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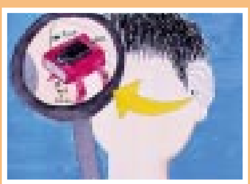


MICROMACHINE CENTER

No. 34

View on Year 2001 at the Beginning of the Year

Iwao Okamoto
Director-General, Manufacturing Industries Bureau,
Ministry of Economy, Trade and Industry

I wish to offer my wholehearted New Year's greeting to each and everyone of you at the beginning of the 21st century.

The economy of Japan has still not extricated itself from a difficult situation due to the delay in improving on its financial and consumption sectors but a continuous movement towards autonomous recovery centering on corporations does exit and, overall, the tendency is a slow but steady improvement in the right direction. To ensure that the economy is on the right track to self-recovery, the government is resolved to continue reforming the structure of the economy in a form appropriate to the new century whilst endeavoring to achieve economic recovery.

I am of the firm belief that the domestic manufacturing industry will continue to develop energetically in the new century and to support the economy of this country, but also I believe there are many outstanding issues that will need to be addressed. Many such issues will depend to a large extent on the endeavors of you in the industrial sector, but the administration will certainly attempt to come to grips with the essential matters which I will refer to hereunder in order to provide support and promote your efforts in this connection.

I. Strengthening Competitive Potential/Reorganization of the Business World

Improving the productivity of Japan's industries and strengthening their competitive potential are two extremely vital strategic themes, the realization of which will enable our economy to secure sustainable growth in the first half of the 21st century as the decline in the number of children and population aging become ever more conspicuous. Again, based on the philosophy of the "Option and Concentration" of management resources, restructuring is being promoted in individual enterprises even in the manufacturing industry, entailing affiliations and mergers as developments take place. However, with foreign competitors accelerating cross-border, large-scale affiliations and mergers and amidst an environment where reforms and intensification are taking place in demand circles worldwide in step with rapid increases in global procurements, what the manufacturing industry of this country needs is a drastic strengthening of its ability to compete. Towards such realization and to come to the point, improving efficiency on a wider scale by way of the consolidation of business and mergers, achieving the optimum scale of production and risk investment to include research and development (R&D), are anticipated. In continuation of the enactment of the Industry Vitality Regeneration Special Law in 1998, the government has been giving full support to corporate business restructuring and to the reinforcement of legislation in connection with corroborative splits and taxation. Every effort will continue to be made to resolve outstanding problems, such as the introduction of a consolidated taxation system, and reform of corporate pension schemes, etc.

II. Strengthening Industrial Technology Skills

In order for Japan to be able to maintain its economic status in the new century, it is recognized that further improvements to its industrial technology skills are essential and, to be specific, we plan to focus on tackling the points which I will now refer to.

In the field of biotechnology, with the announcement of a summary of the entire configuration of human genes in June 2000, we entered a new stage and competition at the international level is intensifying for both R&D and industrialization. Aiming at swift industrialization, the Japanese government has been promoting a millennium project in cooperation with industrial, academic and governmental circles since 1999 concerning genome analysis, analysis of the functions of protein, etc. In addition, we plan to appropriate a development budget for technology to replace existing industrial processing with bio-processing that has a lower environmental load from 2001 and will strive to expand activities in this field. Furthermore, since 2000, this Ministry, in cooperation with other governmental offices, in the process of improving the environment for R&D by preparing ethical guidelines has been relative to research and analysis of genes, etc. Inclusive of such measures, we intend to continually pursue measures to ensure the rapid development of the biotechnology industry.

Material nanotechnology including information technology (IT), biotechnology, etc. will lead to the future development of the social economy in the extensive industrial sector and is fundamental vanguard technology for technological reform, a technological field in which Japan has commanded a leading role to date. The Japanese government has positioned material technology as one of the most vital sectors along with IT, bio and environmental technology in its next Scientific Technology Basic Plan and, by concentrating industrial, academic and governmental efforts, intends to actively push R&D in this field.

Furthermore, in addition to the promotion of a Digital Meister Project targeting developments and improving on the strength of the manufacturing industry to create things, and to develop high-level processing technology required for next-generation semiconductors, we also intend to strive for globalization of standardized parts/ machine systems. In addition, to deal with the rapid approach of an aging society and the evolution of an information driven society, a millennium project for the elderly and an IT barrier-free project will be pursued in order to improve on the international competitiveness of a wide range of products and, simultaneously, improve the environment to contribute towards creating things from the viewpoint of citizens.

As regards aeronautics and space industry sectors, in order to promote relevant advanced technologies and in an attempt to take the lead in fuselage development at an early stage on the initiative of the Japanese government, technological ability in high-tech sectors including engines for supersonic aircraft, composite materials, etc. will be strengthened with the target being to establish technical standards domestically, which can be applied worldwide. In the industrial sectors, which involve the development of large-scale systems such as the rocket industry, etc., system design and R&D for high-tech integration will be pursued to enable trustworthy, low-cost and short-term development.

III. Environmental Measures

Global environment problems and the global warming issue in particular, are important issues which may exert a major influence on the economic activities of the manufacturing industry. At the COP6 scheduled to be resumed this year, we hope to proceed with negotiations so as to enable ratification of the Kyoto Protocol based on the development of the November 2000 negotiations. We shall also undertake to study the practicability and nature of highly efficient measures so as to be able to resolve the global warming issue domestically without imposing undue restrictions on either the economy or the population.

Again, it is recognized that hastening measures to recycle houses/building materials, paper, PET (polyethylene terephthalate) bottles, fiber, petroleum gas equipment, etc. is also important. In particular, regarding the recycling of automobiles and based on the reacquisition of scrapped vehicles, investigations are in progress, including the possible enactment of legislation, with the aim of improving the standard of recycling and securing appropriate disposal and, a draft of such fundamental framework system and basic way of thinking including the necessity to come up with a system is scheduled to be formulated by the end of the current fiscal year.

Concerning measures to protect the ozone layer, together with the promotion of measures for the smooth and total abolition of hydrochlorofluorocarbons (HCFC), etc., a chlorofluorocarbon (CFC) control strategy of comprehensive measures to cope with CFCs will be finalized by the end of the current fiscal year on the basis of the Montreal Protocol. Furthermore, in addition to enforcing the collection of Freon from electrical appliances in accordance with the Electrical Appliances Recycle Law, the Freon contained in air conditioning units installed in automobiles resulting from vehicle disposal, will be collected as a link in the recycling of cars, and Freon collection from discarded air conditioning and freezer units used in business installations will be promoted. Again, fiscal 2001 will see the introduction of a new system to control chemical substances. Based on the Chemical Substances Control Promotion Law, the MSDS (chemical substances, etc. safety data sheet) system will be put into effect from January this year, the PRTR (measures relative to grasping emission volumes, etc. of specific chemical substances to the environment) from April this year and, efforts will be made to improve on the voluntary control of chemical substances by businesses. To date the industrial world has been taking a positive attitude towards environmental conservation measures, but with the recent increase in concerns over environmental pollution by chemical substances, it is expected that further corporate efforts will be exerted with the enforcement of relevant legislation.

IV. Measures Concerning Regional Industry

Promotion of industries, which support employment and local economies, is another vital issue. The situation confronting the textile industry in particular is extremely grave as a result of the sudden increase in imports from China and other countries. To cope with such circumstances, efforts will be exerted to revitalize textile producing areas by comprehensively promoting measures for imports coupled with domestic measures aimed at energizing domestic production centers.

On the other hand, influenced by the changes in the life styles of the domestic population in recent years, etc., demand for products turned out by traditional arts and crafts has declined and problems such as securing such successors, etc. have come to the fore as a result. To overcome such problems and promote independent development of production areas, a review of existing systems (legislation, etc. relative to promoting traditional arts and crafts industry) will take place to correspond with changes in the times and the status quo while fulfilling and providing indirect support to various efforts made at relevant producing areas.

V. Trade Issues

Anti-dumping measures are on the increase in the U.S. and other nations on a whole range of iron and steel products imported from Japan in recent years. To address these problems, measures such as filing suits, etc. to settle disputes on the measures that are not consistent with the rules of the WTO are being implemented in conjunction with concerted efforts to resolve the issue at various levels including multilateral and bilateral consultations. The Japanese government will continue to powerfully promote such efforts hereafter, strive to maintain and develop a fair and free trade environment concerning issues involving bilateral or regional issues and the Fair Trade Agreement (FTA) by taking up matters in multiple stages.

As regards the automobile issue that has arisen between Japan and the U.S., since the measures drawn up in 1995 are due to expire consultations have taken place regarding the nature of the relationship between the two countries and how it should be developed in the years after 2001. In consequence, the Japanese government made a new proposal at a conference which took place in San Francisco in December 2000 regarding a dialogue between the two countries. Although the U.S. government did not respond to this proposal, we hope to deal with the matter in a proper manner whilst taking note of the possibility of reorganization in the automobile industry on an international scale so as to arrive at a mutually satisfactory conclusion.

VI. Conclusion

As of January 6, 2001, the Ministry of International Trade and Industry became the Ministry of Economy, Trade and Industry. The former Basic Industries Bureau together with a section of the Machinery and Information Industries Bureau and Consumer Goods Industries Bureau joined forces to form the Manufacturing Industries Bureau.

In the past we endeavored to make governmental policies reflect requirements of various industries as the point of contact between various industries and the administration. The stance of the Manufacturing Industries Bureau will remain consistent with this. We intend to expand the point of contact with industries and continue to energetically promote measures based on the realities of the manufacturing sector from a much broader perspective. All of you in the manufacturing sector are requested and expected to be aware of the fact that the manufacturing sector is the origin of the economic power of Japan at a time when pessimistic elements are conspicuous regarding Japan's economic prospects and to continue working to come to grips with technological developments, redistribution of management resources and the furtherance of alliances, etc. in order to maintain and strengthen the power of the manufacturing sector. Again, I would like to request that the consequences and details of such efforts be made known positively to the people of Japan. By doing so and in line with the progress in the series of reforms, the confidence of the people in the economy of this country is sure to be recovered and I believe we shall be able to share a bright outlook towards economic revival.

Lastly, I wish all of you happiness and further prosperity in the New Year.

Laboratory Introduction

Dr. Seiki Chiba
Executive Director,
The Advanced Automation Technology Center of SRI International

1. Introduction of AATC

The Advanced Automation Technology Center (AATC) of SRI International (SRI) focuses on the design, development, and transfer to its clients of advanced automation technologies. These technologies span a wide range of fields and include intelligent document understanding, 3-D machine vision, sensor placement, telerobotics, field robotics, and new transducer technologies such as artificial muscle. In the area of new transducer technologies, AATC works closely with other laboratories within SRI, sharing a wide range of facilities and equipment within SRI. These laboratories maintain state-of-the-art design, analysis, and fabrication facilities including special and general measurement and test equipment, an environmental chamber, a model shop, chemistry and spray fabrication facilities, and computer-aided design centers. AATC works closely with SRI's Physical Electronics Laboratory, which maintains clean rooms and other microfabrication facilities.

