonic Mechanism"

Also note that MICROMACHINE '97, the eighth Micromachine Exhibition, will be held from October 29 at the first floor of the Science Museum. The exhibition will show the results of MMC's supporting members as well as 70 micromachine companies, universities, and institutes. MMC's supporting members and the three national institutes will show their actual results in the micromachine related research. As the second day of this Symposium will end at 3:35 p.m., we recommend you to take advantage of this opportunity to go through the Micromachine Exhibition for a better understanding of the micromachine technology.

Participants of this Symposium are entitled to free admission of this MICROMACHINE '97.

Although deadline for registration of the Symposium is October 15, last-minute registration is also accepted if seats are still available. Awaiting your participation!

Sumitomo Electric Industries, Ltd.

Nobuo Noda

1. Work on Micromachine Technology

Great developments have been made in micromachine technology, thanks to dramatic progress in semiconductor technology. Along with the increasing needs for complex machine parts, research has continued for the development of three-dimensional micromachining technology.

At Sumitomo Electric Industries, we have developed a micro-structure fabricating technology, the LIGA process, that uses a compact synchrotron radiation (SR) light source. This technology allows us to produce high-precision three-dimensional micro-structures, and is currently attracting much attention as a key technology in the production of micromachines. Furthermore, the LIGA process has the advantages that there is little restriction on the materials used, and that it is suitable in mass production. Therefore the LIGA process is expected to be able to yield wide application not only to micromachine production, but also in the fields such as data communications and medical equipment which require miniaturization of devices. As the LIGA process has great applicability, we are currently working to apply this exciting technology to the development of new products, and continue further improving for machining technology.

2. Micromachine Technology Development

The first problem in producing micro-functional devices mountable on micromachines is the manufacturing technology itself. During the first phase of the Industrial Science and Technology Frontier Program, we were involved in the development of fabrication process for micro-structured piezoelectric ceramics, which is indispensable to transmission devices that output sonic signals from micromachines moving in water pipes. As the frequency of transmissible sonic waves in water ranges in 400 kHz or less, the piezoelectric ceramics (PZT: Lead zirconate titanate) that are normally used would be about 5 mm or more at these frequencies, which would be difficult to mount in a micromachine. This means that the ceramic needs to be compounded with resin, and have its Young's modulus and the transmitting frequency lowered. Meanwhile, in order to ensure that the compound retains most of its piezoelectric characteristics, the PZT needs to have a fine structure and high aspect ratio (ratio of height to width). In conventional processing techniques, there are limits to miniaturization, which is the reason the LIGA process has been developed.

The basis of the LIGA process is deep lithography, which requires a highly permeable short wave X-ray. Usually, this meant that a medium-sized SR light source was needed. We developed a highly sensitive resist and a new X-ray mask with high level of contrast, and succeeded in developing an original process, whereby patterning to a depth of several hundred μm can be completed in a short time by using an industrial compact SR light source.

Figure 1 shows PZT rod arrays, with diameter 20 μm and height 140 μm. With conventional processing methods, the limit was around 100 μm, which means that the PZT dimensions have been reduced by about 1/5. Figure 2 shows an ant holding a piezoelectric composite transmitter with the gaps between the PZT rod array filled with resin. This transmitter has demonstrated sufficient piezoelectric characteristics for the transmission of signals in water.

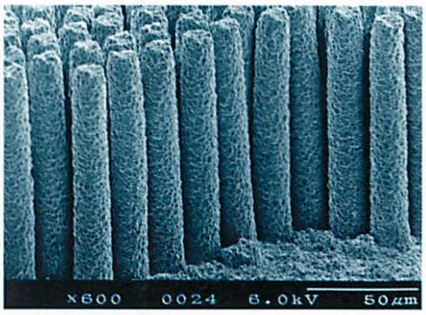


Fig. 1 PZT rod array (diameter: 20 μm, height: 140 μm)

