Development of Synthetic Jet Air Blower for Air-breathing PEM Fuel Cell

Jongpil Choi, Eon-Soo Lee, Jae-Huk Jang, Young Ho Seo and Byeonghee Kim

***Abstract*—** This paper presents a synthetic jet air blower actuated by PZT for air blowing for air-breathing micro PEM fuel cell. The several factors to affect the performance of air-breathing PEM fuel cell such as air flow rate, opening ratio and cathode open type in the cathode side were studied. Especially, an air flow rate is critical condition to improve its performance. In this paper, we developed a synthetic jet air blower to supply a high stoichiometric air flow. The synthetic jet mechanism is a zero mass flux device that converts electrical energy into the momentum. The synthetic jet actuation is usually generated by a traditional PZT actuator, which consists of a small cylindrical cavity, in/outlet channel and PZT diaphragms. The flow rate of the fabricated synthetic jet air blower was 400cc/min at 550Hz and its power consumption was very low under 0.3W. The proposed air-breathing PEM fuel cell which installed synthetic jet air blower was higher performance and stability during continuous operation than the air-breathing fuel cell without auxiliary device to supply the air. The results showed that the maximum power density was 188mW/cm^2 at 400mA/cm^2. This maximum power density and durability were improved more than 40% and 20%, respectively.

***Keywords*—** Air-breathing PEM fuel cell, Synthetic jet air blower, Opening ratio, Power consumption.

I. Introduction

THE interest in micro fuel cell application has significantly increased in the last few years. It is believed that micro fuel cells may have potential in replacing batteries. Especially, considerable attention has been focused on air breathing fuel cells due to the minimization of auxiliary devices and simplified water management. Air breathing fuel cells use free convection airflow to supply air to the cathode. They can outweigh the cost, reliability, complexity, noise, volume, weigh, and parasitic power consumption of the auxiliary devices. However, they are typically characterized by low output power densities compared to forced convection fuel cells with auxiliary device such as fan, pump and compressor. Also, for longer durations, in the absence of convection, the local oxygen concentration adjacent to the cathode will be depleted [1-3]. So, one of the key technologies is a micro air pump and blower which can feed sufficient air into the fuel cell. Micro air pump and blower could also benefit reducing the required electrode size and increasing power density. Another critical challenge for high power air breathing fuel cells is the need to remove the generated water as a by-product of the fuel cell reaction. The generated water can clog GDL pores and channel which supply the air to the cathode [4, 5].

This paper was designed and fabricated the synthetic jet air blower to supply air into the cathode for air breathing PEM fuel cell. The fabricated synthetic jet air blower was installed on the cathode of air breathing PEM fuel cells and experimental schemes for testing methods and performance analysis are also discussed.

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II. Fabrication

A. Synthetic jet air blowers

A synthetic jet is a zero mass flux device that converts electrical energy into momentum. Synthetic jet actuator can be developed in a number of ways, such as with an electromagnetic driver, a piezoelectric driver, or even a mechanical driver such as a piston. Each moves a membrane or diaphragm up and down hundreds of times per second, sucking the surrounding fluid into a chamber and then expelling it [6]. A schematic of the synthetic jet air blower is shown in Fig. 1. The synthetic jet air blower consists of an orifice and a small cavity bounded by the PZT diaphragms. Applying voltage to the PZT causes it to vibrate, and outside air is rapidly pulled into the chamber through the orifice then expelled.

Fig. 2 shows the fabricated synthetic jet air blower which made from acrylic. A synthetic jet air blower was designed to install on the air-breathing fuel cell. The PZT diameter was 20mm and orifice diameter was 1mm.

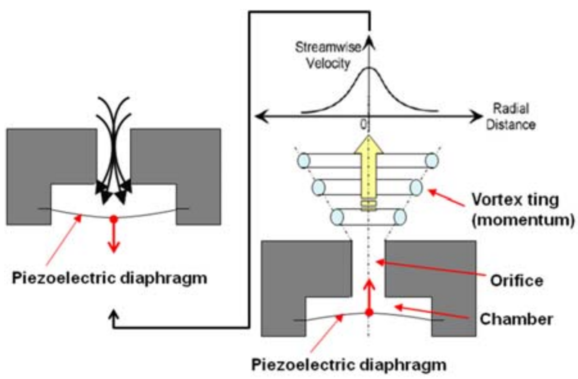


Fig. 1 Schematic and basic principle of Synthetic jet air blower

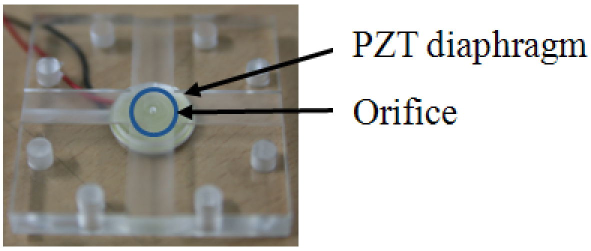


Fig. 2 Photograph of fabricated synthetic jet air blower

B. *Air-breathing PEM fuel cells*

Fig. 3 shows the schematic and fabricated air breathing PEM fuel cell. The membrane electrode assembly (MEA) was used Gore's 55 series and the electrochemical active area of this geometry has a size of 4 cm^2. These components of the air-breathing PEM fuel cells are described as shown in Table 1.