AATC has worked with a wide range of government and commercial clients in the US, Japan, and Europe. As a nonprofit institution, SRI transfers the technologies developed at AATC to the sponsoring commercial clients, or licenses them to manufacturing companies in the case of U.S. government-sponsored work.

AATC has worked on a wide range of robotic and transducer technologies. In the area of robotics, for example, AATC developed a laboratory prototype of a pipeline inspection robot. The pipeline robot used novel magnetic wheels that enabled it to travel on the walls and ceilings of 15-cm natural-gas pipes. Other research and development focuses on basic transducers; In addition to work on artificial muscle, AATC has developed novel levitated devices for applications such as sensors (flow meters, accelerometers, etc.), micromotors, and clean-room automation. AATC demonstrated what is believed to be the

world's first passive self-levitated (no bias forces) magnetic structure at room temperature. Another sensor area of interest to AATC is tonometry, a technique for measuring blood pressure unobtrusively and continuously. For a number of years AATC has developed tonometry technology, some of which is currently sold commercially.

2. Artificial Muscles

AATC has been investigating artificial muscles on the "Artificial Muscles in R&D of Micromachine Technology, industrial Sciences and Technology frontier Program" since 1992. The term artificial muscle, analogous to natural muscle, describes any actuator material that is substantially scale invariant in performance, where larger actuators can be considered as a collection of mechanically linked microactuators. For example, a single electromagnetic voice coil actuator is not an artificial muscle because it is not scale invariant (it has poor performance on small scales), and it is not a collection of mechanically linked microactuators. By contrast, a piezoelectric material has substantially scale-invariant performance, and a large, multilayer piezoelectric actuator consists of a collection of mechanically linked microactuators.

Our goal for the project is to identify and develop an artificial muscle with performance comparable to that of natural muscle. Such an artificial muscle would have overall performance greatly exceeding that of existing artificial actuators and could be used for small robots, inkjet printers, micro light scanners, micropumps, and a wide range of other microapplications. The artificial muscle would be particularly applicable to microdevices, for which existing actuator technologies are limited; but since it is scale invariant, it could also be used for a wide range of macro applications including robots, speakes, and motors.

The principle of operation of the electrostrictive polymers investigated by SRI is shown in Figure 1. Unlike other electrostrictive polymers (EPs), which work via molecular changes, SRI's EP materials work via bulk electrostatic forces (Maxwell stress). As shown in Figure 1, a relatively soft polymer is sandwiched between two compliant electrodes. When a voltage difference is applied between the compliant electrodes, the electrostatic forces squeeze and stretch the polymer, thus providing a mechanism for actuation.

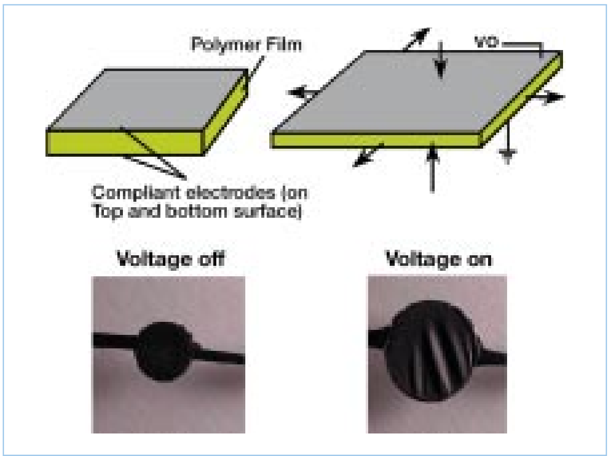


Fig. 1 Principle of Operation of Electrostrictive Polymers (Circular Black Areas in Bottom Photos are Active Electrode Areas).

Figure 2 shows a comparison between artificial muscle and other high-speed actuator technologies. Note that the performance of artificial muscle exceeds that of natural muscle.

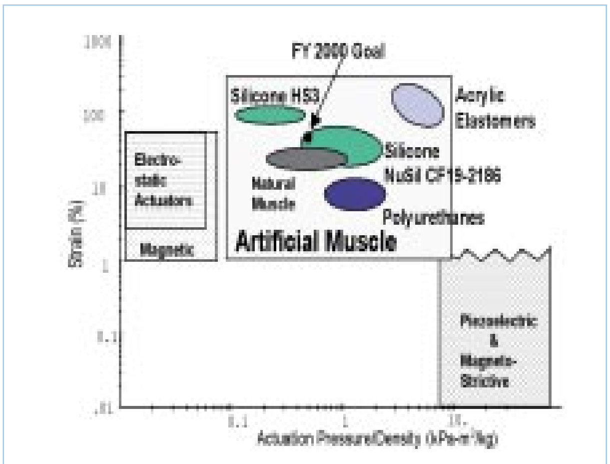


Fig. 2 Comparison Between High-Speed Actuator Technologies

Many polymer materials have been tested as artificial muscle. All insulating polymers show some response, Silicon and acrylic are dramatically better than others. Note that the strain of the acrylic elastomer can exceed 200%, and its energy density is higher than that of any known field-actuated material. The acrylic elastomer is a powerful material, but we note that silicone is faster, due to higher viscoelastic losses in acrylic. Silicones have a bandwidth greater than 1 kHz, while acrylic elastomers are currently limited to below 100 Hz. Research is now concentrating on ways to achieve the high strain and energy density performance of acrylics in operation at the speeds of silicones.

In addition to the polymer, SRI is investigating various electrode materials. Metals such as gold are typically too stiff and crack when actuated, but we have found that by suitable patterning they can elongate up to 80% while retaining their conductivity. For higher strains, particulate materials such as carbon black and carbon nanotubes in a binder generally work well.

We have developed a variety of ways to fabricate artificial muscle. Spin coating of polymers in solvents works well, and we have demonstrated muscle as thin as 1 µm. Thinner films reduce the operating voltage, which tends to be higher for electrostrictive polymer artificial muscle than it is for other electrostatically driven technologies.

We have designed and demonstrated a wide range of artificial muscle actuators. Examples include artificial muscle bimorphs and unimorphs capable of greater than 270 degrees of bending, artificial muscle diaphragms that can actuate from a flat to a hemispherical shape, and a range of simple linear actuators. Application-level devices, such as micro light scanners and minipumps, have also been demonstrated to show the wide applicability of the technology.

An interesting area for research and development has been the investigation of the unique actuation properties of artificial muscle and the design of actuators that can best exploit it. For example, uses a high prestrain in the polymer in one direction, together with a flexure design, to enhance actuation in the low prestrain direction.

3. Summary

Research on artificial muscles at SRI's AATC has reached an application phase. Strain, pressure, energy density, and response time performance parameters have increased by factors of 5-30 in the last 2 years. Technical progress continues in understanding the fundamental design of artificial muscles at the material, fabrication, and actuator levels. Thus, the near future of artificial muscle research at SRI's AATC will focus on both fundamental and application areas.

The 6th International Micromachine Symposium

The 6th International Micromachine Symposium was held at the Science Museum in Kitanomaru Park, Tokyo, for two days from November 9 to 10, 2000.

On the first day, the opening ceremony of the program started with the speeches of three honored guests, Mr. Shinichiro Oota, director-general of the Machinery and Information Industries Bureau in the Ministry of International Trade and Industry, Dr. Koji Kajimura, director-general of the Agency of Industrial Science and Technology, and Mr. Hiroshi Mitsukawa, executive director of NEDO. The total registered participants for the two-day program numbered 447 (51 of them were from overseas).

The first lecture in the symposium on the first day was "Artificial Heart Research by the Use of Micromachine" by Dr. Shinichi Nitta, professor of the Inst. of Develop. Aging and Cancer, who is also vice-president of Tohoku University. He introduced the audience to current R&D on artificial organs such as artificial hearts as well as outlining future expectations and prospects.

This year's program included a study on health and micromachines in Session 3 entitled, "Thinking of Micromachines". Front-line researchers made presentations on today's hot topics related to micromachine technologies, such as medical practices making use of information derived from the deciphering of the genome, telehealth, and robot surgery.

Medical treatment technology has been regarded as one of the most promising micromachine application fields. We were impressed by those presentations that showed how micromachine technology has possibilities for medical care in the near future. The content of the special guest speech is presented on the following pages for your reference.

Other sessions of the program held on the first day include Session 2 "The Path to New Industries in the 21st Century," Session 4 "Overseas Activities," and Session 5 "Innovative R&D." There were 16 invited lecturers, including 8 from abroad, who made presentations in the sessions. The following list shows lecturers from abroad.

Jean Philippe Gouy / LIMMS / CNRS-IIS
Michael Gaitan / National Institute of Standards and Technology
Ming Wu / UCLA
Masako Miyazaki / University of Alberta
Helmann Sandmaier / HSG-IMIT
Paolo Dario / Scoula Superiore Sant' Anna
Young-Ho Cho / KAIST

The second day of the program was intended for the Japanese national project "Micromachine Technology" under the Industrial Science and Technology Frontier Program. Mr. Yoshikazu Yamaguchi, Director for Machinery and Aerospace R&D of the Agency of Industrial Science and Technology reported the current status of R&D activities under the project. He also introduced the status quo and future prospects in conjunction with three national research institutes, including the Mechanical Engineering Laboratory under the Agency of Industrial Science and Technology. Furthermore, Mr. Tatsuaki Ataka, chairman of the R&D working group of Micromachine Center presented state-of-the-art R&D activities in the second phase. Four chief examiners of the R&D working group of Micromachine Center disclosed the results of the technological trend surveys. Also seven other presentations were made concerning achievements of the ISTF projects.

The planning and contents of the presentations in this symposium were highly appreciated by the participants, as proved by their comments in the questionnaire sheets collected upon completion of the whole program.

The schedule for the next symposium is shown below.

The 7th International Micromachine Symposium
Period: October 31 (Wed) to November 1 (Thu), 2001
Place: Science Hall, Science Museum in Kitanomaru Park, Tokyo

View of Symposium Hall

Artificial Heart Research by the Use of Micromachines

Sinichi Nitta
Vice President of Tohoku University and
Professor of the Inst. of Develop. Aging and Cancer

Good morning, everybody. My name is Nitta. I have long been vice-chairman of the Medical Application Working Group of the Micromachine Center. Naturally I have been closely related to micromachines. I specialize in cardiosurgery, and am working in a boundary area now popular, specifically in the area of biomedical engineering.

Today I have been requested to talk about micromachines and artificial organs, so will talk about what comes to mind. However, I am not confident about how to relate micromachines to this lecture.

[Kinds of Artificial Organs and the Current Situation]

The artificial organs are now applied systemically. For example, blood is pumped from the heart in the circulatory system to circulate through the whole body. Every organ related to it falls under this category.

