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Jsme News

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New Trend in Micro Nano Mechanical Engineering

The Japan Society of Mechanical Engineers (JSME) as a public organization

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Introduction

The environment surrounding our society is changing rapidly as we enter into the 21st century (the second century for JSME). We have seen the end of the cold war and the start of global competition. The main economic value of society is shifting from manufacturing to intellectual property. Furthermore, leading-edge disciplines, such as biotechnology, nanotechnology, and IT, are overshadowing the existing disciplines and are receiving a large amount of investment for research and development. There is keen global competition based on the idea that the country that gains important intellectual property in such leading-edge disciplines will lead the business in the coming era. On the other hand, the progress of IT has changed the communication environment of domestic and global societies, and has even changed the business environment. Continued on page 2

Nanolaboratory through Nanorobotic Manipulations

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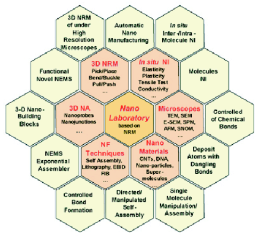
Introduction

Nanoelectromechanical systems (NEMS) have attracted much attention to realize high integrated, miniaturized, and multi-functional devices for various applications. It is expected that the combinations of the top-down and bottom up approaches to fabricate nanostructures effectively.



The nanodevices controlled from atomic scale to meter scale are expected to realize in the near future on "Nanotechnology" "Nanomanipulations", which realize controlling the position at the nanometer scale, are considered to be one Continued on page 3

Engineering Biological Cell Fusion with Field Analysis and its Realization through Microfabrication

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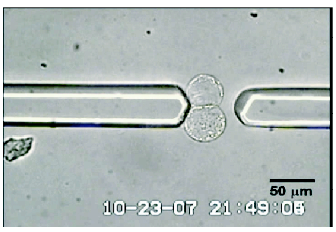
Introduction

High-yield on-chip cell fusion method based on mi-crofabrication techniques is being developed in our lab in collaboration with Prof. Kotera's group of Kyoto University under JST CREST and Kakenhi Bio-manipulation project.



Cell-fusion is a method to create a hybrid among two types of cells, which cannot be crossbred naturally, to obtain a new cell line that has the combined character of the parent cells. For example, by fusing anti-body-secreting B cells with intensely-proliferating cancerous cells, Continued on page 6

Power MEMS for new services and environment

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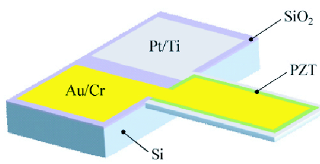
Introduction

Power MEMS (Micro Electro-Mechanical Systems) are defined as micro distributed power generators. The recent development of mobile phones, personal computers, robots and artificial organs need highly efficient distributed micro power generators. Moreover, a micro generator for ubiquitous network services such as active RF-ID tags and sensor network systems will be essential to realize many kinds of new businesses and services.



Power MEMS will play an important role for environmental issues in Continued on page 7

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The Japan Society of Mechanical Engineers (JSME) as a public organization

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Continued from page 1 In this era of such rapid change, the industrial sector, government, and universities need to change drastically. Each is struggling hard with reforms now in order to respond to the requirements of the new era. Societies that consist of members from industry, government, and academia are of no exception. They must also initiate drastic reform to respond to this era of rapid change.

Succession of reforms

To accommodate to the environment of rapid change, JSME has carried out a series of annual reforms under a grand design for its second century. Let me look back on the last two years since I joined in the implementation of reforms as a member of the executive board.

In the 84th term, under the leadership of President Kasagi, various reforms as well as analyses of current issues have been carried out, in line with the following three policies: (1) to reinforce the main functions of the JSME, (2) to contribute to human resource development, and (3) to establish a presence as a technostructure. In particular, the creation of organizations and centers that reinforce the main functions of the JSME, the publication of international journals, the filling of the gap between sciences and technologies in Japanese journals, the promotion of programs for developing core human resources started by former President Taguchi, and the establishment of "Machine Day and Machine Week" have been put into practice.

In the 85th term, under the leadership of President Saito, not only continuing the reforms of the 84th term, but also various other projects were carried out, such as (1) the promotion of collaboration with senior members, (2) steps to prevent the gradual reduction of the number of regular members, (3) a review of our activities for the codes and standards project, (4) a revision of ethical codes, (5) the setting up of an emergency task force for the executive board, and (6) the promotion of collaboration between medical and industrial fields. In particular, an in-depth analysis of the age groups of members was carried out. As a result, it was found that the number of members in their early 30s is decreasing remarkably, and it is important to keep hold of the baby-boomer members who will retire in a few years. To solve these problems, various countermeasures were taken.

Policy of the 86th term

In this 86th term, we consider that it is important to faithfully continue the above reforms that were started in the previous two terms, and to direct our efforts towards accomplishing each reform. In concrete terms, the following seven measures must be taken.

1.Problems in main organizations and their activities

In the 84th term, the following four organizations were set up: Organization of the Promotion for Professional Development, Center for Cooperation of Industries, Government and Academia, Center for Codes and Standards, and Center for Publications. We feel that it is necessary to review their activities from the viewpoint of the degree of enlivenment and contribution to the finances of the JSME.

2.Promotion of codes and standards project

The project of codes and standards must be actively promoted on the basis of the report of the 85th term Council of Policy and Finance. At the same time, we should ensure the governance and financial soundness of the society. In particular, under the new framework, it will be necessary to promote the project of codes for power generation facilities, for which discussions with the related industrial sector are smoothly developing, because the project is significant in the sense that it contributes to society in general.

3.Establishment of financial soundness

Increasing the number of members is the first step ensuring financial soundness. We will promote the collaboration with senior members, which was started by former President Saito, and the projects that are attractive to engineers in their early 30s, such as engineer training programs.