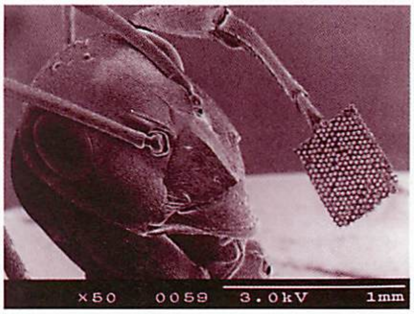


Fig. 2 A piezoelectric composite transmitter (400 μm × 500 μm, thickness: 100 μm)

3. The Challenge of the Future

We are pressing forward with our study of practical uses for our micro-structured piezoelectric composite in the field of medical ultrasonic diagnosis. Furthermore, in the second phase of the Industrial Science and Technology Frontier Program, we are developing a micro-connector that will automatically connect and disconnect micromachines, and are working on further improving processing technology, as well as developing systematization technology.

As we approach the 21st century, micromachine technology is expected to grow up into one of the basic technologies supporting various industries around the world. Sumitomo Electric Industries is committed to realizing practical applications for our unique micro-fabrication techniques in the wide range of fields, and will continue in our mission to produce products that will serve to benefit mankind.

Nobuo Noda, Senior General Manager, R&D Group
General Manager, Harima Research Laboratories,
Sumitomo Electric Industries

Seiko Instruments Inc.

Dr. Sadao Moritomo
Director, Seiko Instruments Inc.

1. Addressing the Challenge of Micromachine Technology

Industrial technology has never stopped evolving since the Industrial Revolution, and has contributed extensively to the improvement of mankind's living standards. Increasing demand for convenience and cost reduction in science and technology advancements, however, has given rise to worldwide problems concerning the environment and energy conservation among others.

Since its founding Seiko Instruments has been progressing with finding ways of making lighter and smaller components in the watches that we produce. In the future, we will continue to mature even further in this respect with an eye to the manufacturing environment. As we progress, the challenge of the core technology: micromachine technology will remain foremost in our minds.

2. Micromachine Technology Development

A wristwatch is basically a very small machine, with an overall volume of approximately 2 cm^3, and most of its components are measured in millimeters. When we look at the machinery used in the manufacture of wristwatches, however, the assembly device alone is over 40 meters in length, and while its accuracy and productivity are never in doubt, one cannot help feeling a sense of contrast when one notices the disparity in size between the assembly device and the finished wristwatch.

Seiko Instruments has begun research and development of Microfactory Technologies with the aim of restructuring the manufacturing systems of the future. In a step away from the development of conventional precision machining technology, we are working on developing machining technology by using electrochemical STMs (scanning tunneling microscope) as fine structure manufacturing technology.

Figure 1 shows an experimental system used in the development of new micro-electrochemical processing.

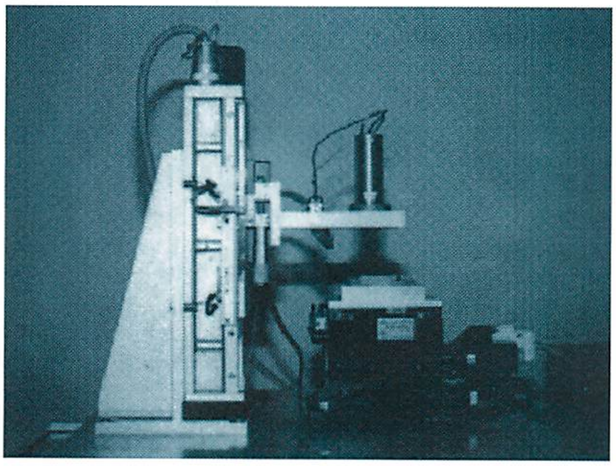


Fig. 1 Experimental testing system for new micro-electrolytic processing. (Ultra-precise machine equipment with STM construction)

This processing technology allows metal etching processing and deposition processing to be performed on the same device. Moreover, precise monitoring is available in SMT mode. With the exception of the control device, the system can even fit on a desktop.