The use of heart pacemakers is now a well-established practice for the circulatory system. It was formerly as big as 10 cm in diameter and 3 cm in thickness, but is now miniaturized to a weight of only 20 g. Its battery lasts as long as 10 years. It drives the heart by emitting electricity periodically. As a cardiac surgeon, I often have a look at the heart by inching an optical instrument through the chest. When I touch the heart lightly, it readily reacts to this mechanical stimulus. It also reacts to a flow of electricity. The heart shrinks when electricity passes through it. The heart pacemaker is based on this principle. If this device is rendered much smaller, it will sooner or later be incorporated into the heart and energized wirelessly from a device in or near the heart. This will also depend on how micromachine systems advances in the future.

Next comes an artificial valve. The heart is driven by a pulsation. Naturally, valves are required at every inlet. This valve is also manufactured artificially. It lasts 20 to 30 years in the human body.

Next, let me explain about an artificial heart in which I specialize. An artificial heart is to be embedded after the original heart has been removed from the human body. How long do you think it will last? May I ask this gentleman sitting in the front. Two years? Great! You are worthy of being at the top. The artificial heart we made works for about two to two and a half years. However, there are several problems to be solved. One is the formation of a thrombus. When blood touches an artificial material, it judges whether the material is friend or foe. On finding it is a foe, blood coagulates to concentrate on attacking it. This is what we call the formation of a thrombus. This should be prevented. The human heart works by a pulsation. It is known now that a man can live with a steady-flow pump, such as a centrifugal pump. However, what God gave us is a pulse pump. This pulse pump is subjected to a fatigue test, a pulsation of 100,000 times a day. No material on the earth can withstand a fatigue test of 100,000 operations a day for over five years. This means that no artificial heart is available that can last over five years. This is a task imposed upon us to find an answer to this problem. We are now getting various kinds of materials of a living body through gene manipulation, including cell engineering and tissue engineering. So eventually, we will be able to manufacture an artificial heart that will last over five years or over ten years if cell engineering, tissue engineering, and organ engineering work to cover an artificially-made one, moving parts, and the parts to withstand a fatigue test. The current heart transplantation has attained a five-year survival rate of 70 to 80%. If an artificial heart surpasses the transplanted heart, which lasts five years, we will be able to manage without relying on the human heart. The general ethical view prevailing in Japan is hindering the progress of heart transplantation. We researchers who are now developing artificial organs think it is ideal that God forgives us if we succeed in managing without relying on the organs of others by manufacturing a heart more excellent than the one God gave us with God-blessed wisdom.

This circulatory system is directly connected to life. For example, a man dies if his heart stops. This system is very important, because a man dies if oxygen is not supplied to the brain for three minutes. Another factor to be considered is the contact with blood. This is very specific, because artificial hearts will not work well unless a more advanced form is devised than other artificial organs.

Next, the respiratory system, where gases are exchanged. An artificial lung dominates this area. An example of lung transplantation survival was reported for the first time in Japan by Tohoku University the other day. We make this artificial lung. We are researching into an artificial lung even now. At present, a heart-lung machine is used clinically, which can be used as long as seven hours for heart operation with almost total safety. However, an artificial lung poses a problem if the operation lasts longer. It is very difficult to make this unit last longer. Our research into a built-in artificial lung are already under way. However, another factor we should consider after the removal of the lung is that the lung is used for speaking. The lung is used for uttering words. This mechanism of speaking should also be manufactured separately. The lung itself is very important, because it functions in various ways, such as the production of hormones. It is utterly impossible for us to copy the lung. What we can do well is only to exchanges gases. The current situation governing an artificial lung is that no artificial lung has been made available that can be used for a prolonged period of time because of its contact with blood.

Then, the digestive system and artificial intestines come next. Organs for the urological area should also be considered. We are working to make artificial valves for patients who are finding it difficult to urinate. Since an artificial valve should open and close, we are using shape memory alloys for the manufacture of artificial valves for patients suffering from dysuria, and confirming whether they serve the purpose by using laboratory animals. The test of laboratory animals is going on successfully.

Next, motor-related organs.

And the sensory system, which should desirably be studied in preference to other areas. We have sensory organs with which we can see, hear, and touch. We are trying to replace this sensory system with a sensor system, which, for example, resembles the eyes of a robo cop such as we see in the movies. However, the information those eyes are actually collecting is different from what our eyes collect. We may copy a human system when we think of a sensor system. It is desirable, however, that, if a microsensor system, for example, is capable of collecting the volume of information beyond the reach of a human system, this function should be utilized to the full. This should be a well-developed area. For example, our brain thinks various things, issues commands, and controls in various ways. The brain issues various commands through the neural system, such as moving hands, raising blood pressure, and secreting hormones. If we can intercept the commands midway to obtain the information and convert it to electric signals, we will be able to do what the brain intends to do next while thinking to do something. We are now doing this by varying the quantity of electricity. The subject of this interface will come up later. I think this will be a main area in which micromachines take part in the future.

Then, the ear, the nose, the intestines, the esophagus, the windpipe, the lung, the liver, the ovaries, joints, and artificial blood vessels. The artificial blood vessel is nearly perfected among the artificial organs in the circulatory system. The aorta and a blood vessel with a large diameter are in the stage of nearly ideal perfection. What is left unsolved is that an artificial blood vessel does not expand as desired when it should expand because of the difference between the properties of the human blood vessel and those of an artificial one. We refer to this as the mismatching of a living body. Such a thing has not yet been solved, but an artificial blood vessel that lasts for a considerably long time has been made available. However, an obstacle has not yet been removed in the case of a slender blood vessel, say, with a diameter of 1 mm, an obstacle in which, when blood takes a slender blood vessel as a foe, it coagulates there. I think this may be a situation in which micromachines will play an active part.

In addition, an eye, a tooth, an artificial heart, a valve, a pacemaker, an artificial kidney, the bladder, the urethra, the skin, and an artificial leg are the subjects of study.

[The Artificial Heart]

Please allow me to dwell on the artificial heart in which I specialize. The artificial heart beats 100,000 times a day with a discharge volume of about 70 cc each time. A displacement of about 70 cc is therefore required if we are to make a pulse pump. Its size is determined in this way. A steady-flow pump and a centrifugal pump have come to be used for men as well. When I started studying artificial hearts, it was believed that a man would not survive with a steady-flow pump. However, a man was found to survive. What makes the difference is that, if a man is required to have 100 cc of blood per kg of his weight for living, a steady-flow pump should have a capacity of 100 cc plus 20 cc. Conditioned as such, however, it is quite intriguing for us in that it can be miniaturized. A man has two pumps for the right and left ventricles. God combined the two together, but the two look like one. Actually, however, there are two pumps. One is a low-pressure pump for sending blood to the lung, a low pressure equivalent to about 20 mm/Hg. The other, the left pump, sends blood systemically with a pressure equal to blood pressure. It therefore follows that the pump should have a power as great as four to five times. Since the right heart sends blood to the lung, it pulsates by breathing. When air is inhaled, the pressure in the lung becomes negative to allow blood to return with a rush. When the heart is checked, it stops sometimes, for example, when struck with a catheter. The patient is conscious, so he keeps breathing. Then, the breathing pressure only comes out in arterial pressure. When the patient is conscious, I tell him, “Cough a little”, while his heart isn’t beating. He coughs, then his heart begins beating again in some case in response to this mechanical stimulus of coughing. Just coughing raises the pressure to about 120. Such a thing occurs at a place just outside the right heart. Therefore, I think a steady-flow pump will do for the right heart in the future, because it makes such pulses, though slow. As for the left heart, a pulsating flow is better than a steady one for making men and laboratory animals vivid. I dare say vivid. If I am allowed to say so, a steady-flow pump is very small, easy to make, and inexpensive. In the future, I believe, a steady-flow pump will be used for the right and a pulsating-flow pump for the left.

This is an artificial heart developed for the first time in the U.S. by Dr. Akutsu, now honorary chairman of TERMO CORPORATION if I remember right. Since it was made in 1957, its history is very short. Generally, an artificial heart has only a short history usually less than half a century. At that time, a laboratory animal could survive only 1.5 hours.

This was also made by Dr. Akutsu in 1975. In this manner, we now have two artificial pumps. This pump served to help a calf survive experimentally 268 days. However, when an artificial pump is embedded in a calf for 268 days, the calf grows two times heavier. This makes it impossible for this heart to answer the purpose.

[Current Problems Related to Artificial Organs]

The artificial organs we are now confronted with are under study by researchers including myself who are currently researching into an artificial heart nearly as long as its history. The points at issue are how deftly we can make very small artificial organs and how we can make them serviceable for a long time without problems. I am thinking of having as many researchers as possible participate in studying the extent to which micromachines can answer the needs so that ideal artificial organs can be made.

Therefore, we have summarized the defects and points at issue with the artificial organs now available. They are too heavy and too big. These problems are indisputably the ones micromachines can answer. The sensors do not work as desired, either. Micromachines are also good at this point. Moreover, they are not well controlled automatically. There are two kinds of controls: one type of control is to have the unit fit the body itself when embedded, and the other, to have the unit last longer such as with an artificial heart, the durability of which poses a problem. However, micromachines enable the processing and control of information, thus dominating this sphere of activity.

They are not energy-effective, either. For example, I am now developing an engine for medical treatment using a shape memory alloy. The shape memory alloy I am now using is a commercially available large-diameter unit. I believe that if the alloy can be divided into very small elements and then re-assembled, it will be easier to control and be energy-effective. I am proposing this concept to the industry, but to no avail.

The engine has been completed in my head, but the industry is quite reluctant in complying with my request. Further, it does not last long. To make matterÇì worse, unpleasant things occur one after another, such as noise and vibration, accompanied by thrombus as a by-product. Since an artificial heart is a foreign body, it can also become a source of infection. The human body reacts to foreign bodies in various ways. Bleeding also poses a problem.

[Characteristics Desired for Upcoming Artificial Organs]

Desirable characteristics for newly developed artificial organs are, first, miniaturization, second, to interface with nerves for automatic control, third, to have a control system that is acceptable for both the living body and the embedded artificial organs, and fourth, to harmonize with the living body in various ways. Many issues have come up in the past, such as noise. Another desirable characteristic for artificial organs is to last several years. The artificial hearts now available last a little over two years, but should desirably last longer.

Now, we have two large national projects in Japan, led by the Ministry of Health and Welfare and NEDO. We are setting about dealing with an artificial heart. The project by the Ministry of Health and Welfare has lasted five years and will come to an end this year. We hope it continues longer. As one of the members participating in the NEDO project, I am glad to know of the decision to continue this project one more time.

Recent Research of Artificial Organs

This is an artificial heart we developed. It is still large, but it has two pumps, right and left, in this form. This shows how it was embedded in the thoracic cavity.

And this is an artificial heart equipped with a microsensor, undoubtedly related to micromachines. I think it is the first product in the world into which a chip was inserted directly. It is a result of the work I did about fifteen years ago together with Professor Esashi at Tohoku University. Frankly, I was also a student of Professor Matsuo for one and half years, who was Professor Esashi's teacher. So I started this work.