Furthermore, sales of our publication, the Mechanical Engineering Handbook, which was initially good, has slowed down, resulting in excess stock. We will do our best to increase sales through cooperation with various divisions and branches.

4.Accommodation to information system

Through the 84th to 85th terms, the IT system of the JSME was fundamentally reconstructed, with attempts being made to unify various systems, such as the member management system, an accounting system, and the home page. To expand our business to cover various member services and publication projects, we are going to reexamine such management systems, including the role of the administrative affairs of the JSME.

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5.Presence of the JSME

The project, "Machine Day and Machine Week," which was established in the 84th term, has spread all over Japan and has evolved into a large project, under the support of divisions and branches of the JSME, in the 85th term. We hope that we can gain support from other societies and associations in the field of mechanical engineering to continue this project and make it a national event.

Meanwhile, "Mechanical Engineering Heritage" and "Technology Roadmaps of Industry," which were inaugurated as 110th anniversary projects in the 85th term, provoked a large reaction when the media introduced this project. We will continue these projects and make them even larger.

6.Accommodation to institutional reform of public corporations

The Non-profit Corporation Law, which fundamentally changes the regulations of public corporations, passed the council in June 2006. This new law will take effect in December 2008 (five years for the transition period), and this society will become a non-profit corporation. To accommodate to this change, we must carefully discuss whether we should become a public association or maintain our status as an ordinary association. We will discuss this subject in the Council of Policy and Finance.

7.Strategy for global expansion

We hope to reinforce the cooperative relationship with other mechanical engineering societies in Asian countries as a first step toward the establishment of JSME international chapter, which has been planned since the 84th term.

Conclusion

As given above, we discussed the policies of the 86th term from the viewpoint of continuing all the projects from the former terms. As a result of the vigorous efforts of the former presidents, executive board, divisions, branches, and the administrative office, the activities of JSME are expanding considerably. In particular, besides the existing activities of the divisions and branches, many projects are progressing: the project of codes and standards, the contract program for developing core human resources, accreditation activities including the Japan Accreditation Board for Engineering Education (JABEE), computational dynamics, and state monitoring, as well as the "Machine Day and Machine Week," "Mechanical Engineering Heritage," and "Technology Roadmaps of Industry" projects. These projects are appreciated not only by academic societies but also by the general public.

The JSME started as a venue for the exchange of information among mechanical engineers. I think that the JSME was a closed community comprising only mechanical engineers and researchers in the past, and this is one of the reasons the dissemination of information to the general public remained relatively limited. We can say that the reforms that have been implemented since the start of our second century are our attempts to send more messages to the general public, under a heightened awareness of the role of the JSME. I consider that it is important to be appreciated by the general public in order to enhance our presence, and satisfy our pride and honor as members of the JSME. I have put forth the ambitious policy, "the Japan Society of Mechanical Engineers (JSME) as a public institution," of the 86th term, with the expectation that we will someday realize such achievements.

Nanolaboratory through Nanorobotic Manipulations

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Continued from page 1 of the promising ways (Fig. 1). The top-down fabrication process, or micro machining, provides numbers of nanometer structures at once. On the other hand, the bottom-up fabrication process, or chemical synthesis such as self-assembly or super-molecule techniques, also provides numerous nanometer structures. In fact, both approaches reach nanometer scale with the limitations of physical/chemical aspects at present. Hence, the technology to fill its gap is considered to be one of the important at this moment.

2.Nanolaboratory through Nanorobotic Manipulations

Nanorobotic manipulation; nanomanipulation, has been received much more attention, because it is an effective strategy for the property characterizations of individual nano-scale materials and the construction of nano-scale devices. It is also readily applied to the scientific exploration of mesoscopic phenomena and the construction of prototype nanodevices. It would be one of the most significant enabling technologies to realize the manipulation and fabrication technology with individual atoms and molecules for the assembly of nanodevices.

We proposed a "Nanolaboratory" based on nanorobotic manipulation system to realize various nanoscale fabrication and assembly to develop novel nanodevices to integrate borderless technologies based on nanorobotic manipulation system (Fig. 2). The Nanolaboratory is a fundamental technology for property characterization of nano materials, structures and mechanisms, for the fabri-

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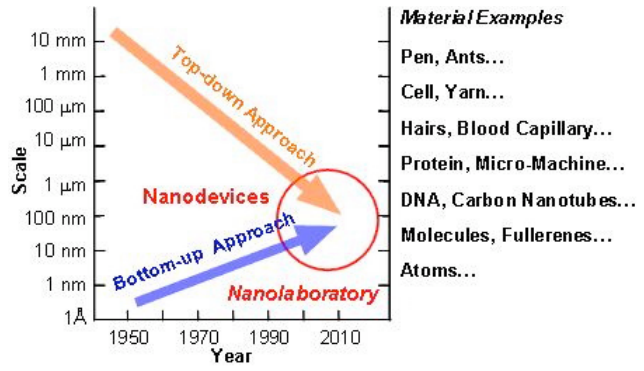

Fig. 1. Schematic diagram of "Nanotechnology" ("Top-Down" and "Bottom-Up")