Figure 2 shows an example processed by this system. The pattern is our company logo, and has been reproduced in a size that would be impossible for conventional machining technology.

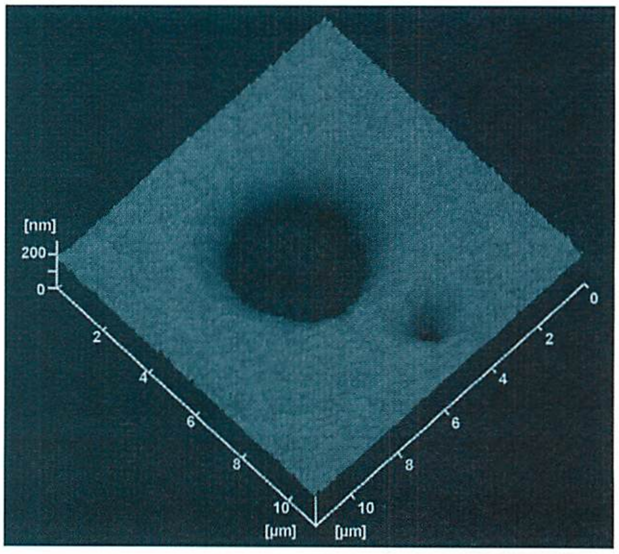


Fig. 2 Example of micro-electrochemical processing sample (Chromium thin film etched with 200 nm resolution.)

3. The Challenge of the Future

Establishing a true microfactory involves much more than merely downsizing the production equipment. With that in mind, we are pushing ahead with fundamental research and development that will revolutionize our entire manufacturing process, in order to produce finished products that have the potential to enrich the lives of people.

Tatsuaki Ataka, Corporate R&D General Manager (Division Executive), Seiko Instruments Inc.

Transducers '97 Report

Transducers '97, the ninth such conference, was held at the Hyatt Regency in downtown Chicago for four days from June 16th to June 19th. The first Transducers conference was held in Boston in 1981, and the conference has already been held twice in Japan. This year's highly-anticipated conference was presided over by Professor Kensall D. Wise of Michigan University, and attended by 1,200 participants from all parts of the world (approximately 120 from Japan).

Transducers '97 Presentations
(Classified by the author)

Classification	Details	Number of Presentations	Posters and Late News
	Plenary	3	
Sensors	Magnetic Sensors	5	7
	AFM & Related Sensors	5	2
	Inertial Sensors I, II, III	13	0
	Accelerometers	5	8
	Vibratory Gyroscopes	5	1
	Physical Sensors	5	13
	Acoustic Chemical Sensors	5	6
	Ion Sensors	5	1
	Force & Flow Sensors	5	3
	Gas Sensors	5	8
	High Temperature Gas Sensors	5	9
	Pressure Sensors	5	9
	Chemical Sensors	5	0
	Immunosensors	4	1
	Biosensors	4	0
	Artificial Noses	4	0
Devices	Actuators I, II, III	14	6
	Resonant Structures	5	3
	Acoustic Devices	5	2
	Device Modeling	5	6
	Data Storage	4	0
	Dynamic Device Modeling	6	5
	Microrelays	5	3
	Microchemical Reactors	5	0
	Micropump	5	2
	Microfluid Devices	5	5
Systems	Optical Microsystems I, II	9	9
	Intelligent Systems	4	3
	Whole-Cell Systems	4	1
	Analytical Systems I, II	10	7
	Telemetry Systems	4	2
	Bioanalytical Systems	5	3
Technology or Processing	Process Technology	5	9
	Packaging Technology	4	5
	Bonded & HARM Technology	5	5
	Bulk Micromachining	5	9
	Novel Materials & Processes	6	7
Properties or Materials	Mechanical Properties	4	5
Total		212	165

There were approximately 370 presentations in total, including oral presentations and poster sessions. Most of the speakers were leading researchers at universities, and there were many speakers from Japan. Five presentations concerning the Industrial Science and Technology Frontier Program were offered by five different speakers. One of them was given by Dr. Tadashi Hattori, ex-chairman of the MMC Research Committee.