This is an auxiliary artificial heart. Pressure sensors are attached to the outlet and inlet, where they are connected to the living body. This is an artificial blood vessel leading to the aorta, and this is a duct. This is a cannula with which to draw blood from the heart. Attached at the top in this manner is a microsensor. Here is another. It is made in this manner, and its surface is covered with an antithrombotic material so that blood can hardly perceive it as a foreign body. It is about 20 microns thick, covering the sensor surface.

This is a diagram of the sensor itself. I am not a specialist in this field, but, according to Professor Esashi, it is very difficult to connect a lead wire to a sensor. I think the solution to this can be found by integrated molding. Actually, it is being perfected. This is the surface of a pressure sensor to be pressured. This is the rear side. This is a connecting part. This is an experiment using a goat. This is a system to assist the left ventricle. This is a sensor. This is a trace of the micro-sensor after two weeks.

We also have to measure the flow. This is a blood flow meter using ultrasonic waves, developed jointly with Cornell University. This is its trace, which is almost the same as that of the conventional electromagnetic flowmeter.

Then, we use an artificial heart to assist the heart. To ensure that the heart can set up for itself, we draw two hysteresis curves of the left ventricle in this manner to connect them with a straight line. The more upright the inclination of the straight line, the more active is the heart. The more it declines, the worse is the heart. We therefore measure using a hysteresis curve to see how active is the left ventricle. This necessitates measuring pressure and the quantity of the discharge from the left ventricle. By measuring the two, we can measure how active the heart is.

[Neural Interface]

Let me explain about the neural interface we just talked about.

This shows the findings of the experiment using a goat. Above is aortic pressure. This is a neurogram, a measurement of the integrated action potential of a nerve. This is aortic flow.

Here, "stand up" is written. When a goat tries to stand up, we can obtain neural information in advance. This means that we can obtain neural information in advance when a goat stands up. With this method, we can manage well by accelerating the beat rate if we can judge whether various kinds of artificial hearts are in a state acceptable to the body and what should be done from that point. This means that we can get signals earlier than God. In the case of God, it sends signals in like manner to have an organ that raises blood pressure and secretes hormones, which in turn raises blood pressure. This takes dozen or so seconds. In the case of an artificial heart, however, we can control the above process in a few seconds instead of dozen or so seconds. This is welcome for us. This kind of work is carried out infrequently, and we are the first in the world to take the initiative.

This is a neural device for that purpose. It is made into a cuff containing a nerve so that the nerve is protected from damage when pierced directly. The cuff is also a kind of interface used, for instance, for applying electricity or stimulation. This is exactly the process by which the nerve is electrically converted to a control system or for use as information. A new trial like this has appeared. As I mentioned just before, this may explain the reason why a new trial like this to what we call a sensor system will be applied more and more frequently.

[Microsensors]

With microsensors, we can obtain a variety of information on vital signs, including blood pressure, blood flow, pulse rate, breathing condition, temperature, and chemical substances for artificial heart, such as glucose, insulin, CRP and ammonia. The microsensors also enable us to obtain information from a living body, such as the concentrations of oxygen and carbon dioxide in the blood, pH level, and electrocardiogram. Those microsensors are embedded in the body, and driven electromagnetically. Our system also has them. In short, a microsensor can send electricity into the body, a device with primary and secondary coils wound around it. Therefore, a microsensor can transmit power and information wirelessly without a cord piercing the skin even when embedded in the body. Its efficiency is such that it can send electricity with an efficiency of about 90% by increasing flux density with an amorphous material in our case. In the future, therefore, various devices will be embedded in, for instance, the body of a sick patient or a postoperative patient, to be controlled intensively at a given place. It is not necessary for those devices to pierce the body for communication. We therefore assume that, as with the artificial heart, we will eventually be able to go to an electric station after several decades when we are short of electric supply in our daily life as we now go to a gas station for gasoline.

At present, most of the microsensors are used for a catheter. It is desirable, however, that microsensors be embedded in artificial organs. If so, we can obtain a variety of information and use it for controlling.

This is a sensor that Esashi Laboratory is researching. This is a self-mobile active catheter, for insertion into a blood vessel in the brain, which is one of our projects we are doing our utmost to promote as members of the committee in the Micromachine Center. Since artificial blood vessels are considered a hard nut to crack, we are in the process of developing this, accompanied by the development of various element technologies.

As I am a cardiac surgeon, we are thinking of embedding sensors in various parts of the heart. By so doing, we can understand well how a pump works. And this is an artificial valve which stands for 20 to 30 years. Since its movement is actuated by a difference in pressure, it moves only passively. If a micromachine can be used skillfully, a valve will come to open spontaneously by controlling it with greater skill.

[Review of the Study of Artificial Organs in the 21st Century]

In 2018 such as, for instance, an artificial kidney, now used in vitro, will be made available for embedding in the body. Here is what we call a hybrid. It will become possible to make what an artificial thing cannot do by using various cells and tissues of the living body. We are also expecting the emergence of a bio-cell by around 2014 as researchers of artificial organs.

In this presentation today, we are looking forward to the realization of artificial organs that are durable, reliable, stable, miniaturized, and biocompatible along with energy transportation or a battery system by utilizing micromachine technology.

Thank you very much.

(This paper is a summary of Prof. Nitta's lecture, prepared by MMC.)

“Micromachine 2000” Held

The 11th Micromachine Exhibition, “Micromachine 2000” was held with The 6th International Micromachine Symposium at the Museum in the Kitanomaru Park, Tokyo, for three days from November 8 to 10, 2000. The exhibition met with an enthusiastic reception.

The exhibitors include Micromachine Center and 22 supporting member companies of the center. A record number of 94 companies, organizations, universities, and research institutes joined the exhibition program from Japan and foreign countries. This exhibition covered state-of-the-art micromachine technology and results of researches. The size and contents of the exhibition have been highly valued year after year as the largest exhibition specializing in micromachine technology, not only in Japan, but also in Asia.

This year’s exhibition disclosed and demonstrated all the prototype systems created by the respective member companies which participated in the 10-year project “Micromachine Technology” under the Industrial Science and Technology Frontier Program promoted by the Ministry of International Trade and Industry. In other words, the exhibition was full of the comprehensive achievements of the R&D activities conducted by MMC’s member companies over a period of 10 years.

The exhibited items on general exhibition included micromachines, their components and applied systems, MEMS-related systems, molecular machine related technologies, micromachine manufacturing related equipment and materials, micromachine evaluation technologies andequipment. This exhibition was intended for experts and specialists in such fields as R&D, engineering, design, production, manufacturing, management, and administration of almost all industrial genres such as machine and precision machine, electric and electronics, medical, information and communications, automobile and transportation, biology, physics, chemistry, construction, steel, aerospace, ship and marine industries.

The exhibition is an ideal place for companies involved in the R&D of micromachines to promote their technology, equipment and products. It is also a good opportunity for universities and research institutes to make the results of their researches known to the public. In addition, new companies in the market find this occasion useful to introduce their products and technologies.

The exhibition was broadcast on several TV news programs. For example, NHK’s “News 10” aired the exhibition report for about 3 minutes from 10:30 p.m. on November 7, while Television Tokyo’s “News Eye” reported on the micromachine exhibition also for about 3 minutes from 5:30 p.m. on November 9. On the same day, NHK Satellite 1 “Economy Frontline” on BS23 broadcasted a special report on micromachines for 8 minutes from about 11:50 p.m. Furthermore, NHK’s “Good Morning Japan” on General Channel 1 introduced detailed contents of the micromachine exhibition in terms of micromachines which serve the micro world in its “Information Box” corner on the morning of November 15.

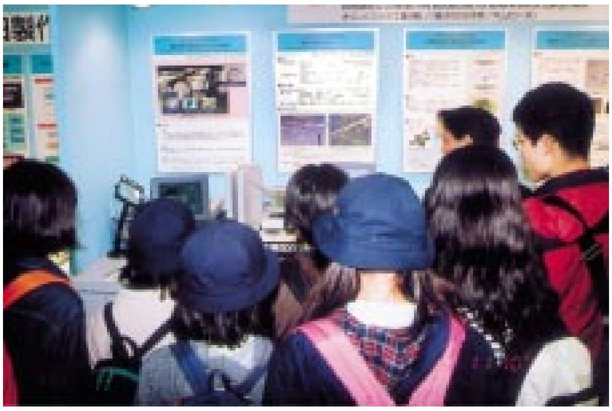
The broadcasts focussed on areas of achievements of the national project “Micromachine Technology” including the “Experimental wireless micromachine system for inspection on inner surface of tubes” (developed by DENSO CORPORATION, SANYO Electric Co., LTD. and TOSHIBA CORPORATION), “Experimental chain-type micromachine system for inspection of outer tube surfaces “ (by MITSUBISHI ELECTRIC CORPORATION, Matsushita Electric Industrial Co., Ltd., and SUMITOMO ELECTRIC INDUSTRIES, LTD.), “Micro Catheter” (by OLYMPAS OPTICAL CO., LTD.), and the world-smallest experimental system for micro processing and assembling “Microfactory” (developed jointly by Seiko Instrument Inc., FANUC LTD., Hitachi LTD., Aisin Cosmos R&D Co., LTD. YASKAWA ELECTRIC CORPORATION, Fuji Electric Corporate Research Institute, and MITSUBISHI CABLE INDUSTRIES, LTD.). Developers of respective systems were interviewed and the inner mechanisms and parts were described in detail.

There were a record number of about 5,500 visitors to the three-day exhibition. The exhibition floors were crowded with enthusiastic visitors who spent a long time looking at the exhibited items and asking questions to booth attendants.

Schedule of next exhibition “Micromachine 2001” Exhibition is shown below.

“Micromachine 2001”
Period: October 31 (Wed) to November 2 (Thu), 2001
Place: Science Museum in Kitanomaru Park, Tokyo
Inquiry: Mesago Messe Frankfurt Corporation.
Tel.: +81-3-3262-8411 Fax.:+81-3-3262-8442
E-mail: micro@mesago-messefrankfurt.com
URL: http//:www.mesago-messefrankfurt.com/micro

Exhibition full of visitors From Japan and abroad



Groups of elementary school children studying the exhibited items with enthusiasm

Research on the Application of Sprout Technologies in other Fields to Micromachine Technology for Fiscal 1999 (Part II)

Since 1992, the Micromachine Center has taken up various seeds of technology as themes for joint research by academic, governmental 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 1999, research has been carried out on nine themes. Continuing from the last issue, the remaining five themes are summarized below.

Investigation of the Trend Related to the Fusion of Biosensor Technology with Micromachine Technology

Masuo Aizawa
Professor, Graduate School of Bioscience and Biotechnology,
Tokyo Institute of Technology

1. Introduction

The research and development of biosensors has rushed into an age of upheaval. The main reason for this drastic change may be found in the rapid diversification of needs for biosensor technology and the progress of related technologies.

In response to these diversified needs, targets of the research and development of biosensor technology have been clarified as described below:

(1) On-site sensing, (2) massive information sensing, (3) complex information sensing, and (4) ultimate sensing technology. This paper will describe what can be realized when biosensor technology is fused with micromachine technology, and it will investigate the current status of the application of micromachine technology to the foregoing items.

