MEMS power generator operated by fluorocarbon gas

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Abstract. This paper proposed a MEMS air turbine generator. The conventional miniature power sources like a battery required a replacement. Therefore, it is limitation for an IoT (Internet of Things) device, and it is required to develop a miniature generator. The proposed generator shows a millimetre scale structure that combined the different technology. The MEMS process is used for the miniature air turbine structure. To achieve the high output power, the electromagnetic induction type is employed. The miniature magnetic circuit is fabricated by the multilayer ceramic technology. Fluorocarbon gas is used as a working fluid to generate the rotational motion of the rotor. By this reason, the miniature power generation system will be realized in the future. Dimensions of the fabricated MEMS power generator were 5.62 mm, 6.17 mm, and 7.12 mm, respectively. The rotational motion was demonstrated using R245fa of fluorocarbon gas. The maximum rotational speed was 154,620rpm when the outside temperature was 46.3 Celsius degree. The output voltage was 10 mV at the load resistance of 1 kΩ. The calculated output power was 0.6 mVA at when the load resistance was 2 Ω.

1. Introduction
A miniature power generator is required for miniature devices. For example, the IoT (Internet of Things) device is required for various fields from the industrial field to human health care. In the industrial field, the IoT device catches the machine error. For the human health care, it checks a body temperature, heart sound, and more. These devices are constructed by a sensor, a control IC, and a wireless communication device, and these are researched by the MEMS process. Moreover, the devices require a battery to drive everywhere. Conventionally, the devices use a button battery or a lithium-ion-secondly battery. These batteries have miniature body and high energy density. However, the batteries will be required a replacement, and the using field is limited. Therefore, the miniature power source like a generator is required.

In the MEMS process, a miniature electrostatic type generator has been researched [1] because it is suitable for the MEMS process. However, it shows small output power by their charge saturation and high internal impedance. On the other hand, the MEMS electromagnetic induction type generators were researched [2] because it shows high output power, but the miniaturization of a magnetic circuit is difficult. Previously, we proposed the electromagnetic induction type MEMS air turbine generator [3]. The proposed generators realized the miniature magnetic circuit by using the multilayer ceramic technology. This technology is usually used for miniature electronic components, and it can form a miniature three-dimensional structure coil with the magnetic core. The proposed MEMS generators showed the rotational motion with compressed nitrogen gas. However, it is difficult to construct the
miniature power generation system because the nitrogen gas required the compressed system. Therefore, the working fluid that alternative the compressed nitrogen gas is required.

In this research, fluorocarbon gas, which is usually used as working fluids for refrigeration cycle system due to low boiling point, is adopted for this system. Fluorocarbon of a gas and liquid state makes possible to miniaturize the system in comparison with compressed nitrogen gas. This paper is reported the experimental results by our MEMS turbine generator operated using R245fa of the fluorocarbon gas.

2. Design and Experiment
The proposed MEMS generator has the MEMS air turbine structure and the multilayer ceramic magnetic circuit. An electromagnetic induction revolving-field type is used. The magnetic circuit employs the three-phase alternating current generation method. Power generation of the MEMS air turbine generator is demonstrated by the fluorocarbon gas.

2.1. MEMS air turbine generator
The designed MEMS generator is shown in Figure 1. The upper side is MEMS air turbine and the lower side is the multilayer ceramic circuit. The MEMS air turbine parts are made from the single crystal silicon. And these are fabricated by the dry etched by high-aspect-ratio inductively coupled plasma etching combined with a Bosch process [4]. Figure 2 (a) shows the cross-sectional image of the designed MEMS air turbine. A 2-pole ring shape magnet is arranged in the turbine structure, and it is connected to the rotor through the shaft. Designed rotor shape is a rim-type rotor. Figure 2 (b) shows the rotor design and a flow path pattern. The dimensions of the rim-type rotor are 3mm (diameter) and 0.85 mm (thickness), respectively. The working fluid is inserted through the brass tube that attached to the inlet pattern. When the working fluid inserted into the turbine it generates the rotational motion. The stable rotational motion is realized because the miniature ball bearing suppresses the eccentric motion of the rotor. A magnetic yoke is attached on the magnet. Moreover, the distance between the magnet and the magnetic circuit is adjusted to 130 μm by the turbine frames. The fabricated MEMS air turbine was assembled by hand, and these were bonded by the cyanoacrylate resin. The rotational motion of the fabricated MEMS air turbine structure is observed by compressed nitrogen gas. Rotational speeds are adjusted by changing a pressure and a flow rate.