The presentations covered sensors, actuators, devices, systems and processes with applications in many fields such as automobiles, data storage devices, optics, fluidics, chemical analysis, and medical diagnosis and therapy. Many production technologies make use of silicon micromachining based on thin film formation and etching. In universities such as the Berkeley and Los Angeles campuses of the University of California, Michigan University and Cornell University in America, and at the Technical University in Berlin, advances made in micromachining might easily be described as art.

Let us examine some of the topics in greater detail.

• Sensors

In the presentations on sensors, there were inertia sensors, accelerometers, and gyroscopes whose application might be expected to lie in automobiles. In many of the applications, the common feature was the fact that the central mass was usually connected to the sides by very fine bridges. Depending on their purpose, these bridges had either single or double shafts. A gyroscope normally requires three axles, but there was a presentation concerning one system whereby the rotation of the mass could be detected by the electrical capacity of sector electrodes attached to the rear, and another whereby two axles could be assembled three dimensionally. Three methods for detecting displacement; one that detects electrical capacity by means of interdigital electrodes, another that detects fluctuations in the magnetic charge obtained from a permanent magnet attached to a cap, and one where displacement is detected by means of a piezoelectric body on the connecting bridge, were reported.

With regard to sensors that are used with fluids, there are some that detect the flow rate, others that detect pressure. Flow sensors that work on the principle of having a floating element between two photodiodes, and detecting the difference in the light quantity from the gaps, and others that detect the inclination of a floating balance, or detect the pressure difference applied to two electrostatic pressure sensors, were also announced. All of these sensors perform detection mechanically, so they cannot detect the type of fluid being used. Rather, chemical reaction is most often used to detect the type of fluid. There were reports on sensors using inorganic materials, for H_2, CO, CH_4, NO, NO_2 and O_3 gas, ethanol, and moisture. In addition, bio-sensors, immunosensors, medical sensors and smell sensors (artificial noses) were reported.

• Devices

In the world of data storage devices, the smaller the better, so the size of the device read/write head also needs to be minimized. This would appear to be one of the good job for heads produced using the silicon micromachining method. In this field, besides planar magnetic heads, precise tracking systems, and gimbals, a method for opening data bits using an AFM cantilever was also presented.

There are some micro-pumps with valves, and others without valves. For those with valves, we heard presentations on methods of manufacturing the valves, and for those without, there were presentations on improved pump designs. In this case in particular, the design of the liquid intake/outflow is important.

In the field of sonic devices, a hearing devices that can be implanted in the ears of persons suffering from hearing disabilities, small microphones, and microphones were presented.

There were also presentations introducing cantilever type relay (thermal type and electrostatical type) micro relays (switches), and bridge type relays (electrostatical type and magnetic type).

• Systems

Fields in which there have been a recent increase in presentations include microsystems for optics and micro analysis systems. The reports on the former field described a variety of systems from the University of California and other top research institutions, including one system whereby elements are produced on a silicon surface using micromachining techniques then assembled three dimensionally, thus allowing the optical axes to be adjusted in x, y, z directions by an actuator. For example, mirror arrays on a silicon substrate can rotate freely along three axes for display, arrays for optical waveguide switches, and other examples of microtechnology integration that utilizes the latest in silicon microtechnology.

In the field of analysis systems, there were reports on various analysis methods, such as separation by electrical migration, fluorescence analysis, and methods for measuring the size of corpuscles in the blood. In the field of bio-analysis, much work is being done in blood analysis, DNA analysis and other types of medical diagnosis.

