Power MEMS Research from Hundreds of Watts to Sub-milliwatt Classes

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The power level of Power MEMS research ranges widely from several hundred W to sub mW. This paper introduces a micro compressor with impellers of 10 mm diameter for a 100–1000 W class gas turbine generator, an electrostatic microvalve to control fuel in a portable direct methanol fuel cell, a micro methanol reformer integrated with a catalytic combustor and surface acoustic wave (SAW) passive wireless sensors.

Keywords: Gas turbine, Fuel cell, Microvalve, Fuel reformer, Wireless sensor, SAW

1 INTRODUCTION

A self-powered system is defined as a system working without wires for power supply. A motor vehicle is one of the most common self-powered systems used around us. Mobile electronics such as a cellular phone and a laptop computer has also become daily-used self-powered systems for many peoples. In the near future, we will be unconsciously surrounded by a huge amount of tiny self-powered systems, which are called ubiquitous sensors.

These self-powered systems must secure power for themselves by storing, generating or harvesting necessary power. At the present, storing electrical energy in batteries is the most versatile way for small self-powered systems. However, some of future self-powered systems might not satisfy energy requirement of themselves using existing batteries. This paper introduces some of devices recently developed by us for medium to micro self-powered systems.

2 PALMTOP GAS TURBINE GENERATOR FOR MOBILE ROBOTS

In coming aging society with less working population, self-powered autonomous robots are expected to work at construction sites, farms, hospices, homes etc. For such applications, a 100–1000 W class compact power source which continuously works by refueling is expected, and a down-scaled gas turbine generator will answer this requirement.

We are developing a palmtop gas turbine generator with impellers of 10–20 mm diameter. The development of a compressor, a turbine, air bearings, a combustor and a generator are underway with collaborators. One of the most important and difficult challenges in these developments is to achieve a practically high compressor performance at ultrahigh rotation speed. This needs the synthesis of various technologies related air bearings, the design and fabrication of tiny impellers, rotor dynamics and rotor balancing.

We succeeded to rotate a turbine impeller of 10 mm diameter shown in Fig. 1 at a rotation speed of 890000 rpm (a tip speed of 470 m/s) [1]. The turbine impeller made of titanium alloy is connected to a shaft of 4 mm diameter and supported by a newly-developed hydroinertia air bearings. Using the developed rotation components, a compressor impeller of 10 mm diameter shown in Fig. 1 was tested up to 720000 rpm, which is 83 % of the rated rotation speed (870000 rpm) [2]. Figure 2 (a) and (b) show measured pressure ratio and adiabatic efficiency, respectively. By comparing target values shown by solid lines in these figures, the measured compressor performance suggests that such a small gas turbine is aerodynamically feasible.

3 MICRO FLUIDIC DEVICE FOR PORTABLE FUEL CELLS

Fuel cells are correcting much attention as power sources for portable electronics due to their high potential energy density. Although there are several types of portable fuel cell, an active direct methanol fuel cell (DMFC) is the most promising one for laptop computers and video camcorders. The active DMFC uses active peripherals such as valves and pumps to supply fuel and air to the fuel cell. For high efficiency and power output, the concentration of methanol in the fuel must be controlled in a narrow rage. This is because a higher concentration of methanol promotes methanol crossover, which largely degrades the efficiency and power density, due to an increased gradient of methanol concentration across a polymer electrolyte membrane (PEM). Contrarily,

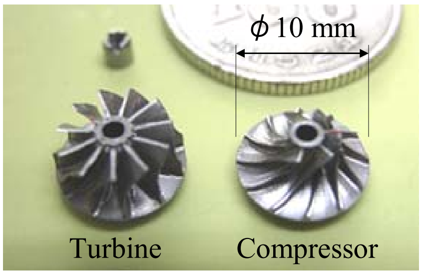

Figure 1 Microimpellers of 10 mm diameter.