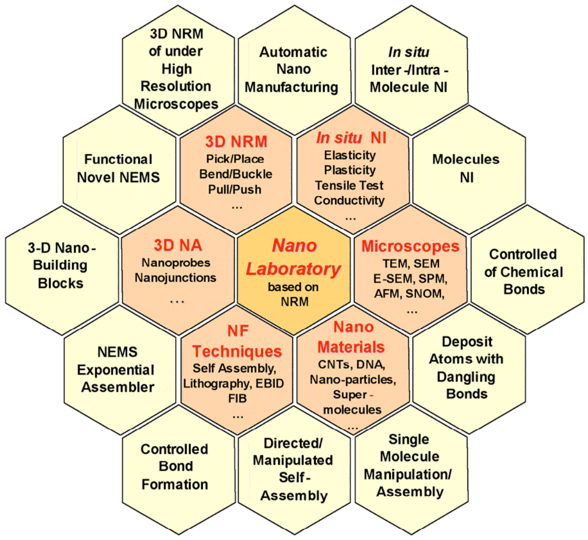

Fig. 2. Various applications of Nanolaboratory based on Nanorobotic Manipulation System. (NI: Nano Instrumentation, NA: Nano Assembly NF: Nano Fabrication, NRM: Nanorobotic Manipulation, NEMS: Nanoelectromechanical System)

cation of nano building blocks, and for the assembly of nano devices. It can be also applied for nanoassembly and nanoinstrumentation, such as the nanohandling, the nanomodification, and the nanowiring using various nanomaterials under microscopes through nanofabrication techniques based on nanorobotic manipulation system.

To manipulate nano-scale objects, it is needed to observe them with a resolution higher than nano-scale. Hence, the manipulators and observation systems, microscopes in general, are necessary for nanomanipulations. Optical microscope is one of the most historical and basic microscope. However, its resolution is limited to ~100 nm because of the diffraction limit of optical wavelength. Hence, the special techniques (using ex. evanescent light or fluorescent light) are required for the nanometer scale observation. Until now, the scanning probe microscopes (SPMs) and electron microscopes (EMs) are readily used for the nanomanipulation techniques. They might finally be the core-most part of nanotechnology.

The nanomanipulations under EMs show their uniqueness on the capability to contain an independent nanomanipuloator with real-time observation capability in 3D space. We constructed the Nanolaboratory under dry or semi wet conditions through transmission/scanning electron microscopes (TEM/SEM) or environmental-SEM (E-SEM) nanorobotic manipulation systems (Fig. 3). The high resolutions of TEMs can be readily used for the precise nanomanipulation and instrumentations. The issue of the TEM nanomanipulator is that its specimen chamber and observation area are too narrow to contain manipulators with complex functions. Hence we proposed an exchangeable robotic manipulator between a SEM and a TEM as hybrid nanorobotic manipulation system. On the other hand, hydroscopic samples can be observed directly under nanometer scale resolution by an E-SEM. Hence E-SEM nanorobotic manipulation system can be readily

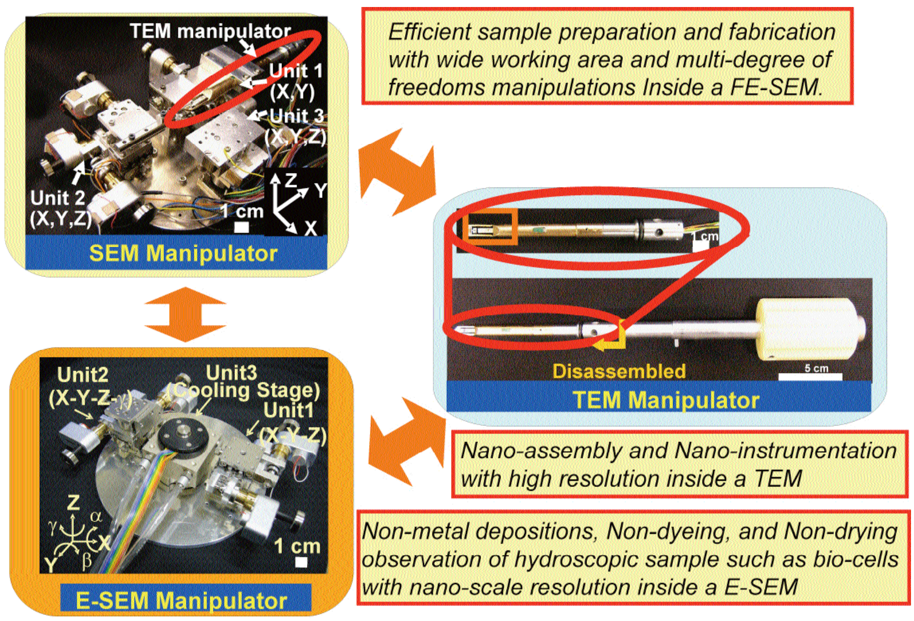

Fig. 3. Nanoraboratory based on nanorobotic manipulation system.

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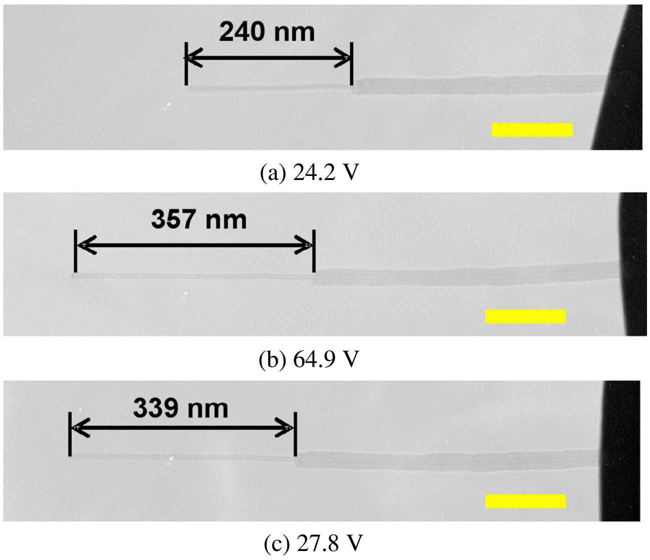

Fig. 4. Actuation of telescoping MWNT at each applied voltage. (Scale bar: 100 nm)