In the field of medical treatment, there were reports on telemetry systems. One system allows various data on the human body to be extracted using microwaves, while another permits data pertaining to the heart to be transmitted via microscopic electric current to recorders attached to the hands or feet.

There was a banquet on the first day in the museum exhibiting mammoths and dinosaurs, and on the second day, there was a boat cruise on Lake Michigan. As we drifted gently over placid waters that belied the name "windy city," we were treated to the city's spectacular night view, all topped off with a fireworks display. On the third day, Professor Wise presided over an awards ceremony to honor exceptional workers, and Professor Masayoshi Esashi of Tohoku University gave a brief introduction to Sendai, the scheduled site of the next conference.

Discussions at one of the poster sessions

The banquet on the first day was held in the museum, right beside the mammoth and dinosaur exhibits.

Micromachine Technology Portable Exhibition

In order to promote the achievements of the Industrial Science and Technology Frontier Program's development of Micromachine Technology, four portable micromachine technology exhibits produced with the cooperation of related firms in 1996 were used by external organizations at two events in July and August of this year. The exhibits were:

- Laser light driven micro-pump: AISIN COSMOS R&D CO., LTD.
- Photovoltaic micro-devices: SANYO Electric Co., Ltd.
- 1 mm diam. SMA tube type manipulator: OLYMPUS OPTICAL CO., LTD.
- In-pipe micro inspection machine: DENSO CORPORATION

(1) MIPE '97

The Japan Society of Mechanical Engineers celebrated its centennial anniversary at MIPE '97 (International Conference on Micromechatronics for Information and Precision Equipment), which was held at the Tokyo International Forum in Yurakucho from July 20th to July 23rd. In conjunction with this event, the micromachine technology portable exhibits were opened on July 21st.

Since the demonstration was held at the request of the Information, Intelligence and Precision Equipment Division of the Japan Society of Mechanical Engineers, a Micromachine Information Corner was set up next to the MIPE information desk, separate from the MIPE '97 exhibition hall, which featured explanatory posters including two posters for the MMC's activities as well as the four portable exhibits mentioned above. The same setup was used at MEMS '97, held in Nagoya in January of this year.

The exhibition was only open for a very short time, from 4:00 to 6:30 in the afternoon, but some 80 odd MIPE '97 participants, including Japanese researchers and researchers from China, Korea, and Europe and America, visited the exhibition corner and were pleasantly surprised at the workings of these tiny machines. Many of these visitors were observed in heated discussion of the technology and its applications with the exhibition representatives.

(2) The Industrial Technology Exhibition – Techno Festa 21

Micromachine Technology was exhibited at The Industrial Technology Exhibition – Techno Festa 21, held a over period of 21 days from August 8th to August 28th at Pacifico Yokohama in Yokohama's MM 21 area.

The Industrial Technology Exhibition was sponsored by the Industrial Technology Exhibition Executive Committee of the Industrial Research Association. The event was held with the cooperation with industry, government and educational bodies as part of activities designed to promote awareness of the history of Japan's industrial technology among children. On the opening day, August 8th, the Vice Minister of the Ministry of International Trade and Industry, Head of the National Center for Science Information Systems, President of The Japan Federation of Engineering Societies, the mayor of Yokohama and other distinguished guests from the industrial technology world took part in the grand opening ceremony. Following this, the guests were given a guided tour. At the entrance, there was an exhibition of winning paintings by children depicting society in the 21st century, displayed so that they could be easily enjoyed by the children.

At the exhibition, there were display corners for fields such as steel, automobiles, living, machinery, aerospace, railroads, energy, chemicals, ceramics, electronics, information, communications, and others, and each one presented an aspect of the history of

Exhibits on display at MIPE '97

Opening ceremony of The Industrial Technology Exhibition – Techno Festa 21

Japanese industrial technology in the 50 years since the end of the Second World War. In addition, there was a joint exhibition space that focused on questions surrounding the latest technologies. The micromachine booth was part of this exhibition space.