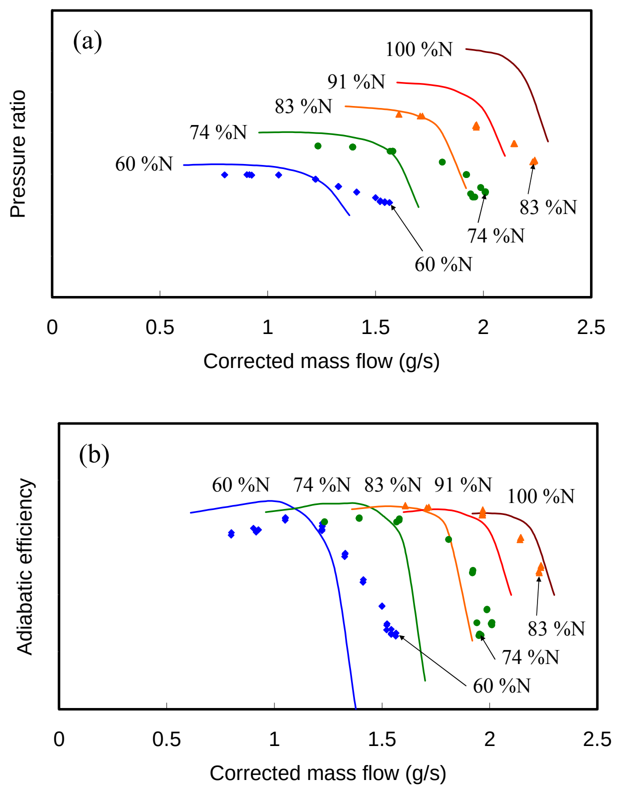

Figure 2 Performance of the micro centrifugal compressor.

a lower concentration of methanol makes the output of a DMFC limited by methanol diffusion at the anode.

Figure 3 illustrates an electrostatic microvalve to control methanol from a pressurized fuel tank [3]. To realize normally-closed operation against the pressurized fuel at acceptably low driving voltage, a novel pressure balance mechanism is adopted. The microvalve has a sealed space separated from a liquid flow channel by a corrugated diaphragm. The corrugated diaphragm is pushed up by the pressure of the liquid, and air inside the sealed space is pressurized. As a result, upward force from the liquid and downward force from the air are balanced on the electrostatic actuator, and the microvalve can keep close state against the pressurized fuel.

Figure 4 shows a prototyped microvalve. The microvalve was first characterized using air as a working fluid. Figure 5 shows the relationship between input pressure and air flow rate measured with no driving voltage applied. Due to the pressure balance mechanism, the microvalve keeps close state until the input pressure reaches 40 kPa. Figure 6 shows the relationship between applied voltage and air flow rate at an input pressure of 15 kPa. The flow characteristic shows hysteresis due to the pull-in phenomenon of the electrostatic actuator as anticipated by simulation.

The microvalve was used in a prototyped active DMFC to keep methanol concentration at 5 %. The methanol flow rate was controlled by the pulse width modulation of the driving voltage due to the hysteresis in the flow characteristic shown in Fig. 6.

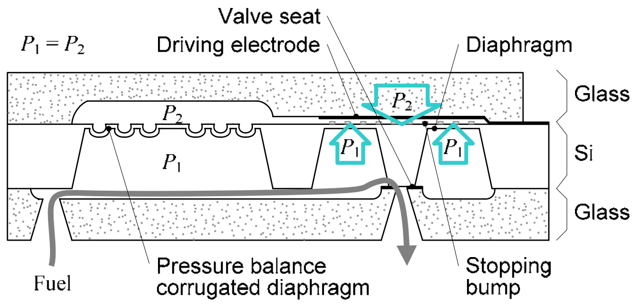

Figure 3 Structure of the electrostatic microvalve with pressure balance mechanism.

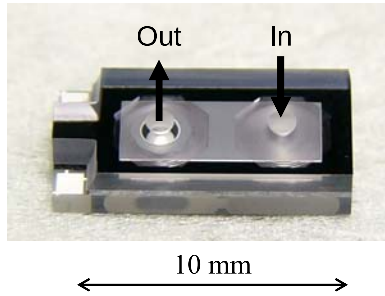

Figure 4 Prototyped microvalve for fuel control in DMFC.