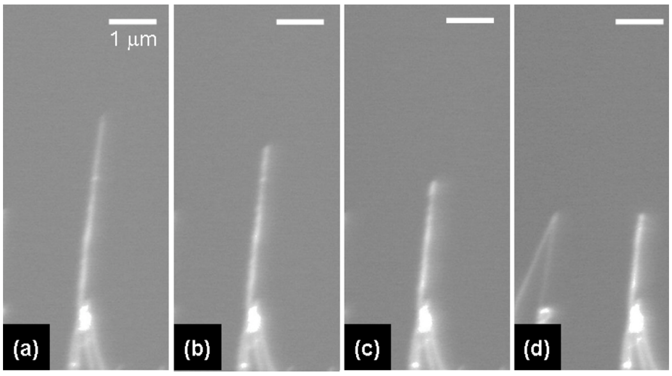

Fig. 5. (a) Before and (b-d) after cutting of a single CNT in less than 1 minute.

used for the single cell manipulation and evaluation.

3.Nanomanipulations, Nanoinstrumentations, and Nanoassemblies by Nanolaboratory

Carbon nanotubes (CNTs) have been regarded as promising nanomaterials for nanostructures and nanodevices since their extraordinary properties. For the high integrated, miniaturized, and functional NEMS, one of the effective ways is to use the bottom-up fabricated nanostructures directly. Basically, the CNTs have single or multi- rolled up cylindrical graphite sheets with the interlayer. Hence, there is possibility to use their fine structures directly. For example, "telescoping carbon nanotube" , which is fabricated by peeling off the outer layers of multi-walled carbon nanotubes (MWNTs), is one of the most interest nanostructures, which is fabricated by peeling off its outer layers, is one of the most interesting nanostructures. We fabricate the telescoping structure by peeling off its outer layers of a MWNT though destructive fabrication process and actuated its inner core by applying the external electric field inside a TEM (Fig. 4).

We also presented a technique for high-speed cutting of CNTs inside a field emission-SEM (FE-SEM) by introducing oxygen gas into the vicinity of the samples (Fig. 5). The acceleration voltages and the beam currents can cut CNTs in less than 1 minute. Cutting is easy and rapid at low-acceleration voltages and high beam currents. The presence of oxygen gas can be readily used for the bending of CNT by controlling the irradiation of electron beam. The 3-D nanostructure is assembled using a CNT with cutting, bending and manipulation techniques (Fig. 6).

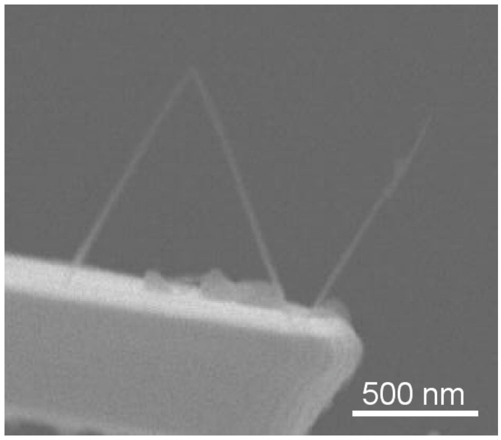

Fig. 6. Assembly of 3-D nanostructure based on a CNT assisted with welding, bending, and cutting techniques. The letter "N" stands on the substrate.

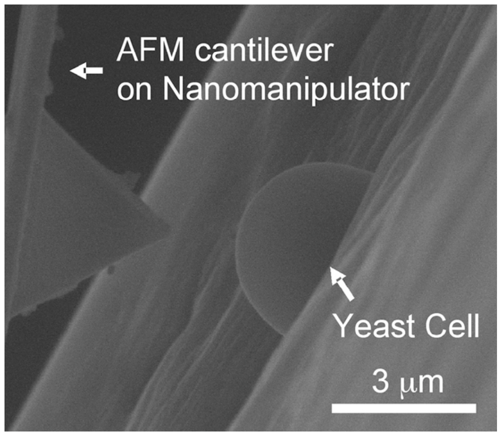

Fig. 7. E-SEM image of stiffness measurement of single yeast cells by an AFM cantilever tip.

Recently single cells analysis has been much more attentions because of the progress of the micro/nano scale techniques on the local environmental measurements and controls. Under conventional SEMs and TEMs, the sample chambers of these electron microscopes are set under the high vacuum to reduce the disturbance of electron beam for observation. On the other hand, the E-SEM can be realized the direct observation of water-containing samples with nanometer high resolution by specially built secondly electron detector. We proposed the nanomanipulation system inside the E-SEM is considered to be an effective tool for water-containing biological samples with nanometer resolution. The stiffness measurements of single Yeast cells were presented based on the E-SEM nanorobotic manipulation system (Fig. 7).

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Engineering Biological Cell Fusion with Field Analysis and its Realization through Microfabrication

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Continued from page 1 a fast-growing antibody-secreting cell line can be obtained. There are several methods for cell fusion including chemical or viral, but among them frequently-used is the electrical fusion.

A biological cell consists of the electrically conducting cytoplasm enclosed by an insulating cell membrane. When an external field is applied, electrical charge accumulates on the insulating membrane, and the voltage across the membrane builds up, just like charging a capacitor. And when this membrane voltage exceeds a certain value, typically 1V regardless of cell type, dielectric breakdown occurs. If a moderate break-down occurs at the contact point of two cells, the two membranes reconnect and the cytoplasm are merged, due to the lateral fluidity of the biological phospholipid membrane. It is just like electrically "spot-welding" the cells.