The micromachine booth contained the MMC's four portable exhibits mentioned earlier as well as a video produced in 1996 for children, entitled "What are micromachines?", and the best entries of the last three micromachine painting contests. In the adjacent Mechanical Engineering Laboratory booth, there was an exhibition of a micro-lathe.

As the exhibition lasted a full 21 days and was the longest event at which the four portable exhibits had ever been used, the exhibits were set up so that the visitors were able to operate the micromachines by themselves, but there was still some concern as to whether the exhibits would stand up to such prolonged handling by children who might not fully understand the equipment. Fortunately, although there were occasional minor accidents and machine failures, there was no major trouble, and the exhibits somehow survived for the entire 21 days.

In all, Techno Festa 21 was visited by over 51 thousand people, and the micromachine booth was visited by people of every age group, who expressed wonder at and interest in the workings of the micromachines. The exhibition proved an excellent opportunity to introduce ordinary members of the public, who normally never come into contact with cutting edge technology at the research and development level, to the potential of micromachines.

The above-mentioned portable exhibits are normally kept at the Micromachine Center, and are used to promote the success of Micromachine Technology development in the Industrial Science and Technology Frontier Program to visitors to the center from throughout Japan and abroad. In the future, it is expected that the exhibits will be used at more events sponsored by external agencies, and new portable exhibits will also be added, contributing further to the work of promoting the achievements of Micromachine Technology in the Industrial Science and Technology Frontier Program.

The Industrial Technology Exhibition – Techno Festa 21 Micromachine exhibition booth

Exhibits on display at The Industrial Technology Exhibition – Techno Festa 21

Living Organisms and Micromachines (II)

Sense Organs, Hints for Sensors

Isao Shimoyama
Associate Professor, Department of Mechano-informatics, Graduate School of Engineering, The University of Tokyo

1. Visual Sensor: Compound Eye

The compound eye is a well-known sense organ of insects. A compound eye consists of multiple ommatidia as shown in Fig. 1. The compound eye of an ordinary house fly is composed of about ten thousands of ommatidia, each of which has photoreceptors in it. Each photoreceptor reacts selectively to particular wavelengths of light, for example, to near-ultraviolet rays. This specificity is assumed to be advantageous for the insect to be active in the sun. Opinions vary about how the world looks like through the compound eye of a fly. Each ommatidium has typically several photoreceptors that receive optical information from the light coming through the facet as shown in Fig. 2. This means that the amount of information obtained by each ommatidium is about several bits, determined by the number of the photoreceptors. Since the resolution is by far coarser than the photoreceptors of a human eye, information acquired by the compound eye of a fly may form a mosaic image, although it is still in controversy. Why insects had acquired compound eyes through natural selection is unknown, but probably compound eyes are advantageous to cover a wide field of view in a simple but efficient way.

Our group is trying to fabricate a 3-dimensional compound eye by a technological method. For this purpose, micro lens arrays, photo-sensor arrays, information processing circuits to handle output information from photo-sensors, and curved surface processing technology are indispensable. There has been a report that information processing of the output from a photo-sensor array can be realized with a low-pass and high-pass filters in terms of time, and visual information network processing in terms of space. With all these technologies and knowledge, we consider that a compound eye about 1 mm in diameter would be feasible. This prospective compound eye can have omni-directional view. Probably the signal processing circuit for the photo-sensor array output can be incorporated in the eye by silicon processing technology. Our compound eye will merely detect contrast in visual information, but no recognition of shape or measurement of distance is considered. Since various sensors can be mounted on a micro robot, we can build a purposive robot that would avoid obstacles.

2. Wind Sensor: Cercus

As an artificial wind sensor, we have hot-wire anemometer. This instrument has an electrified thin wire, whose temperature depends on the flow around the wire. By negative feedback, the wire temperature is kept constant, and the feedback value is converted into the flow speed. This type of hot-wire anemometer is already miniaturized by the micro electro mechanical system (MEMS) technology.