2. Massive information sensing and micromachine technology

The importance of molecular information about DNA and chemical substances has come to be recognized, which in turn has led to attaching greater importance to massive information sensing technology with which molecular information contained in a trace amount of sample can be analyzed at one time. Massive information sensing is used for or expected in the detection of DNA, evaluation of substances synthesized by combinatorial chemistry, and detection of environment-related substances. This paper summarizes the trend of massive information sensing related to the analysis of gene information chiefly on DNA chips, and a report is presented on the findings of the investigation of micromachine technology required in that field. Also summarized are the evaluation of molecular functions in combinatorial chemistry where massive information sensing is expected to develop in the future, the trend of research in the micro total analysis system, μTAS, in neural network information sensing, and the application of micromachine technology.

3. Ultimate sensing and micromachine technology

Chapter 2 deals with the trend toward research of massive information sensing and the utilization and technical problems of micromachine technology. In addition to the micromachine technology chiefly related to processing, another micromachine technology for evaluation and observation is also available. This is probe microscope technology (SPM), including AFM. In recent years, SPM has developed rapidly as a technology for sensing minute targets, and it is beginning to be utilized. Particularly for developing research that delves into the constituents of microorganisms and materials a technology is required that will allow a single molecule to be observed.

With this background, "a probe microscope", which enables topologic information to be obtained by probing for a sample without relying on light or electron rays, is considered essential as a new technology by which observation and function measurement can be made possible on a single molecular level. This chapter deals with the contribution of micromachine technology in the technology of sensing minute molecules and minute areas with emphasis on various probe microscopes to probe for single molecules and single cells as their targets.

4. Bio-system microprobe

For those with health problems, the aged and disabled, it is necessary to routinely monitor their health management information so that they can participate in social activities. For that purpose, it is most effective to use a sensor embedded in a biosystem for measurement. This makes it inevitable not only to micronize a sensor device, but also to realize the application of the device using materials compatible with a living body. This paper summarized the trends in research of microprobes that can be used directly for a living body along with tasks for which micromachine technology is required.

5. Conclusion

Research and development of biosensor technology has entered a new stage aiming at high performance by micronization and integration. In a narrow sense, DNA chips and μTAS are not categorized as sensing devices. With the enlargement of the base of biosensor technology, however, they have had a strong impact. In this investigative research, by assuming the future targets of biosensor research, the present state of related research was generalized after reviewing how micromachine technology can contribute to the achievement of those targets. Since the related research branches out broadly, its investigation was limited. However, many themes of research and development to be promoted in the future have come to the fore.

Microprocessing technology is making rapid progress. However, sizes that can be processed at present are considered to be on the submicron order. It will be necessary to transfer to a processing form unlike the present one if processing to the nanometer order is required. Further miniaturization is needed, particularly to permit a sensing device to be embedded in a living body. In addition, the device should have a structure wrapped in a material compatible with a living body. Developing a technology capable of using various materials compatible with a living body as the raw materials of micromachines or the importance of developing materials compatible with a living body, suitable for micromachine processing, is expected to grow in importance. Again, for micronizing sensing devices, it is necessary to develop a method suitable for modifying molecules (enzymes and antibodies) precisely into minute materials.

Currently, various research themes to be promoted in the future have surfaced. At the same time, it has been demonstrated that the fusion of biosensor technology with micromachine technology is an important theme for development of future biosensor technologies.

Investigative Study of Chemical Reactions and Synthesis Using Microreactors

Jun-ichi Yoshida
Professor, Graduate School of Engineering,
Kyoto University

Microreactor technology has recently become a new and very promising field within a very short time in the fields of chemistry, process engineering, and biotechnology. The application of micromachine technology to chemical synthesis is progressing at a particularly rapid rate. On finding that this technology could be realized, the chemical industries in Europe and the U.S. have aggressively set about the trial manufacture and operation of microreaction systems in only a few years.

Downsizing as represented by microreactors is expected to contribute greatly not only to future chemical synthesis but also to industry and society as a whole. This has prompted the investigation of chemical reactions and syntheses using microreactors with the emphasis on the nature of reactions, the manufactures of reactors and application to the development of functional materials and drugs.

Several organic reactions using microreactors have already been reported. Particularly noteworthy is the fact that microreactors, characterized by a large specific surface area per unit volume, could realize reactions hitherto considered impossible to achieve. In addition, heterogeneous catalytic reactions and electrochemical reactions that take place on a solid surface will develop dramatically using microreactors in the future. Microreactors are also expected to enable chemical manufacture using hitherto considered difficult to use due to limitations of process engineering and safety. What is more, microreactors enable the realization of a comparatively small-scale economical plant easily and quickly when set in parallel, making it possible to transfer the findings of research and development more promptly to the manufacture of materials. This will simultaneously enable more rapid compliance with market demands.

The technology of chemical analysis or biochips, so-called micro-TAS or Lab-on-a-chip, can be used for manufacturing microreactors. However, other technologies will also be required for the manufacture of microreactors suitable for chemical synthesis because of the great difference in the requirements for organic synthesis and those for analysis and biotechnology. For example, technologies of materials for reactors, joints and connectors that are resistant to solvents frequently used for organic synthesis will become increasingly important.

The applications of microreactors to chemical synthesis involve the development and manufacture of functional materials and drugs. In the former case, it is particularly worth noting that, by the use of microreactors, the process of manufacturing functional materials, including microcapsules, dispersion of micro-particles and polymers, so far considered impossible to manufacture with conventional reactors, will be revolutionized. In the latter case, the development of new drugs by combinatorial synthesis and their manufacture using microreactors attract our attention. Although not many examples have been reported in either case, great developments can be expected in those fields in the future.

Our investigation, which emphasized the above points, reveals that a potential of microreactors has not yet been fully utilized, leaving much room for dramatic and revolutionary development in the future. It is, therefore, premature to completely forecast and evaluate the direction of the development of microreactors. It is beyond doubt, however, that microreactors will bring about a revolution in research, development and manufacture in the chemical industry, presumably wielding great influence on the future shape of the chemical industry as well as our entire society. Microreactors will bring about a new paradigm of science and technology, leading to the creation of new disciplines and new fields of industry. It is indispensable for the development of microreactors in theory, design, manufacture, reaction, and application to concentrate the intelligence in a variety of fields, including microfluidics, microfabrication, process engineering, reaction engineering, microanalysis, catalyst and organic synthesis. Since these fields spread widely over electric and electronic engineering, mechanical engineering, chemical engineering, analytical chemistry, physical chemistry, and organic chemistry, they should be organized to work together. Although the research into the application of microreactors to chemical synthesis is not mature in Japan. However, energetic research and development should be made in the future in view of the growing expectations in this field.

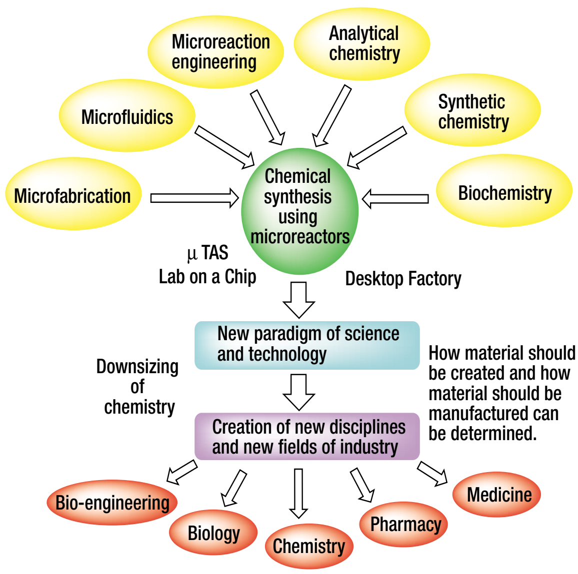


Fig. 1 Chemical Reactions and Synthesis Using Microreactors

Investigative Study of Micro Heat Design Technology

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Tokyo Institute of Technology

It is well known that many problems related to engineering and industry arise from poor heat design and control. This also applies to micromachines, which may break down unexpectedly as seen in malfunctions and failures without a prediction of temperature and heat elimination needs based on appropriate heat design, and heat control based on the above prediction. For instance, deformation due to thermal expansion of component parts, changes in action characteristics at high temperatures, and the progress of corrosion can be cited. This may be attributable to the failure in a temperature prediction for the part that goes out of order and in heat control stemming from poor temperature prediction. It is important, however, to include an appropriate heat design in the design stage.

In the heat design of micromachines as well, it is equally important as in the heat design of conventional size machines to evaluate local heat value and thermal load along with the quantity of heat to be removed when considering how to remove the heat generated. However, the distribution of temperature and heat conduction characteristics in an infinitesimal area have not been entirely clarified because of the very small size of the target machines. This may also explain why no effective cooling system has been satisfactorily established.

This investigative study reports on a technique for measuring temperatures on an immeasurably short scale, the importance of which should particularly be considered in the heat design and control of micro devices, a method for theoretical and experimental handling of contact and interface heat resistance at the component interface, and a technique for calculating heat conduction for heat design.

In micro devices, the area in which temperature information is required is incalculably too small to handle by conventional temperature measurement techniques in many cases. This area may be characterized by requiring a technique of high-degree space resolution measurement. Accompanied by progress in micro processing techniques, measuring techniques have also made progress recently so that it can meet the needs for measuring temperatures at sites in such micro systems. In this investigative study, various techniques for measuring temperatures in the proposed micro areas were investigated for analysis to compile a report on the findings, citing actual examples.

In addition to the foregoing, it is possible to list various problems in thermal engineering as specific to micro devices. Important among these is thermal resistance at the interface of dissimilar materials. Thermal resistance stands for an index by which the difficulty of heat conduction is represented. It may safely be called a physical volume that controls a rise in device temperature because of a large difference caused in an area with a large heat resistance. For example, heat is transferred by conduction in device components such as substrates or thin film devices. However, as is clear from Fourier's law relative to heat conduction, a temperature difference is sure to be caused in the elements unless a material is present with an infinitely large thermal conductivity. This will result in the presence of a thermal resistance, large or small, in those elements. What is more, a temperature difference is caused at the interface of the elements because of the presence of a thermal transfer resistance that differs from the inside. As is clear from Newton's cooling law, no heat can be transferred unless a temperature difference exists between the perimeter of the device and the surrounding environment as we see in the final removal of heat to the surrounding environment outside the device. Particularly in the case of micro devices, because of the small size of each device component, the contribution of thermal resistance arising from the heat of conduction inside those elements becomes relatively smaller and smaller. Generally, thermal resistance at the interface of elements does not depend on the size of the device. It therefore follows that thermal resistance at the interface comes to be regarded as relatively important. In this investigative study, the considerations described above are classified into the following problems for discussion:

1) A surface-related problem at the interface, which becomes important in various film-forming processes.
2) A volume-related problem arising from an incomplete layer near the interface.
3) A problem at the joining interface where respective materials are present as if pasted together.