In general, the PEM fuel cells require a supply of hydrogen and oxygen to generate electricity, which are introduced into the flow field plates of the fuel cell through the both inlets. However, the air-breathing PEM fuel cells supply the oxidant to the cathode by free air convection, because the energy consumption and size of auxiliary should be minimized. Therefore, the design of the cathode flow field plate is very important factor. Therefore, one of the most important factors which affect its performance and life-time is structural configurations and operating condition of cathode. In this paper, to evaluate the performance of the air-breathing PEM fuel cells according to the cathode opening ratios and open type, the cathode flow field plates which has opening slits and square of 40~72% were designed and fabricated (Fig. 4).

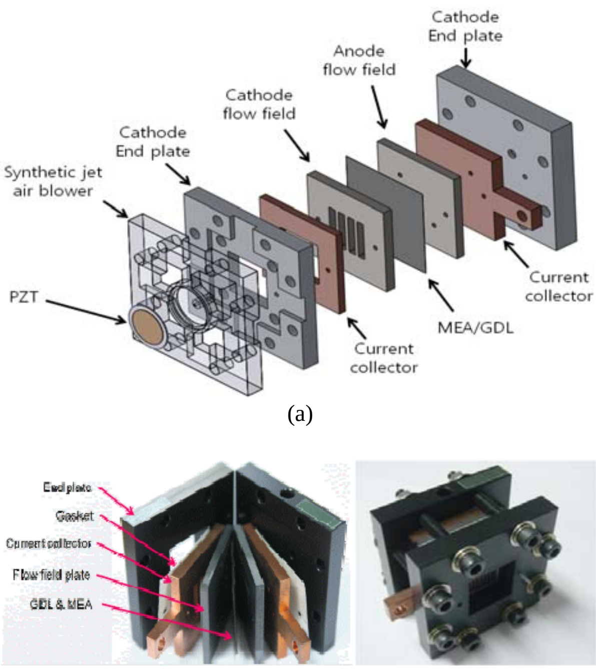


Fig. 3 Air breathing fuel cell: (a) schematic; and (b) images of components and assembled cathode view.

TABLE I
COMPONENTS OF FABRICATED AIR-BREATHING FUEL CELLS

Components	Specification
MEA	GORE® 5510 series (Pt:0.4mg/cm^2)
GDL	GORE® Carbel CL
Flow field plate	Graphite
Current collector	Copper
Gasket	PTFE polymer
Active area	4 cm^2
Assembly pressure	25kgf cm

MEA : Membrane Electrolyte Assembly, GDL : Gas Diffusion Layer, PTFE : Polytetrafluoroethylene

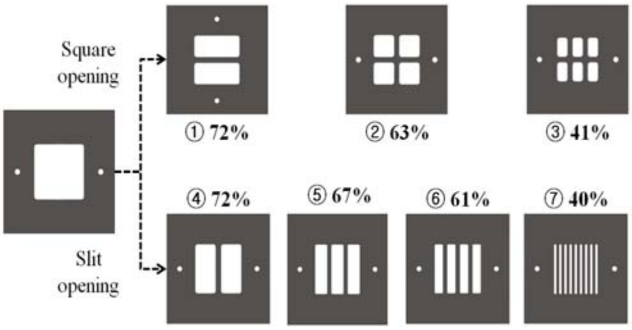


Fig. 4 Design of cathode flow field plates with various opening ratios.

III. EXPERIMENTAL RESULTS AND DISCUSSION

Fig. 5 shows the flow rate of fabricated synthetic jet air blower with respect to the frequency. With increasing the frequency, the flow rate gradually increases. The maximum flow rate of 500cc/min was measured at 650 Hz and it is sufficient to operate the air-breathing PEM fuel cell for portable applications.

In order to operate the PZT, the sine wave as input was used to minimize the sound level of the synthetic jet air pump. The experimental results of sound level of synthetic jet air pump according to the input wave is shown Fig. 6. However, even though the sine wave was used, the sound levels increase dramatically when the operating frequency is increased over 600Hz.