In order to achieve electrical cell fusion, a) cells must be brought into contact, and b) appropriate magnitude of the membrane voltage, enough to trigger the breakdown yet not too high to rupture the cell, must be induced at the cell contacting point. Conventional electrical cell fusion is done in the following step as shown in fig.1 a). 1) feed the suspension mixture of the two types of cells into a cuvette equipped with a pair of parallel-plate electrode, 2) apply an a.c. voltage to form chains of cells (this occurs spontaneously due to the attraction of induced electrical dipole moments on the cells), 3) apply a pulsed voltage, typically several hundred volts across 1cm electrode spacing, to breakdown the membrane. However, in this method, how many of which type of cells is forming the cell chain is unpredictable. And more importantly, due to the size-dependence of the induced membrane voltage under such a uniform field, large cells receive too much voltage and disrupt, while small cells remain unaffected by the pulse. As a result, the fusion yield is said to be as low as 0.01%.

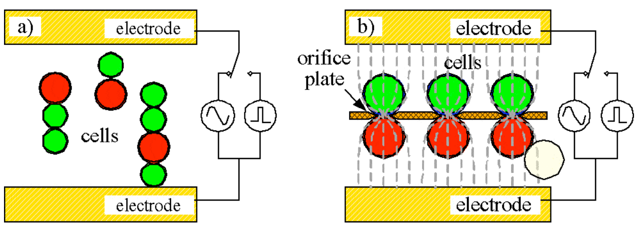

Fig.1 Conventional electrofusion in a uniform field (a) and the electrofusion based on field constriction (b).

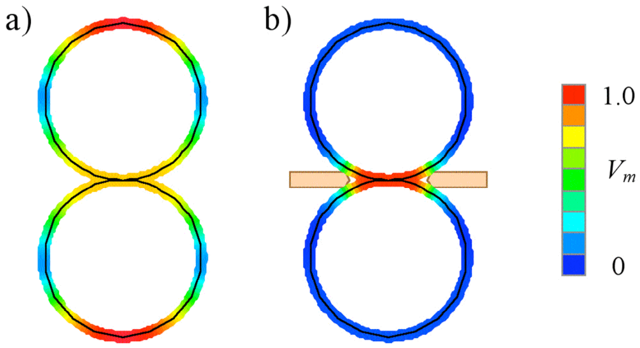

Fig.2 Calculated magnitude of membrane voltage V_m. (a) without an orifice, (b) with an orifice

High yield cell fusion based on field constriction

In order to solve the problem, we made a BEM (Boundary Element Method)-based analysis on the membrane voltage under an influence of an external field, and found that a high fusion yield can be expected by properly designing the field shape. As shown in fig.1 b), the method uses an insulator plate with an array of micro-orifices whose diameter is smaller than that of the cells. The electrodes are placed on both sides, and the suspensions of two types of cells to be fused are fed into each side. The function of the orifice plate is to create a field constriction; the field lines, being unable to penetrate the insulating plate, converges into the orifice, thus creating the area of high field intensity in the vicinity of the orifice, and the field gradient around it. When the electrodes are energized with an appropriate frequency, the cells are attracted towards the higher field area by a phenomenon called dielectrophoresis (DEP), i.e. towards the orifice, and form a cell pair. Then a pulse voltage is applied to trigger the cell fusion. Here again the field constriction plays its role: because the voltage drop occurs dominantly around the orifice which is smaller than the cell itself, the membrane voltage is localized to the membrane within the orifice, and its magnitude is approximately equal to the applied voltage.

Fig.2 shows an example of the field analysis to illustrate this situation. The magnitude of the membrane voltage V_m, normalized by its maximum value, is shown by color. Without an orifice (fig.2 a), V_m is higher at the upper and lower end of the cell pair rather than at the contact point. This implies that the cells are more likely to rupture than to fuse, which may be another reason why conventional electrofusion has low yield. And more importantly, V_m is proportional to the size of the cells. On the other hand, with the orifice, V_m is localized at the orifice where the cells make contact, as shown in fig.2 b), and virtually zero elsewhere. The applied voltage is impressed on the two membranes in contact, and thus V_m on one membrane is half of the applied voltage, regardless of the cell size. The fusion takes place only between the

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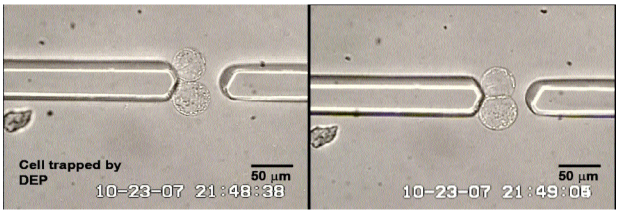
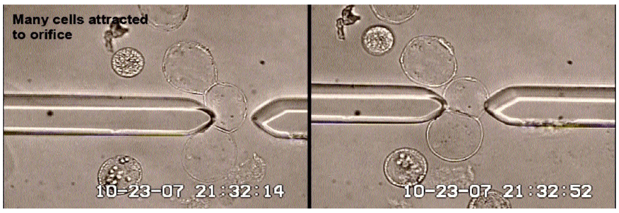


a-1) two cells, before a-2) two cells, after



b-1) multiple cells, before b-2) multiple cells, after

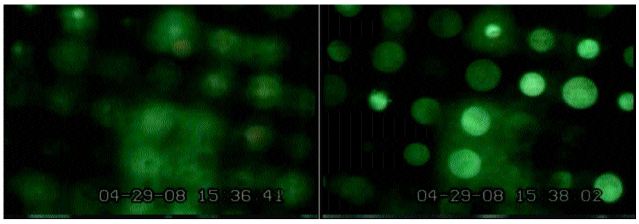
Fig.3 Electrofusion in the constriction field.array.

array.

cells in contact at the orifice, and even when a third cell is in contact with one of the cells as shown at the right bottom of fig. 1 b), this cell will not take part in the fusion, because $V_m \approx 0$ there. Reproducible high-yield 1:1 fusion can be expected through the inherent advantage of the method, the localized and precisely controllable V_m.