The surface-related problem is important, particularly at low temperatures. Explanation of this viewpoint is therefore given. In addition, a technique for measuring thermal resistance is proposed in various ways for verifying the value of thermal resistance, obtained theoretically. This is also under study.

Further, it becomes necessary to study the technique of calculating heat transfer with all of these factors combined. It is possible to select a technique for the respective purposes, ranging from a technique of simple analysis for a basic order estimate to a more exact one that solves a three-dimensional energy equation numerically. Those techniques and related problems are introduced along with the concept of the thermal resistance.

Investigative Study of the Possibility of Greatly Upgrading Micromachine Technology by Utilizing Physical Phenomena that Characterize the Mesoscopic Area

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1. Introduction

Micromachine component parts are as small, ranging from 1 mm to 1 μm, which is larger than an atom or a molecule by 3 to 4 orders of magnitude and smaller than conventional machine parts by 1 to 3 orders of magnitude. This area lies between the area to which a macro physical phenomenon model can be applied, hitherto used by conventional technology, and the area to which a micro phenomenon model is applicable, with atoms or molecules used as units, an area that has been making marked progress in recent years.

The modeling and practical application of physical phenomena in this mesoscopic region is seldom seen except for the technology related to hard disk drives. It is indispensable to grasp physical phenomena in this area so as to establish methods for utilizing them so that micromachine technology can grow into a basic industrial technology.

2. Physical phenomena and related research trends

In this investigative study, physical phenomena related to greatly upgrading macro mechanisms were itemized (Refer to Table 1). The items considered particularly important were investigated relative to their research trends.

One of them is tribology. The coefficient of friction in the mesoscopic region often grows into a large value, and interfacial force or the surface tension of a liquid film are closely related to this value.

Water repellency has much to do with minute surface structure and chemical factors. The contact angle between a liquid and a solid is related with the surface tension of the two.

Water repellency is exhibited when a liquid with a high surface energy is combined with a solid having a low surface energy. Again, it has been clarified that water repellency is enhanced when the minute structure on the surface of a solid or an air layer is formed.

The effect of viscosity on macro mechanism components can be measured by the law of similarity if it is within the range where Newton's viscosity law holds good. From the Reynolds numbers of microorganisms, the Reynolds numbers of the micromachine mechanism parts are assumed to be below 1.

Many thin-film parts are used for micromachines. To measure their mechanical properties, it is necessary to make a model in which the effect of the surface layer is considered. At present, however, methods for measuring various mechanical properties are still in the proposal stage.

3. Application map and the status of research and development

There are physical phenomena that stand out in the mesoscopic region work as a positive factor in some cases, and as a negative factor in other cases. Those phenomena were itemized into interfacial force, surface tension, viscous force, adsorption layer, and mechanical strength, and their relationship to the basic technology and manufacturing technology of micromachines and device system technology was arranged in order as their application map.

Various surface forces lead to an increase in friction force in tribology. It is reported that minute unevenness formed on the sliding surface reduces friction. On the other hand, an attempt is being made to handle micro parts by taking advantage of the surface force. A traction drive is also considered by utilizing high friction force.

An example is reported in which the minutely uneven functional surface having super water repellency was used for sealing an axis. Viscous force can be considered applicable to simple-structure devices, including torque converters, brakes, and vibration dampers.

Various methods of joining are used for micro application. Adhesives can be used as a substitute method for separable thread fastening. An adhesion and tensile strength tester was manufactured on a trial basis for butt adhesive joint of slender axes with a diameter of less than 2 mm. A strength of 18 MPs was attained with an epoxy adhesive. This enabled confirmation of the possibility of adhering micro parts.

Many prototypes of micro fluid devices were manufactured by taking advantage of the laminar flow, high heat transfer, and other characteristics of a micro fluid. In the μ-TAS, now attracting our attention, the above characteristics are integrated.

4. Conclusion

In upgrading micromachine technology to a higher degree, it is important to utilize and overcome physical phenomena in the mesoscopic region. There are many cases in which useful functions are exhibited, accompanied by multiple phenomena. It will be necessary to grasp quantitatively their synergistic and counterbalancing effects in the future.

Table 1 Main physical phenomena that stand out when micronizing

Items	Related matter
Interfacial force	Van der Waals forces Electrostatic force
Surface tension	Capillary phenomenon
Adsorption (layer)	LB film, surfactants, Stiction
Viscous force	Electric viscosity effect, Magnetic fluid, Low Reynolds number
Super water repellency	Surface tension, minute form on solid surface
Mechanical strength	Crystal size, crystal anisotropy

Summary of Investigative Study of the Possibility of Innovative Gene Therapy by the Use of Micromachine Technology

Kazunori Kataoka
Professor, Graduate School of Engineering,
The University of Tokyo

Interest is growing rapidly in gene targeting to deliver genes into the living body for the purpose of cancer therapy, and the study of the delivery system is being actively pursued utilizing liposomes, viruses, and cationic polymers as the carriers of genes. Those carriers are required to have various functions, such as stability in blood flow, accumulation inside the targeted cells, transfer to cellular nuclei, and release of effective genes inside the nuclei. An additional important point is the need for those functions to be realized on the micro scale, say, in order of micrometers or nanometers so that they can be used for a living body. In this sense, the carriers (gene vectors) for gene targeting, applicable to clinical uses, that surpass the properties of viruses would be worthy of the term “biomicromachines”. Recently, an accidental death was reported in gene therapy using adenoviruses in the U.S. This poses a serious problem for spreading gene therapy in the future. It is urgently required to develop non-viral vectors with excellent safety and transfer characteristics without relying on conventional virus vectors if gene therapy is to break the category of a hitherto-used special method of medical treatment and grow into a universal method of medical treatment, applicable to a wide range of diseases.

In this case, an active approach is increasingly desired from the fields of medicine and biology as well as from the field of engineering. This approach includes the establishment of a chemical engineering methodology to grasp the trends in the bio-environment beginning with a vector design based on molecular assembly engineering (artificial viruses), and the development of new analytical techniques to measure quantitatively and over time the behavior inside the cells.

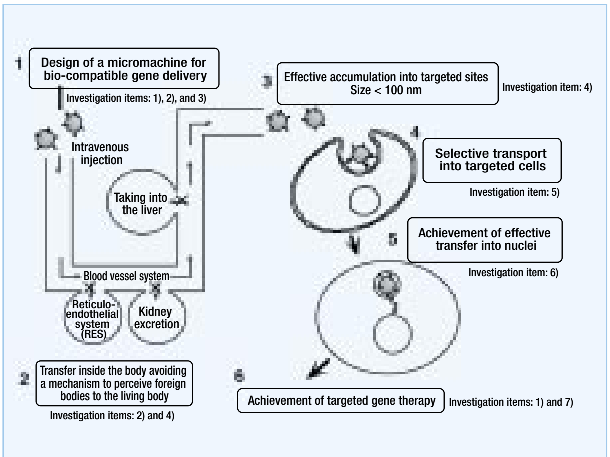

Figure Image of a micromachine used for intravenous in-vivo gene therapy and study items

In this investigative study, therefore, specialists in polymer synthesis and researchers from the companies that have succeeded in developing the materials for targeting carcinostatic agents. In addition, researchers who have been carrying out the study of gene targeting carriers also individually participated in systematic investigation of the merits and demerits of the many trials carried out thus far with the intention of establishing a guideline for the design of micromachines for gene targeting.

The major study items are summarized below together with a diagram of the positioning of each item in intravenous in-vivo gene therapy:

① method for introducing various genes and its commercialization
② A technique for device surface treatment using biocompatible elements
③ A gene including association based on molecular assembly
④ Polymeric nanocapsules oriented toward gene vectors
⑤ Structuring of an environment-responsive material system
⑥ Clarification of a DNA delivery system in the cell
⑦ Various technical problems and their solutions in in-vivo gene therapy

The author believes that a series of important points as described below can be clarified thus to contribute to the development of next-generation micromachines for gene delivery by carrying out the investigative study of the above items.

A series of important points are: 1) structuring of micromachines for gene delivery, 2) mounting of genes onto micromachines, 3) grasping of movements inside the body and accumulation in targeted sites, 4) establishing of routes into targeted genes, 5) clarification of traffic inside the cells and the routes for transferring to nuclei, and 6) release of mounted genes and gene expression.

Seiko Instruments Inc.

Toshihiko Sakuhara
General Manager,
Corporate R&D Department

1. The Challenge of Micromachine Technology

With the rapid advance of information technology, the network society has been growing as never before in history, and nanotechnology has attracted worldwide attention. Seiko Instruments Inc.developed their original watch manufacturing plant and the company's precision machining technology has served as the company's basic technological power. In other words, Seiko Instruments has had a close association with micromachine technology from the beginning. In the new century, we consider micro nanotechnology to be one of our most important technological assets, and will continue our R&D efforts along with ISTF project.

2. Development of Micromachine Technology

Seiko Instruments Inc. is now doing its best to act as the organizer of prototype system development and also to promote its own machining technology based on the utilization of probe microscopes as manager for the development of micro-factory technology under the ISTF project "Micromachine Technology."

"Micro-factory" is a new production system with the catch phrase "Small products by small machines." Conventional production systems have been developed to satisfy high-volume and high-speed production, with the result that they have become larger in size. Micro-factory technology proposes to meet the social demand of the next generation which advocates production systems be changed to low-volume and wide-variety production. At the same time, production systems should be in conformance with such environment-friendly requirements as energy saving, space saving, and resource conservation. At present we are working on the second-phase prototype system (see Fig. 1) which suggests to us the high feasibility of micro-factory systems in the near future.

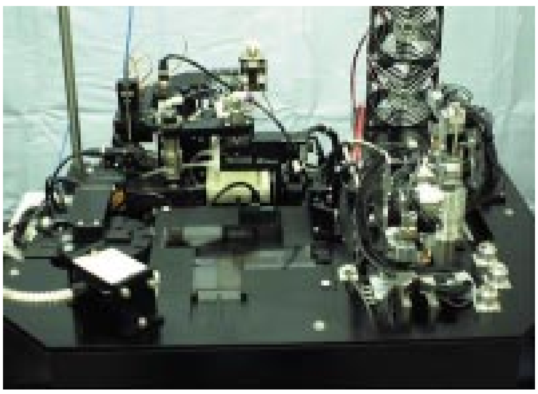

Fig. 1 Second-phase micro-factory prototype system

We have directed our R&D efforts related to machining technology as a part of micro-factory technology toward developing new machining methods instead of merely targeting downsizing conventional machining methods. For example, micro electrolytic machining and micro optical machining, making use of Scanning probe microscope (SPM) technology are being developed. SPM technology is focused on as providing the means to examine objects at the atomic or molecular levels and also as a type of nanotechnology tool. We are conducting R&D activities involving this SPM technology as micro-factory machining technology. Fig. 2 shows an example of micro electrolytic machining, which has sub-micron resolution performance and allows both electroplating and electrolytic etching (attaching and detaching) in a 1-mm^2 area.

The other machining method, micro optical machining, uses near visual field light to prove its performance beyond light diffraction limits. The micro piezoelectric motor developed in the first phase of the project is under further study for expected commercialization.