Fig. 1 Compound eye of fly

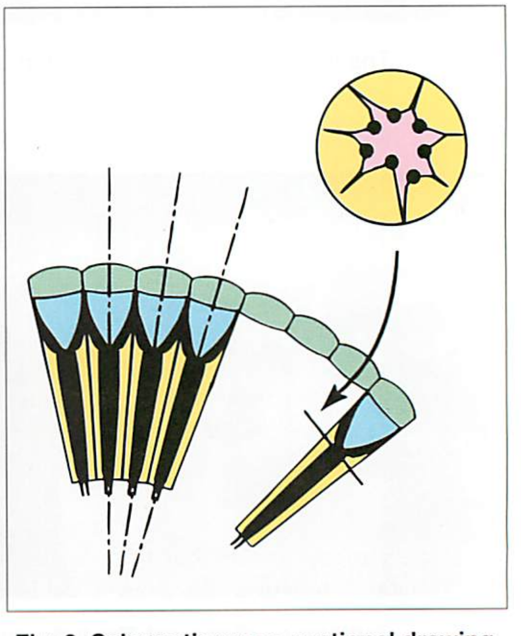


Fig. 2 Schematic cross-sectional drawing of compound eye

Meanwhile, the cercus of a cockroach or a cricket is an important sensor for them to trigger the escape behavior. If wind blows against the cerci, the insect shows the escape behavior. A cercus, as shown in Fig. 3, has dense, short hair. When blown by wind, the hair is turned down and the nerve at the bottom of the hair receives the stimulus. The force that turns down the hair is the hydrodynamics, which is significantly affected by the viscosity of the air in the region of a low Reynolds number. A cricket varies its characteristics of frequency response to air by having different geometric dimensions of hair. The cercus with dense hair of different frequency characteristics, as a whole, makes up a sensor that triggers the escape behavior.

A micromachine is characterized by its geometric design. For the conventional machines, we have replaced geometric mechanisms with software as expressed in the word "mechatronics". But intelligence of a micromachine is determined by its geometric mechanism because of the size restrictions.

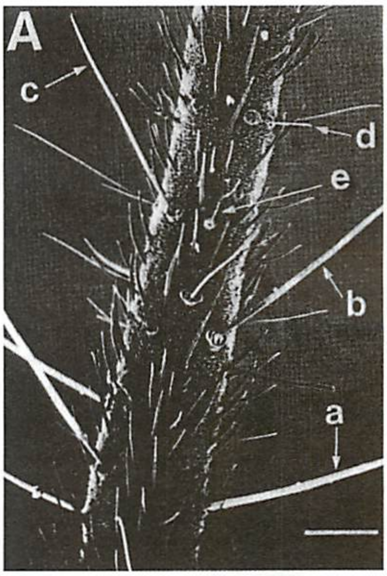


Fig. 3 Sensitive hair of cricket's cercus (T. Shimozawa and M. Kanou: J. Comp. Physiol., A (1984) 155:485-493)

3. Olfactory Sensor: Antenna

The antenna of a male silkworm moth shown in Fig. 4 is a high sensitivity sensor for detecting pheromone emitted by female silkworm moths. A male silkworm moth stays still if the pheromone is absent. If the pheromone reaches to his antennae, the moth tracks the flow of the pheromone to a female, and mates. Life of a silkworm moth after emergence is about a week, during which male moths do nothing but the tracking to a female and mating. The pheromone that has reached the antenna stimulates the antenna nerve, which transmits the pheromone information to the brain. The antenna serves as a very sensitive pheromone sensor. In the world of insects, many examples are known of receiving information by olfactories, for instance, with ants and cabbage butterflies.

If an artificial bio-sensor can be miniaturized, acquisition of such olfactory information will be possible. By the use of chemicals, easy placement of markers will be possible. The nature of smell of spreading in space by wind and diffusion would be advantageous in particular scenes. Another probable advantage is that molecules of chemicals can pass through narrow clearances and folded paths.