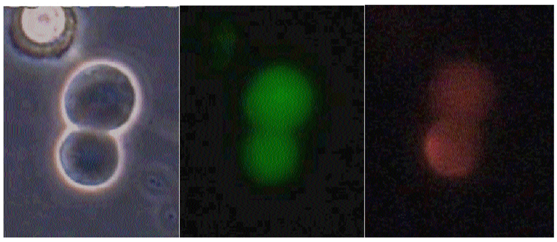
In fig.3 is shown the photographs of the cell fusion of plant protoplasts with the device having a single orifice. In the photo, the orifice is made rather large to facilitate the observation from the side, but the effect of the field constriction is still there. Fig.3 a) is the fusion with a pair of cells. a-1) is after DEP alignment, and before the application of the fusion pulse. a-2) is after the pulse, and two cells are fused to form a snowman-like shape. Fig. 3 b) is with multiple cells. In fig. b-1) several cells are forming a chain by dielectrophoresis. However, fusion takes place only among two cells in the orifice, as seen in fig. b-2). More than 90% yield is observed in such experiments.

Fig.4 shows the fusion with an orifice array. The orifices with 3μm in diameter are arranged in x-y manner with the spacing of 40μm. The cells used are mammalian Jurkat cells, the cytoplasm of the cells in the upper chamber stained with green fluorescence dye, while those in the lower chamber with red, as was depicted in fig.1 b). The observation is made from the bottom with a confocal microscope, with its plane of focus on the lower cells. If



a-1) before fusion a-2) after fusion

contrast fluorescence fluorescence



b-1) phase b-2) green c) red

Fig.4 Electrofusion with an orifice array.

the fusion takes place, the cytoplasm of the pairing cells are mixed, so that green dye will diffuse into the lower cell, which is being observed in the photographs in fig.4 a). a-1) is before the pulse, and off-focus green fluorescence from the upper cells are seen. a-2) is after the pulse, and the majority of the lower cells start emitting fluorescence with clear contours, which is the evidence that the cells fused without rupturing. The observed fusion yield was about 70%, which is primarily because of the difficulty in filling all orifices with a cell pair rather than the fusion itself. Photographs in fig.4 b) are of the fused cells taken out from the orifice and viewed from the side. The merged cell emit both fluorescence, showing that the cytoplasm mixing did take place.

Conclusions

Analysis and design are two major keywords in mechanical engineering. It has been shown that these keywords apply to biological applications, taking the cell fusion as an example. By the numerical analysis and the proper field design based on it, high-yield electrofu-sion device is realized. There are a lot of chances for mechanical engineers to contribute to medicine and biology.

Power MEMS for new services and environment

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Continued from page 1 the field of environmental sensing and the reduction of harmful waste as well as new services in the field of medicine, information and communication technology. Power MEMS devices such as a micro fuel cell is anticipated as a power supply for mobile phones and personal computers. Also micro gas turbine would be utilized as a desktop type generator. On the other hand, other kind of Power MEMS can efficiently harvest energy from the low-density energy resources such as temperature gradient, ambient vibration and nutri-

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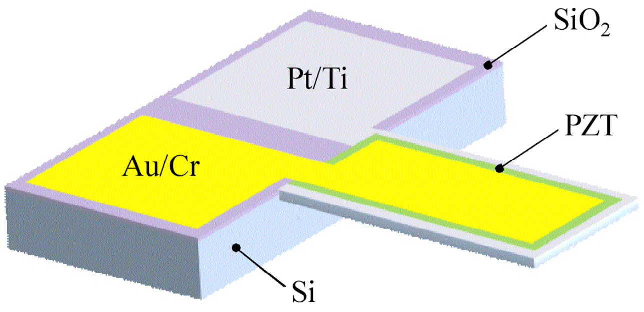


Fig.1: A diagram of energy harvesting using piezoelectric film on micro Si cantilever.

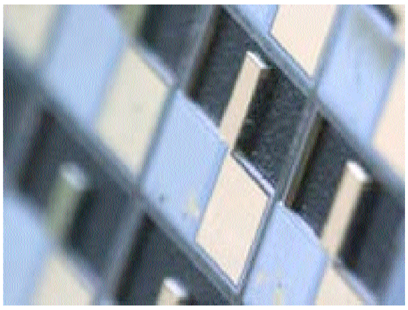


Fig.2: Photograph of piezoelectric micro generator array fabricated by micromachining.

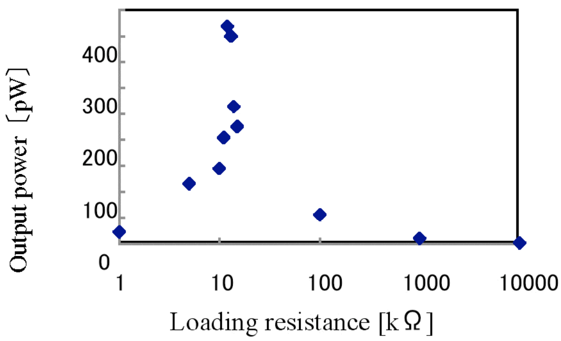


Fig.3: Correlation between loading impedance and output power.

ent in the blood flow, which is then converted into electrical energy.

Power MEMS are intended to power widely deployed, networked sensors for environmental monitoring and/or safety purposes, and also devices that work in a body of a patient for medical diagnostic/treatment purposes. Power MEMS should eventually enable an effective control of energy-related systems, thus resulting in a large energy saving. Furthermore, Power MEMS may largely replace the batteries that currently represent harmful wastes to the environment.

