Research on the Application of Sprout Multi-Disciplinary Technologies in Micromachine Technology in Fiscal 2000

Since 1992, the Micromachine Center has taken up a diverse range of technology seeds as themes for joint research by academic, governmental, and industrial sectors, all with the aim of reinforcing basic technologies by searching for the technology seeds, especially in the scientific and technological fields, necessary to build various micro systems. In fiscal 2000, research has been conducted along five themes; these five themes are summarized below.

Study on Wearable Energy Sources

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Wearable energy sources are compact energy sources that can be mounted in humans, animals, robots, and the like. Presently, primary and secondary batteries are widely used as wearable energy sources. In the present study, we investigated the feasibility of new wearable energy sources with functions not found in primary and secondary batteries.

By efficiently supplying electricity from chemical fuels having an energy density 1-2 digits greater than batteries, wearable energy sources using chemical fuels are advantageous in that they have potential for achieving a high energy density and high output density. Moreover, unlike secondary batteries that must be recharged, the new wearable energy sources can be continuously used simply by refilling them with fuel. By combining a reusable compact generator with an easily recyclable fuel cartridge, this type of energy source is more environmentally friendly than primary and secondary batteries that accompany such problems as organic matter and waste. Hence, these wearable energy sources support a recycling society. Currently, micro-fuel cells, silicon micro-gas turbine generators, and the like are being studied as energy sources.

Since automatic generating and charging systems free the user from secondary battery charging and fuel refilling, these systems are suitable for such applications as portable health care terminals, which require that a minimum of mental and physical burden be placed on the user, and animal tracking devices or polar environment observing equipment, on which maintenance is not practical. Technologies for automatic generating systems used in wristwatches and noncontact electrical supply systems used in wireless ID tags are employed as base technologies of these automatic generating and charging systems.

This paper discusses examples of wearable and compact energy sources, including fuel cells, fuel reformers, automatic mechanical generators, thermoelectric generators, noncontact electrical supply systems, double-layer capacitors, thin film batteries, and heat engines. The paper also clarifies the current state and future of wearable energy sources used in place of primary and secondary batteries and their relationship with micromachine technologies.

A Study on Applied Technologies for Microchannels

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Progress in microfabrication technology has spurred advances in the density and performance of electronic devices, typified by the CPU, and has increased the power of semiconductor lasers. At the same time, we have seen developments in R&D on micromachines, microreactors, and other micro-equipment, as well as in applied research using this equipment. A problem common to all these devices that has been raised is how to dissipate heat with high heat flux from micro-domain. The heat dissipation from microprocessors around the year 2006, for example, is projected to be about 100 W/cm^2. That from high-power diode lasers is estimated to reach 100-500 W/cm^2, while the APS, a next-generation X-ray source, is expected to reach 2000 W/cm^2. In order for these devices to operate properly, a large amount of heat generated therein must be removed to maintain a low temperature (about 100℃ or less). It is an extremely severe requirement to remove high heat flux under a law temperature difference. In fact, technology used in extreme thermal environments, such as to protect a space shuttle reentering the Earth's atmosphere or nuclear reactor barriers wherein it is necessary to dissipate heat of high heat flux under a high temperature difference, is said to be insufficient to remove heat generated in these micro devices. When considering that the thermal resistance $R = \Delta T/q$, defined by the maximum temperature difference ΔT between the device and ambient environment and the heat flux q as parameters for evaluating the severity of heat removal, it is apparent that we must urgently develop a low-heat resistance technique for dissipating heat.

To achieve this, Tuckerman, et al., proposed a method for removing heat from electronic devices using microchannels, clarifying the heat transfer characteristics and indicating the effectiveness thereof. This technique can conceivably be applied not only to cooling of electronic devices, but also to high-performance micro heat exchangers and the like. While related research activities are being actively pursued, the use of this technique is not yet practical for such applications. This is because heat transfer characteristics of microchannels have not been sufficiently sorted out and the concept and technologies for applying this technique have not been organized in a form readily understandable by technicians and researchers of fields outside of thermal engineering.

From this background, we studied a microchannel cooling technique from the perspective of designing microchannel heat sinks. This paper, entitled "A Study on Applied Technologies for Microchannels," reports the following.