Fig. 4 Antenna of silkworm moth

4. Utilization of Particulars

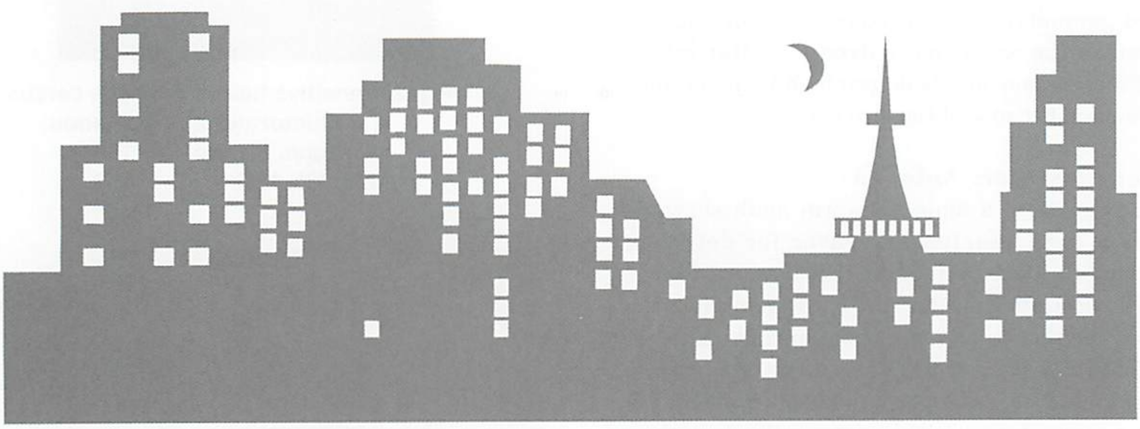
An insect has sensors equivalent to the five senses of a human. Each sensor, like the compound eye and the antenna, is simple and not for general purposes. But the sensors are indispensable for insect behaviors. For design of micromachines, priority would be given not to pursuit of the generality expected in conventional robots, but to invention of simple structures and functions required to achieve specific purposes.

The other day, in a meeting at Micromachine Center, I chanced to listen to Professor Yoshihide Momotani (of Kyoto International University) talks about origami, the art of folding paper into various figures. If my memory serves properly, his words went as follows. Biologists have been interested in common facts among different species. However, observation of a particular species may lead us to discover particularities that have been ignored, but can be valuable suggestions for micromachine design. This remark was very impressive. Apart from the common facts among general organisms written in the textbook of biology, we may find great ideas of micromachines in particular species.

References:
"Nerve biology of insects" by Eiko Tatsuta, Keiichi Mimura, Yoshiya Tominaga, and Yoshiaki Ohara, published in 1980, from Baifukan

The 3rd
International Micromachine Symposium

October 30 and 31, 1997
at Science Hall, Science Museum, Tokyo, JAPAN



Exhibition: MICROMACHINE '97

October 29▶▶ October 31, 1997
at Science Museum, Tokyo, JAPAN

MICROMACHINE No.21

MICROMACHINE is published quarterly by Micromachine Center (MMC) to promote the international exchange of information related to micromachines, R&D and other technical topics, and is circulated free of charge. Please send your comments about **MICROMACHINE** to the publisher:

Takayuki Hirano, Executive Director, Micromachine Center (MMC)
5-F, Niikura Building, 2-2, Kanda-tsukasacho, Chiyoda-ku, Tokyo 101, Japan
Tel: +81-3-5294-7131, Fax: +81-3-5294-7137
Internetn Home Page http://www.iijnet.or.jp/MMC/

Change of Address: Please send old address label and new address to the publisher.
Editorial and Production Management: Japan Technical Information Service (JATIS)
Date of Issue: Oct. 21, 1997

MMC