The magnetic circuit is made from the co-fired NiCuZn ferrite as the magnetic ceramic and the silver paste. It is fabricated by the multilayer ceramic technology. Characteristics of the designed circuit are that it has three-dimensional coil pattern and magnetic core, and these are fabricated simultaneously. The coil pattern inside the ceramic is axial direction because the magnetic flux is occurred to axial direction. Figure 3 (a) shows the schematic illustration of the designed multilayer ceramic magnetic circuit. The three-phase type circuit is combined with fired three coils on the magnetic layer. Each coil has 27 turns, and the connecting method is Y-connection. Coils are arranged with the air gap to suppress the magnetic flux leakage [3]. Figure 3 (b) shows the fabricated magnetic circuit. The monolithic three-phase circuit was achieved. Output wires were connected to each coil. The internal DC resistances of each coil were 0.85 ~ 0.86 Ω.
2.2. Experimental procedure for power generation
R245fa whose boiling point is about 15 Celsius degree is used as fluorocarbon gas in this work. The sample of R245fa is supplied from AGC Inc., Japan. The R245fa in gas and liquid states is filled in a small cylinder whose temperature kept constant by the thermostated water bath of the heat source. The temperature is measured with a thermocouple in the water bath. The pressure becomes saturated vapor pressure of R245fa in temperature of the water bath. The gas of R245fa is provided from the upside of the small cylinder to the MEMS turbine and released to the atmosphere.

3. Results and discusses

3.1. Rotational motion of air turbine structure
Figure 4 shows the rotational speed of the MEMS air turbine structure at each pressure and each flow rate. Inflow pressure was increased by 0.1 MPa from 0.1 MPa to 0.3 MPa. And it was outlet pressure of the gas bomb. When the pressed nitrogen gas was used, the maximum rotational speed of the turbine structure was 348,840 rpm at 0.3 MPa and 2.4 l/min.

3.2. Fabricated MEMS generator and power generation experiment by fluorocarbon gas
Figure 5 shows the fabricated MEMS air turbine generator. Dimensions of the generator were 5.62 mm, 6.17 mm, and 7.12 mm, respectively. The weight was 1.34 g including the MEMS air turbine structure and the ceramic magnetic circuit. In the power generation, the R245fa gas was inserted to the fabricated generator. The rotational speeds at each temperature are shown in Figure 6. The maximum rotational speed was 154,620 rpm when the outside temperature was 46.3 Celsius degree. The output waveform at the load resistance of 1 kΩ is shown in Figure 7. The output voltage was 10 mV. By this result, the maximum output power when the load resistance is 2 Ω and the inductance value of the magnetic circuit at 2577 Hz was calculated, and it was 0.6 mVA.
In this experiment, it is observed that the R245fa provided to the MEMS turbine in the gas state is released from outlet of that in the gas and liquid states. This is because the R245fa goes into two phase region of gas and liquid due to pressure loss reduction inside the MEMS turbine. The liquefied R245fa makes the speed of the rotor down. So the structure of the turbine should be analysed in the future work.

**Figure 5.** Fabricated MEMS air turbine generator.

**Figure 6.** Rotational speed at each temperature.

**Figure 7.** Output waveform of generator at 1 kΩ.

### 4. Conclusions

This paper proposed the MEMS air turbine generator operated by the fluorocarbon gas. The proposed power generator realize the miniature structure (5.62 mm, 6.17 mm, 7.12 mm) because these structures were fabricated by the MEMS process and the multilayer ceramic technology. The fabricated MEMS generator demonstrated the rotational motion and the power generation. The working fluid was R245fa as a fluorocarbon gas. The maximum rotational speed was 154,620 rpm when the outside temperature was 46.3 Celsius degree. The output voltage was 10 mV, and the maximum output power of 0.6 mVA was expected. By these result, it will be realize the miniature generation system in the future.

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