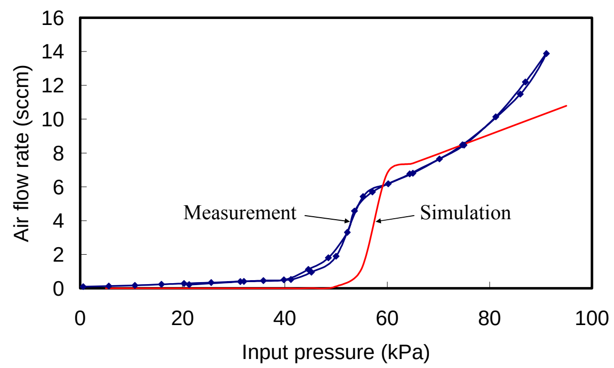

Figure 5 Relationship between input pressure and air flow rate.

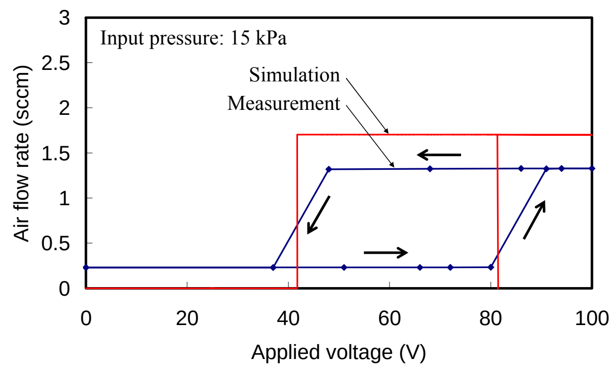

Figure 6 Relationship between applied voltage and air flow rate at an input pressure of 30 kPa.

4 MICRO FUEL REFORMER FOR PORTABLE FUEL CELLS

A hydrogen-fueled fuel cell has a much higher power density than DMFC. However, hydrogen storage is impractical for portable applications, because hydrogen storage capacity is still low per weight, and recharging hydrogen is limited in place. The most practical way to supply hydrogen to portable fuel cells is to convert hydrocarbons to hydrogen using microreactors.

Steam reforming reaction to convert hydrocarbons to hydrogen is endothermic, and a fuel reformer needs a combustor as a heat source. Figure 7 shows a prototyped micro methanol fuel reformer, in which a catalytic combustor is sandwiched by fuel reforming reactors [4]. The chamber of the catalytic combustor is wash-coated with Pt/TiO_2 catalyst, and that of the fuel reforming reactor is filled with $CuO/ZnO/Al_2O_3$ catalyst powder.

Methanol (steam/carbon = 1.38) was reformed using the prototyped fuel reformer by changing the flow rate of methanol to the catalytic combustor and fuel reforming reactors. Figure 8 shows the production rate of hydrogen represented by lower heating value (LHV). 5.9 W equivalence of hydrogen was produced from a device volume of 2.1 cm^3, showing the world highest power density to the best of our knowledge. However, the concentration of CO in reformed gas is as high as 2–3 %, and the total thermal efficiency is lower than 40 %. For practical use, the integration with a CO remover and a thermal insulation package is needed.

5 SAW PASSIVE WIRELESS SENSORS

There are enormous potential applications of tiny wireless sensors. Information technology is going toward ubiquitous computer and sensor society, where tiny wireless sensors will be embedded in various items around us. For vehicle applications, wireless sensors are needed for measurements in rotating parts such as tires, driving shafts, steering shafts and turbine blades. Biosensors implantable in a human or animal body are also strongly expected to be wireless. For some of these applications, batteries are not preferable. It is impractical to periodically replace batteries in innumerable ubiquitous sensors, and a battery is often too bulky to be used in rotating parts.