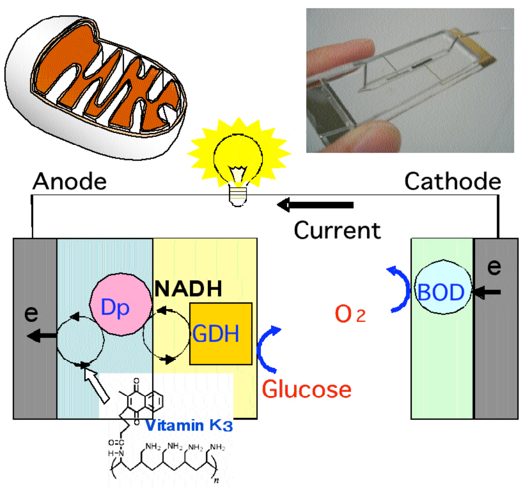
Integration of many research fields are needed to realize this new application of power MEMS: the fields span not only fundamental disciplines such as physics, chemistry, biology but also technological fields such as materials science, microfabrication, ionics, electrical engineering, thermal engineering, fluidics, and control engineering. Some of our Power MEMS studies at Tohoku University are described below.

1) Micro energy harvesting using piezoelectric effect

A diagram of a micro energy harvesting device using piezoelectric effect is shown in Fig. 1. A piezoelectric PZT film with 3 μm in thickness is formed on a bottom Pt/Ti electrode of Si cantilever by RF magnetron sputtering. The upper Au/Cr electrode is deposited on PZT film. A photograph of the micro generator is shown in Fig. 2 [1]. Electric power is generated when the cantilever is bent and stressed by the piezoelectric effect. The device therefore converts mechanical vibration energy into electric energy. Figure 3 shows a result of impedance matching. The micro generator produced the maximum output power of 0.45 nW at the resonant frequency of 8.81 kHz [1].

2) A bio fuel cell

A bio-fuel cell employs enzymes as electrode catalysts. The advantage of such a fuel cell is that it could be made



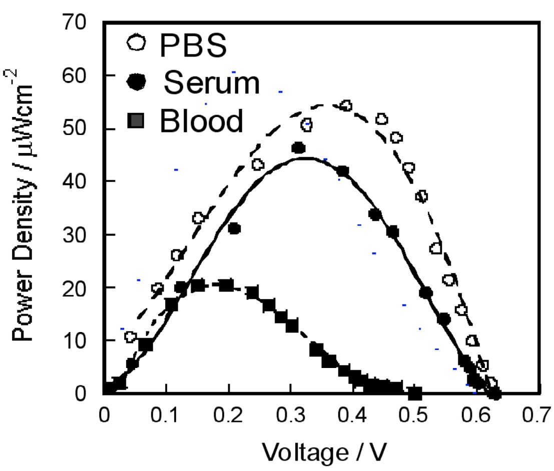


Fig.4: Schematic illustration showing structure of the enzymebased biological fuel Cell. Performance of the cell in PBS, FBS and human venous blood at 37°C. 0.5 mM NADH was added.

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entirely of harmless organic materials; for instance, even soft drinks could be used as a fuel. Therefore, bio-fuel cells can be made truly environmentally- friendly. They could even be eaten. One application area of such a small, safe battery is medicine. In particular, it has been estimated that the output of an implanted bio -fuel cell, which uses glucose in blood stream as a fuel, would be sufficient to power devices such as bio -sensors. While there are still many problems to be solved, such as the problem of durability, once realized they will be extremely safe, compatible with biological matters, and environmentally friendly.

Nishizawa et. al. have studied the glucose anode composed of a bi-layer enzyme membrane, the inner layer containing diaphorase (Dp) and the outer, glucose dehydrogenase (GDH), as illustrated in Figure 1 [2]. The Dp membrane was formed from a newly synthesized Vitamin K3-based mediator polymer. The enzyme cathode for oxygen reduction can be prepared by using bilirubin oxidase (BOD). The performance of the cell was preliminarily evaluated in 37°C biofluids that are bovine serum and human venous blood. It is worthwhile to note that the fuel cell performance in serum is comparable with that in a buffer solution, although serum contains proteins, lipids, redox active vitamin C and so on. The reaction selectivity of enzyme ensures these performances. On the other hand, the performance in blood was significantly unstable. In order to get higher stable power from blood, biological stability, associated with the natural immune response to foreign materials, should be ensured.

3) Micro fuel cell

The largest challenge for the practical applications is about increasing power density. The current level of power density is relatively small, which prevents the total system from being small enough for the practical use, and hence the reduced fuel volume compromises the high energy potential of the fuel cell.

Micro fuel cells are expected as a next-generation power source for portable devices. While conventional rechargeable batteries are facing the theoretical limit in terms of energy density, the micro fuel cell has a potential of achieving a several times higher level of energy density than the current rechargeable battery. The micro fuel cells also have advantages not only in the ability of rapid energy charging with a fuel cartridge, but also in reducing environmentally harmful wastes.

Tanaka et al. have developed a fully-microfabricated wafer-level vacuum package of a micro fuel reformer[3]. For thermal insulation, a high-temperature reactor is suspended by microfabricated tubes, in which fuel and reformed gas flow, and is vacuum-packaged by anodic bonding. Conductive heat loss through air in the package was investigated as a function of the internal pressure as a parameter. The measured heat loss is 1.2 W at a reforming temperature of 240°C, showing a potential to realize a micro fuel reformer with a thermal efficiency of 75 %. Also, the temperature of the package outside is as low as 60°C, which is low enough to install the micro fuel reformer in portable electronics.

4) Detonation for micro turbine.