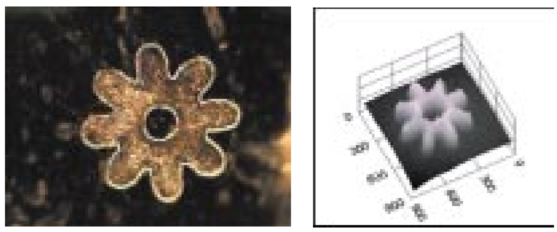

Fig. 2 A gear manufactured by micro electrolytic machining technology (Diameter: 600μm)

3. Future Stances

While working for on ISTF project, we have established our micromachine technology as the fundamental technology. From now on we will continue our efforts for commercialization of the developed devices, utilization of the technology in other applications, and application of the technology for the creation of new production systems.

TERUMO CORPORATION

Akira Takahashi, Ph. D.
Senior Managing Director,
R&D Center

1. The Challenge of Micromachine Technology

Medical care in the future will have to meet such patients' needs as alleviation of physical burdens, support of human dignity, and reduction of medical expenses. Medical issues will have to be solved with the highest priority given to patients. In this sense, minimally invasive treatment methods are highly required. Micromachine technology is indispensable for realizing minimally invasive treatment methods. We have conducted our R & D activities based on our belief that micromachine technology will be the basic technology for medical care in the 21 century.

2. Development of Micromachine Technology

TERMO has participated in the ISTF project "Micromachine Technology" and developed "Optically driven free joint devices" and "Micro laser catheters," along with which Terumo has advanced its own micro catheter technology and micro laser technology. A single micro laser catheter, which is used in a narrow lumen such as a brain blood vessel or the like, can serve both diagnosis and treatment purposes.

In the first phase of the project, we examined techniques for laying electric wires over the external surface of a catheter tube for the purpose of mounting multiple sensors while securing the lumen for inserting a treatment device inside. As a result, we have successfully mounted a thermistor or ultrasonic vibrator in the form of a chip on the outer surface of a catheter tip. We also conducted a basic study for the utilization of a 2.8-µm laser, which allows excellent absorption in human tissues so that safe treatment would be available in blood vessels.

In the second phase of the project, we further developed the basic achievements attained in the first term. We optimized the micro catheter by making it flexible for higher operability. As for the micro laser, we implemented a micro laser head by integrating it onto the end tip of an optical fiber with the capacity of solid laser vibration having a wavelength of 2.8-µm developed in the first phase. Furthermore, we examined measures against the heat generated on the laser head and reduced the diameter of the laser head so that it can be used in combination with the micro catheter.

As for the final structure of the optically driven free joint device, we integrated a photoelectric converter and SMA actuator into a single body.

Photo 1 Prototype of optically driven free joint device

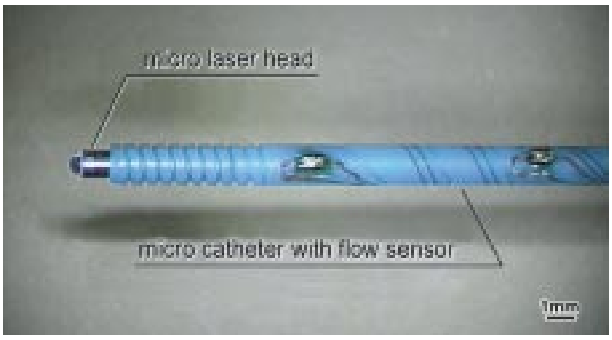

Photo 2 Prototype of micro laser catheter

3. Future Stances

In order to realize minimally invasive surgery treatment devices, micromachine technology plays an important role in downsizing those devices. We will do our best to realize such medical treatment through developing micromachine technology-based devices on the basis of our achievements accomplished in the past.

IWMF 2000 Held in Switzerland

The second meeting of IWMF was held at the Golden Tulip Hotel in Fribourg, Switzerland under the initiative of FSRM for three days, October 9 through 11, 2000 (see Photo 1).

IWMF : International Workshop on Microfactories, which had started on the initiative of the Mechanical Engineering Laboratory of the Agency of Industrial Science and Technology in December 1998
FSRM : Swiss Foundation for Research in Microtechnology

In the IWMF, two days were assigned to convention and a total of 49 presentations were made during this period, including 11 invited lectures, 17 oral presentations, and 21 poster presentations.

The number of presentations by country, excluding the 11 invited lectures, were :10 from Japan, 10 from Switzerland, 7 from Germany, 3 from U.K., 2 from the U.S.A., 2 from Finland, 2 from France, 1 from China, and 1 from The Netherlands. The member companies of the ISTF project "Micromachine Technology" also participated in the presentations on seven topics as listed in Table 1 below (including invited lectures).

The list of workshop participants counted 75 names, and the number of participants by country were : 26 from Japan, 23 from Switzerland, 10 from Germany, 4 from the U.S.A., 4 from U.K., 3 from Finland, 2 from France, 2 from The Netherlands, and 1 from Russia. The attendance from Japan and Switzerland was noticeably high.

The oral presentation consisted of five sessions and the number of presentations in each session shown below (including invited lectures).

(1) System Aspects of Microfactories: 5 presentations
(2) Microassembly and Handling: 10 presentations
(3) Micromachining and 3-D Microstructuring: 5 presentations
(4) Links to Nanotechnologies, Innovation, Visions for the Future: 2 presentations
(5) Microfactories for Medical, Pharmaceutical and Biotechnological Applications: 6 presentations

In session (1) above, presentations focused on practical systems impressed the progress made in current R&D activities.

On the third day of the workshop, a technical tour to EPFL in Lousanne was held and following four laboratories were visited. (see Photo 2).

- Robotics and Parallel Kinematics
- Micro-actuators Stick and Slip
- Micro-ECDM
- AFM and STM Applications

The next IWMF will be held in Minneapolis, Minnesota, U.S.A. in 2002.

Table 1 Results of studies on the ISTF project "Micromachine Technology" presented at IWMF 2000

[Oral presentations]
(1) "Visual Inspection Mechanism for Microfactory" by O. Tohyama, Mitsubishi Cable Industries, Ltd.
(2) "Industrial Impact of Microfactory" by T Hirano, MMC (invited lecture)
(3) "Development of Micro Stages for Microfactories" by T. Matsuo, Yaskawa Electric Corporation
(4) "The Microfactory for Processing and Assembly" by T. Ataka, Seiko Instruments Inc. (invited lecture)

[Poster presentations]
- "Wafer Level Three-dimensional Integration Technology" by A. Satoh, Fujikura Ltd.
- "Development of Micro Servo Actuators" by H. Nakamura, Yaskawa Electric Corporation
- "Micro Fabrication Using Electrochemical Machining" by M. Suda, Seiko Instruments Inc.

Photo 1 View of workshop meeting

Photo 2 Technical tour to EPFL

Micromachine Asia Seminar

Micromachine seminars were held in Malaysia, Singapore, and Thailand November 19 (Sun) through 28 (Tue), 2000. Micromachine Center hold overseas seminars twice a year for the purpose of circulating information originating in Japan, collecting information abroad, and promoting interaction between countries. It was the second occasion for the Micromachine Center to hold the seminars in Asia; the first one was conducted in 1997.

The list below shows the Japanese lecturers and titles of the seminars.

"MMC Activities and Prospect of Micromachine"
by Takayuki Hirano, Micromachine Center
"Multiple Distributed Micromachine Systems"
by Munehisa Takeda, Mitsubishi Electric
"In-pipe Wireless Inspection Micromachine"
by Hideaki Nishikawa, Denso
"The Experimental Microfactory System in Japanese National R&D Project"
by Kazuyoshi Furuta, Seiko Instruments
"Medical Application of Micromachine"
by Takashi Mihara, Olympus Optical
"Novel Actuators for Microrobots"
by Koichi Suzumori, Micromachine Center

The following reports were on the respective seminar events.

(1) Seminar on Micromachine Technology

The seminar was held in cooperation with SIRIM Berhad in Kuala Lumpur, Malaysia on November 21 (Tue), 2000. SIRIM is an organization owned by the Malaysian government and responsible for the standardization of industrial technologies and R&D activities. A total of 47 participants from organizations related to SIRIM and Malaysian universities joined the seminar. After the keynote speech by Dr. Othman, vice-president of SIRIM, 6 lectures were made by Japanese, who received a lot of technology related questions.

(2) Singapore-Japan Forum on MEMS

The forum was held in Singapore on November 23 (Thu), 2000. "Gintic" which cooperated with MMC for the forum is a national research institute established as an independent institute out of Nanyang Technological University. Gintic conducts research activities for production technologies in various industrial fields. The seminar was held at the Grand Hyatt Hotel located at the center of Singapore. It was a success with about 90 participants from institutes, universities, private companies, and government organizations throughout Singapore. In addition to the 6 Japanese lectures, presentations by Singapore University and Nanyang Technological University were given. Those included " MEMS Tunneling & its applications," "Microgyroscopes and packaging process," "MEMS simulation technology," and "Optical MEMS."

(3) Micromachine Technology Seminar

The seminar was held in Bangkok, Thailand, on November 27 (Mon), 2000, as part of an education program hosted by Technology Promotion Association (TPA). TPA was established for the promotion of technological exchange programs between Thailand and Japan by Thai engineers and business men/women who had once studied or worked in Japan. The seminar was attended by 28 enthusiastic participants from Thai companies and universities etc.

The atmosphere and manner mentioned above differ from one country to another. However, these countries without exception seemed to be actively promoting the new technologies and their industrial application.

Seminar in Malaysia

Seminar in Thailand

2000 Micromachine Asia Mission

During the Micromachine Asia Seminar, we visited related institutes in each country and exchanged views with the respective representatives as reported below.

SIRIM Berhad

Location: Kuala Lumpur, Malaysia
Date: November 20 (Mon)
Attended by: Dr. Mohd Shazali Hj Othman, Mr. Yahaya bin Ahmad, et al.

SIRIM Berhad is a Malaysian government institute founded in 1975, and has been responsible for the standardization of industrial technologies and R&D activities. In 1996 it was incorporated though owned by the Malaysian government. The institute also offers assistance for technical transfer to small and medium sized companies. The institute also takes great interest in providing technological assistance to small and medium sized companies.

We visited a computer training room, machine shop, and show room, where prototypes of automobile battery chargers, welding robot jigs, and draft machines for batik (cloth) were exhibited. The representatives told us that the institute was willing to include micromachine technology and other state-of-the-art technologies in their activities on the condition that such technologies would support businesses.

Gintic Institute of Manufacturing Technology

Location: Singapore
Date: November 24 (Fri), 2000
Attended by: Dr. Wang, et al.

Gintic is an institute on the premise of Nanyong Technological University in the outskirts of Jurong City which is about 20 km west from Singapore City. The research division consists of three sections, Automation Technology, Manufacturing Technology, and Process Technology sections. The institute currently has 375 staff members (70% of them are researchers) and is operated with a 60 million dollar annual budget for research projects.