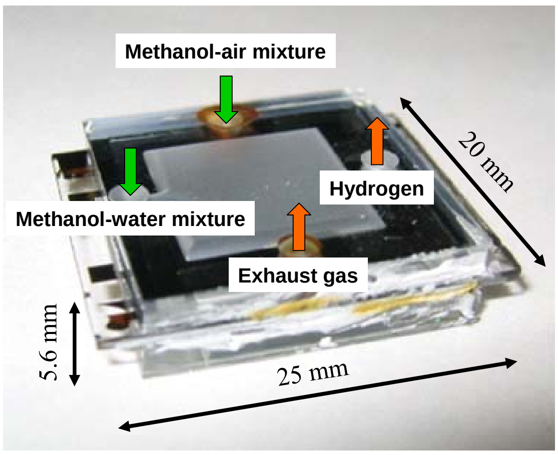

Figure 7 Prototyped micro methanol fuel reformer.

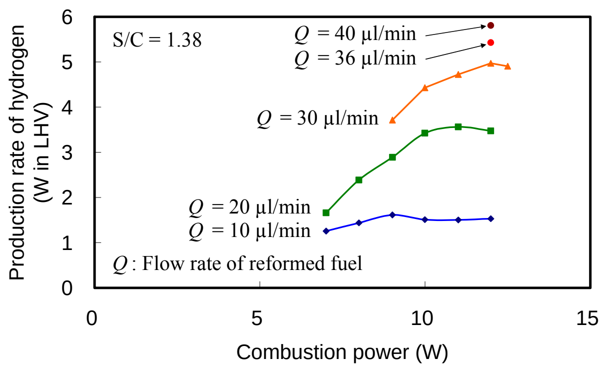

Figure 8 Production rate of hydrogen from the micro methanol reformer.

Recently, energy harvesting microdevices to generate electric power from vibration or temperature gradient are widely studied. Another approach is wireless power transfer by radio wave. We are studying surface acoustic wave (SAW) passive wireless sensors. Figure 9 shows the working mechanism of SAW passive wireless sensors. Radio wave from a transceiver is received by an antenna, and SAW is generated by an interdigital transducer (IDT) connected to the antenna. The SAWs travel on a piezoelectric crystal, reflect at reflectors, and then return to the IDT. The returned SAW is reconverted to radio wave, which is transmitted to the transceiver. If deformation, absorption or mechanical contact occurs between the IDT and the reflector, SAW velocity changes, and eventually the delay time of the returned signal changes.

The simplest SAW wireless sensor is a thermometer, which uses the temperature dependence of SAW velocity and the change of the length between the IDT and the reflector due to thermal expansion. We developed 2.45 GHz SAW passive wireless thermometers on a 128 ° Y-X $LiNbO_3$ wafer [5]. Figure 10 shows 4 packaged sensors with a patch antenna. Our main progress is that time division multiple access (TDMA) has been achieved by an advanced design technology. Returned signals from 4 sensors are shown in Fig. 11, where no signal overlaps with each other. The temperature resolution of 0.19 °C (6σ) was achieved at a transmission power of 1.59 mW by three step evaluation scheme using a time delay and phases, when the distance between the transceiver and the sensors was 140 cm.

If a diaphragm is made between the IDT and the reflector, pressure can be measured. Figure 12 shows the structure of a SAW passive wireless pressure sensor, and Fig. 13 shows a diaphragm made in a Z-cut $LiNbO_3$ wafer. The diaphragm was made by a novel etch stop technique. The polarization direction of $LiNbO_3$ is thermally inverted from +Z surface into bulk in wet argon atmosphere at 1050 °C, and then the wafer is etched in hot HF from the original –Z surface using a Cr/Au/Cr mask. The etching stops at the thermally-inverted layer, which becomes the diaphragm, because etch rate on +Z surface is much slower than that on –Z surface.