Detonation is a combustion wave propagating in a combustible medium faster than its sound speed, typically in order of km/s. Deflagration, which is a term representing ordinary combustion, usually propagates in cm/s to m/s range. Difference is how the combustible medium is ignited. In deflagration, heat conduction from flame front heats up unburned medium and then ignites it, so flame propagation speed is governed by heat conduction speed. In detonation, shock compression heats up unburned portion, thus the propagation speed can be as fast as shock propagation speed. Using detonative combustion in a heat engine, such as gas turbine engine, has an advantage in thermal efficiency compared to conventional isobaric combustor, because detonation involves compression process in itself. Recently, extensive research has been done on the Pulse Detonation Engine (PDE), which utilizes detonative combustion and is aimed to replace not only the conventional rocket engine, but also the gas turbine engine. There are some studies on the Micro PDE,

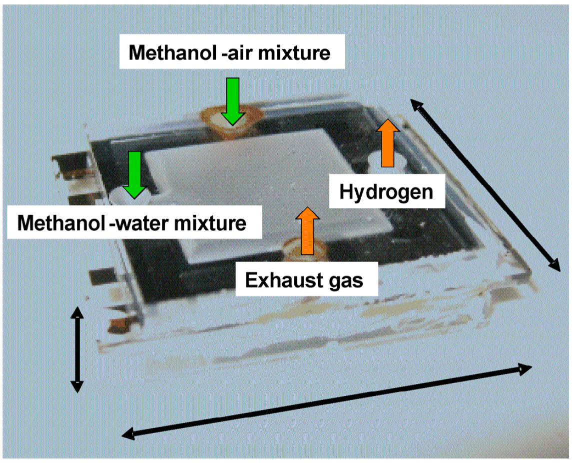

Fig. 5: Integrated micro fuel reformer.

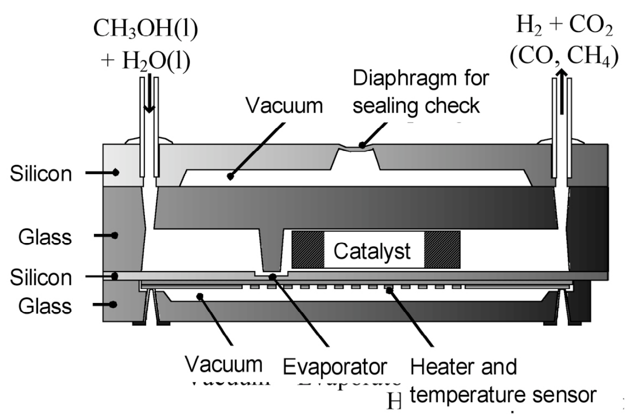

Fig. 6: Structure of a vacuum-packaged micro reactor.

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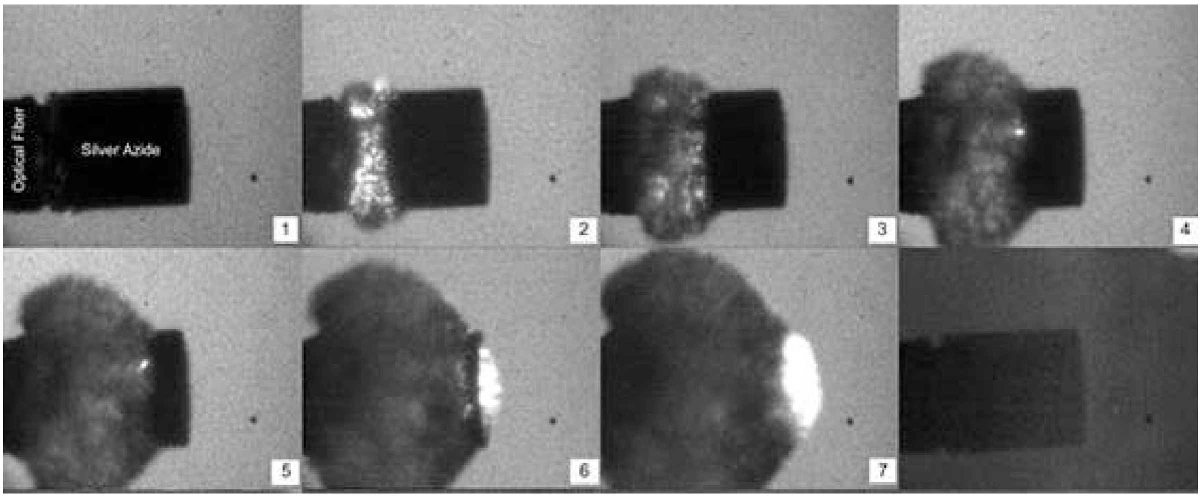

Fig. 7: Series of ultra high speed photography showing detonation propagating in a silver azide pellet.

but it has difficulties in downsizing detonative combustor. Just like micro combustor facing a quenching distance problem, detonation can not be driven in a medium of certain size or less, where it is called detonation limit or critical diameter. Hamate et al are developing micro detonative combustor to achieve higher efficiency, especially utilizing solid/liquid detonation that is explosives [4]. Figure 7 shows a series of ultra high speed photography showing detonation propagating in a silver azide pellet with only 1.5 mm diameter. Framing speed is 50ns/frame. Detonation is initiated by Nd: YAG laser and propagates in around 5km/s. Scattered bright spot, so-called "hot-spot" can be seen in initiation stage (frame 2). Detonation front has a certain curvature due to rarefaction wave, and can be recognized in frame 6.

Conclusion

Power MEMS have seen a tremendous rise in academia and industries. New devices and new materials related to Power MEMS are directly connected to new businesses and environmental applications. Micro energy research group has been established this March 2008 in JSME. The Eighth International workshop on Micro and Nanotechnology for Power Generation and Energy Conversion Application, PowerMEMS 2008 + μEMS 2008 will be held in Sendai from 9 to 12, November 2008. The author hopes these two meetings will catalyze collaborations and promote the advancement in the field of micro energy technologies and its applications.

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