(1) Asserting that microchannel cooling technology differs from conventional cooling technology in that it has a smaller thermal resistance, we indicated why the use of microchannels can achieve a low thermal resistance. We also clarified in which cases it is best to use microchannel cooling technology, by organizing each cooling technology's scope of application according to temperature and heat flux.
(2) A theoretical analysis was conducted on the heat transfer in microchannels and the basic characteristics of heat transfer were given. We also described the scope of application of experimental correlations for conventional systems and factors that come out when using microchannels.
(3) We described the heat transfer and flow characteristics of microchannels with or without a phase change and pointed out that phase change caused a large pressure loss.
(4) Microchannel cooling characteristics were clarified when using water or air as the working fluid, and factors coming out when using air were noted. Next, we described our views on conducting an optimal thermal design of the microchannel heat sinks and gave an optimal design rule.
(5) In order to evaluate quantities of heat transfer characteristics for the microchannels, it is necessary to perform accurate measurements of each physical quantity. From this perspective, we summarized methods of measuring flow rate, velocity, temperature, and pressure and provided example.
(6) Techniques for reducing flow resistance and enhancing heat transfer are important for increasing the microchannel's performance. We studied techniques that have been proposed thus far and investigated their applicability to microchannels.
(7) Lastly, we provided various examples of microchannel production and practical use.

Elucidating Fluid Phenomena in Microchannels and Studying Applications of Microchannels in Micromachine Technology

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In relevant studies conducted thus far, it is clear that applications of micromachine technology to systems aimed at chemical and biochemical analyses and synthesis are progressing. There are now many studies being conducted in this field. At the 4th International μTAS Conference held in May 2000 at the University of Twente in the Netherlands, 134 papers selected out of 230 contributed were presented. Nearly 500 people from 22 countries participated at the conference. There has also been a sharp increase in research presentations on this field at conferences on MEMS, Transducers, HPCE, and other conferences, indicating a definite increasing interest in the topic.

In light of the above conditions, the present study again focused on microscale fluid phenomena and microfluidic systems, the importance of which is gradually being recognized. This year's study particularly emphasized fluid behavior in microspaces, the characteristics of its chemical reaction processes, as well as techniques for its measurement and evaluation. As a continuation of previous studies, we summarized examples of developing microfluidic devices used as components in microfluidic systems and their example applications to genome/proteome analysis. This paper also includes information on European trends in this field.

Since the ratio of surface area to volume increases in microspaces, forces incurred by the fluid, such as surface tension, are relatively large. The fluid has a laminar flow due to its small Reynolds number. Chemical reactions can be performed quickly and efficiently because the interface between two different contacting fluids is relatively large; the distance of molecular diffusion can be shortened; and it is easier to uniformly control such conditions as temperature.

In measuring and evaluating microscale flows, shear stress is the most common measurement in flow fields on an object's surface. For a long time, shear stress sensors using a thin film heater were proposed. Electroosmotic flow was used for pumping the fluid in electrophoresis on microfluidic devices. However, determining the flow profile in this case is an important measurement for evaluating a separating function . There have been reports on experiments for studying the effects of the zeta-potential that determines the driving force of the fluid in electroosmotic flow and examples of measuring flow in microchannels using a particle image velocimetry (PIV). An experiment using color reaction was performed to evaluate the mixing properties of a micromixer, while much research has been reported on microfluidic devices, micropumps, microvalves, and micromixers based on new principles and constructions are emerging. Reports on microvalves include pneumatic normally-closed valves using PDMS, a plurality of valves arranged in one channel that can be used as a peristaltic pump, horizontal valve structures formed by a DRIE process. A new concept of microvalves using hydrogel was proposed. Reports on micropumps included a diaphragm pump using a piezo bimorph actuator, pumps using continuous electrowetting (CEW), and a bubble pump. Two kinds of micromixer are proposed ; one is using an electrohydrodynamic (EHD) effect to generate convention, and the other is using a bubble pump to actively disturb the two-liquid interface.

Some example applications of microfluidic devices in genome/proteome analysis are already being implemented. In the example of incorporating capillary electrophoresis on a microchip, ninety-six microchannels are arranged radially to perform high-speed processes. Products emerging with an eye to the market include sixteen microchannels formed on a 4-inch wafer. Studies are being performed on integrating two-dimensional gel electrophoresis, an important method in proteome analysis, and a mass spectrometer on a microchip. Separation by protein electrophoresis has been implemented on a microchip in an attempt to automate the proteome analysis by connecting the microchip to a protein analyzer.

The end of this paper talks about the state of research in Europe, introducing IMTEK at the University of Freiburg and describing the research system there, as well as discussing the commercialization trends of microsystems in Switzerland. In the future, it is important that we consider how we can strategically construct systems such as those represented in Switzerland from the research stage to production and commercialization in order to further develop micromachine technology that has been fostered in Japan and to make such technology useful in the real world.