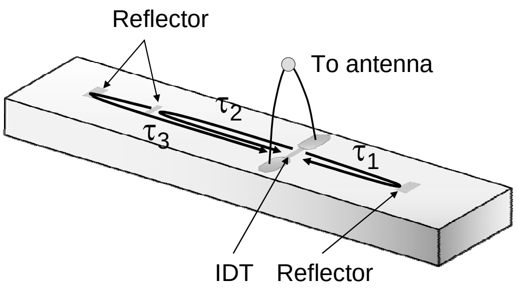

Figure 9 Working mechanism of SAW passive wireless sensors.

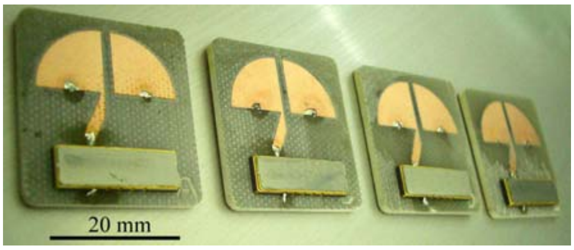

Figure 10 Prototyped SAW passive wireless thermometers with a patch antenna.

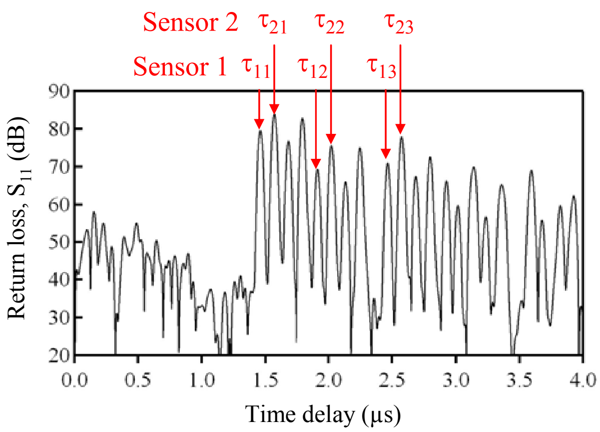

Figure 11 Returned signals from 4 SAW passive wireless thermometers.

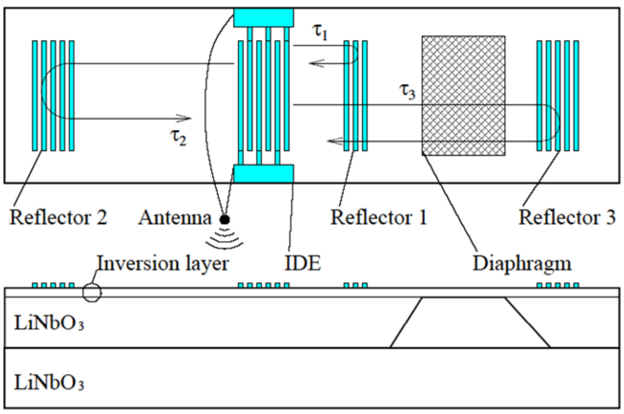

Figure 12 Structure of a SAW passive wireless pressure sensor.

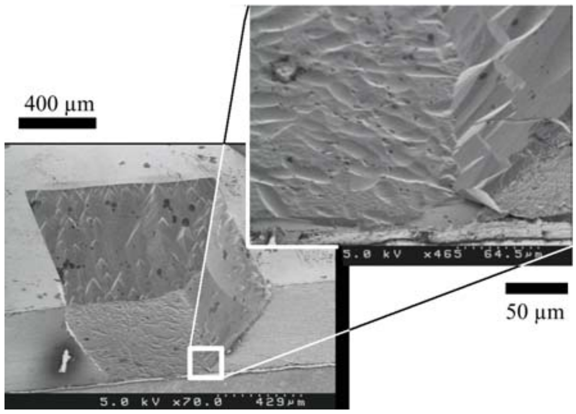

Figure 13 Diaphragm made in a Z-cut $LiNbO_3$ wafer for pressure sensing.

6 CONCLUSION

This paper introduced the recent Power MEMS researches in Tohoku University. “Personal”, “portable” and “ubiquitous” are becoming more important key words for information technology, and self-powered systems including autonomous robots, portable electronics and ubiquitous sensors seem promising products in the future. The contribution of microtechnology to these products will be enormous.

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