Nanyong Technological University

Location: Singapore
Date: November 24 (Fri), 2000
Attended by: Dr. Miao Jianmin, et al.

The Micro Machine Laboratory of Nanyong Technological University was established as an attached laboratory to the Mechanical Engineering Department of Nanyong Technological University three years ago. The laboratory has 12 researchers, 5 research fellows, and about 20 students. Their 200-m^2 clean room is equipped with the complete set of equipment necessary for MEMS. Researches related with acceleration sensors, fluid devices, optical devices, TiNi micro grippers, etc. are being conducted. The achievements of this laboratory will serve the country greatly from now on.

The National University of Singapore

Date: November 24 (Fri), 2000
Attended by: Prof. Francis E. H. Tay

We visited Dr. Francis E. H. Tay's MEMS Laboratory in the Mechanical Engineering Department of the National University of Singapore. At the MEMS Lab we were briefed on their researches on the microgyro using tunnel phenomena, micropositioner, micropump with a bimorph actuator (targeted at insulin medication application), and oscillatory pressure sensor. The laboratory has obtained a lot of patents for oscillatory microsensors. For manufacturing sensors, the laboratory uses Cronos' foundry service.

Economic Development Board

Date: November 24 (Fri), 2000
Attended by: Mr. Wong Peng Wai, et al.

We visited the Economic Development Board (EDB) and exchanged views and related information with the representatives on micromachines and MEMS. EDB is an organization under the Singaporean Ministry of Trade and Industry.

The meeting session was not only participated in by EDB staff but also a lot of people from universities, research institutes, and companies related with this technology. They explained the state-of-the-art technology development in Singapore and the commercialization plans of new technologies including micromachines/MEMS were discussed.

Tour to SIRIM

Tour to GINTIC

Latest Micromachining Technology — Part 4

Reproduction of Small Shapes — Molding Technologies

Professor Kazuo Sato
Department of Micro System Engineering, Nagoya University

In this last part of this series of lectures, I would like to deal with technologies to transfer microscopic shapes, which are fabricated by the methods discussed previously, in other materials. These technologies feature two outstanding effects as follows: (1) The mass production of microscopic parts is possible. (2) Micromachining using various types of materials including silicon becomes possible. These technologies will be the basis for a number of applied micromachine technologies to be introduced into industries of different genres.

1. Transcription of etched shapes

By etching a pattern on a silicon single crystal substrate and molding the shape on the surface, a 3-D structure of a different material from the substrate can be formed. For example, nonplanner structures can be created with films such as silicon dioxide or silicon nitride. Fig. 1 shows an AFM-probe chip made of a silicon dioxide film with a thickness of 1.2 µm.

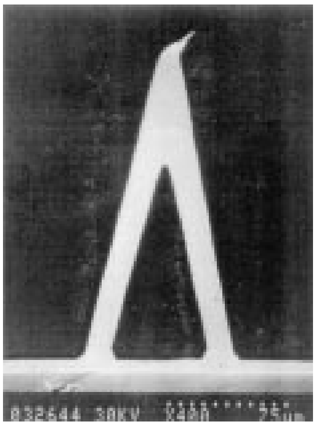

Fig. 1 AFM-probe chip made of silicon dioxide film 1.2 micron thick having a bend tip.

To produce a structure with a bend tip, steps equivalent to bend cross-sections are formed on the surface of the silicon substrate. Next, the entire surface is oxidized. Then the surrounding oxide film and silicon substrate are selectively etched away leaving the profile of the probe.

It is also possible to transcribe the shape on a silicon single crystal substrate, where deep recesses are machined by an etching method, in polycrystalline silicon film. In the second part of this lecture series, an example of a film structure with a T-shaped cross-section in connection with the technology to produce a high-rigidity structure with a film was introduced. In addition to these, a honeycomb type film structure is also available. Fig. 2 shows the cross-sectional view of the fabrication process of a honeycomb type film structure. A film structure is separated after processing a silicon single crystal substrate with a large depth-to-aperture ratio (aspect ratio) by reactive ion etching (RIE: Refer to the first part of this lecture series), laminating a sacrificial layer such as a silicon dioxide film and structure material such as polycrystalline silicon film in order over the substrate surface entirely, including inner surfaces of recesses, and finally etching away the sacrificial layer selectively. Through this procedure, a honeycomb structure with a thickness of 100 µm is produced with a film with a thickness of 1 to 2 µm.

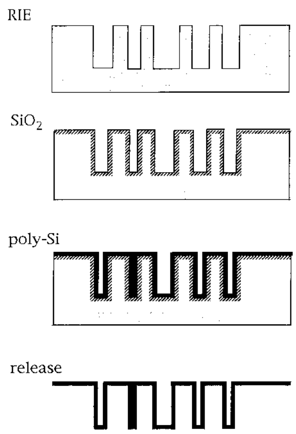

Fig. 2 Cross-sectional view of a fabrication process of a honeycomb structure made of polycrystalline silicon film.

In the field of biochemical technology that is expected to be one of the micromachine applications, disposable micro fluid devices are currently in demand. To meet such application purposes, the shape of a micro fluid channel created on a silicon substrate by an etching method is transcribed in styrol resin etc. for mass-replication. The technology to transcribe microscopic shapes, or replication technology, itself is not new. For example, in the field of spectroscopic devices, the technology of transcribing a surface profile of diffraction grating which is mechanically engraved on an aluminum film with a pitch of 0.1 µm in resin material has already been established.

2. Reproduction of shapes developed in photoresist

Fine patterns are developed in a thick photoresist layer by exposure to light to create micro cavities. Metal is deposited inside the cavities by electroplating method to produce micro metal parts.

2.1 LIGA process

The LIGA process was developed by Karlsruhe Research Center, Germany, in 1986. LIGA stands for the three processes mentioned below, using initials of German words.

(1) Cavity formation by lithography (Lithografie in German)

(2) Molding of cavity by metal electroplating (Galvanoformung in German)

(3) Reproduction of metal mold shape in resin by injection molding (Abformung in German)

Fig. 3 illustrates the cross-sectional view of steps (1) and (2) in the LIGA process above. This process features the use of synchrotron radiation (SOR) in place of ordinary UV light. With SOR used, exposure of the 2-D mask pattern is deeply and accurately made in PMMA-system photoresist with a thickness of several millimeters. By developing this pattern, a cavity with an aspect ratio in excess of 100 is formed. A metal structure as shown in Fig. 4 can be processed by electroplating the inside of the cavity and reproducing the shape. The structure in this phase can be directly put into practical use. However, by performing injection molding of plastics (Fig. 5) with the structure of a die, and reproducing the shape with electroplating further applied, or using the structure for ceramic molding (sol-gel method), the structure can be applied to various types of materials.

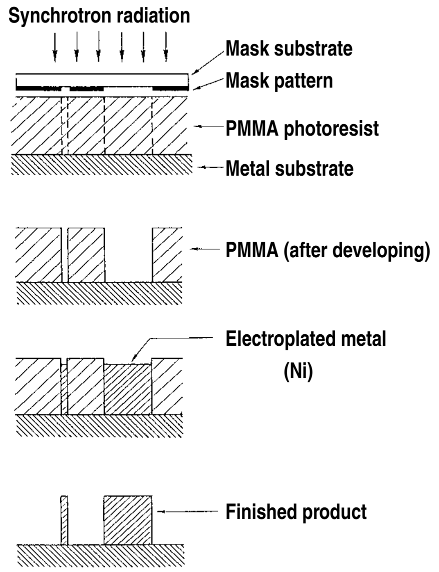

Fig. 3 Cross-sectional view of the LIGA process.

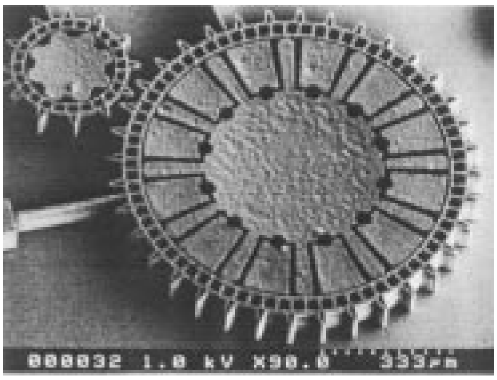

Fig. 4 Micromotor structure made of Ni by the LIGA process (Courtesy of Prof. S. Sugiyama of Ritsumeikan Univ.).

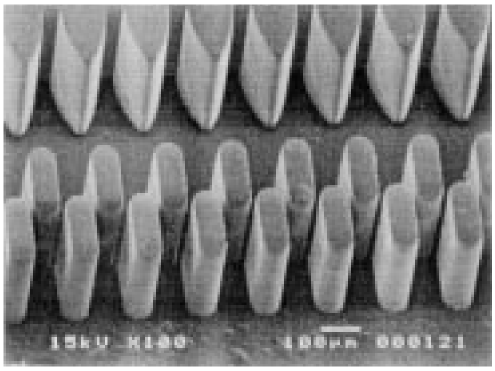

Fig. 5 Example of a molded plastic part made by using the LIGA process (Courtesy of Brother Industries, Ltd.).

The high-precision processing accuracy of the transcription technology as represented by the aspect ratio is used in such applications as optical communication devices, for example 3-D grating (diffraction grating) or optical waveguide, and chemical analysis devices with fine fluid channels.

The challenge in using the LIGA process is the limitation that it cannot produce anything without SOR equipment. It is true that the original die must be prepared by the use of SOR equipment. However, once the master mold is prepared, the following processes can be set for mass production. In Japan, a research team at Himeji Institute of Technology following the team at Ritsumeikan University has successfully started the LIGA process using radiation equipment.

2.2 High aspect ratio UV photoresist

Now available is a new type of photoresist that allows for high aspect ratio exposure and development by ordinary UV exposure techniques, though the processing accuracy is lower than that of the LIGA process. For example, SU-8 photoresist developed by IBM can be exposed to a layer depth of several hundred microns by the UV light method. The transcription process using plating technique of the shape of the cavity after exposure and development process is identical to that used in the LIGA process.

Though even oxygen plasma cannot easily decompose the photoresist resin for removal, the fact that UV exposure can be used is an advantage. Besides, the transparency of the resin is very high allowing the product to be used directly as an optical component material regardless of the transcription technique.

Summary

With transcription technologies of microscopic shapes, 3-D structures can be made of films. In addition, microscopic shapes can now be created from such materials as metal, resin, and ceramic. Increased material diversity is expected to expand the application range of micromachine technology.

Preliminary Announcement

The 7th International Micromachine Symposium

October 31 and Novemver 1, 2001
at Science Hall, Science Museum, Tokyo, JAPAN

Exhibition
MICROMACHINE2001

October 31 -November 1, 2001
at Science Museum, Tokyo, JAPAN

The Detail will be announced later.

Pictures on the cover: Winning artworks in the Micromachine Drawing Contests
Any language is OK, Mini Japanese translator, Threader, Communication Machine, Mini-mini barber (from top to bottom)

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