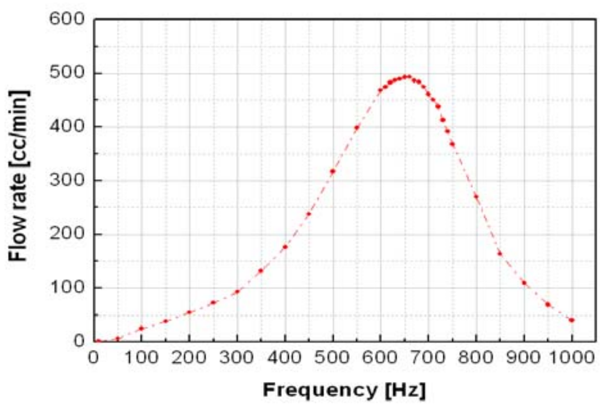


Fig. 5 Flow rate of the fabricated synthetic jet air blower with the frequency

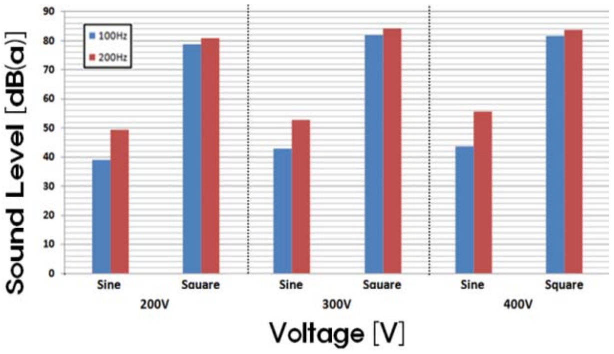


Fig. 6 Sound level of micro synthetic jet air blower according to the input wave and voltage

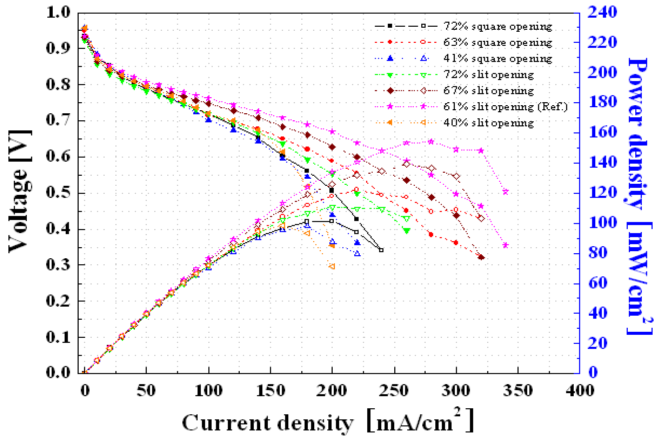
To measure the performance of the air breathing fuel cell with various opening ratio of the cathode, a hydrogen gas is provided for the anode with no humidification and an air is provided by free breathing. The temperature and relative humidity in atmosphere were 23~25℃ and 55~60%. Table 2 describes the operating conditions of air-breathing PEM fuel cells.

Fig. 7 shows the polarization curve and cell voltages at constant current for the air breathing cell with varying opening ratios of the cathode flow field. With increasing the opening ratio, open circuit voltage (OCV) was lowered from 0.95V to 0.9V due to the high contact resistance. On the other hand, at high current range, with increasing the cathode opening ratio, the cell performance increased due to the improved mass transport of air from the atmosphere to the cathode catalyst layer. However, the opening ratio of 72%, even though it did not show fast voltage drop at high current densities by mass transport limitation, exhibited a lower performance due to higher contact resistance. The open rates of 61% and 63% of cathode flow field show the best performance.

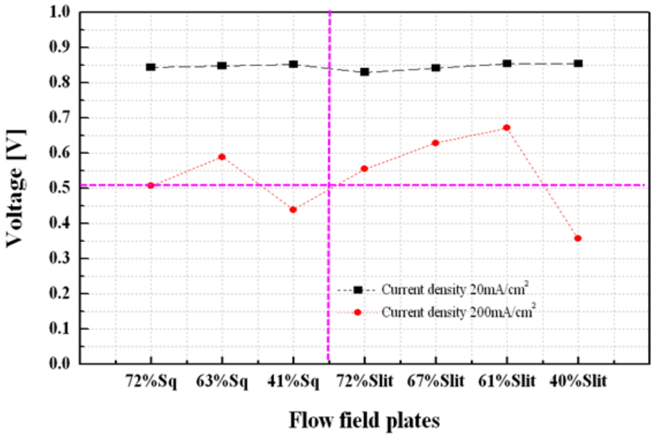
In the cathode open type, the performance of slit open type is better than the square one, because the generated water was easily flow down and removed on the surface of the GDL. So, the air supply to the cathode is easy and the power density is increased. On the other hand, in the case of the square opening, the horizontal rib makes it hard to remove the generated water and decreases the effective diffusion area, which blocks an air supply to the cathode. This mechanism of droplet accumulation is shown in Fig. 8. Therefore, the maximum power density of 124mW/㎠ at 250mA/㎠ was obtained for the cathode opening ratio of 61% having slit opening.

TABLE I
OPERATING CONDITIONS FOR PERFORMANCE TEST OF AIR-BREATHING FUEL CELL

Operating conditions	Values
Flow rate(cc/min) (Air/H2)	Free convection/30
Temperature (℃) (Cathode / Anode)	23℃-25℃
Humidification (Cathode / Anode)	55-60% / Dry gas
Pressure (Cathode / Anode)	Atmosphere



(a)



(b)

Fig. 7 Effects of cathode opening ratio on the air-breathing cell performance : (a) polarization curves; and (b) cell voltage at 20 mA/㎠ and 200mA/㎠.

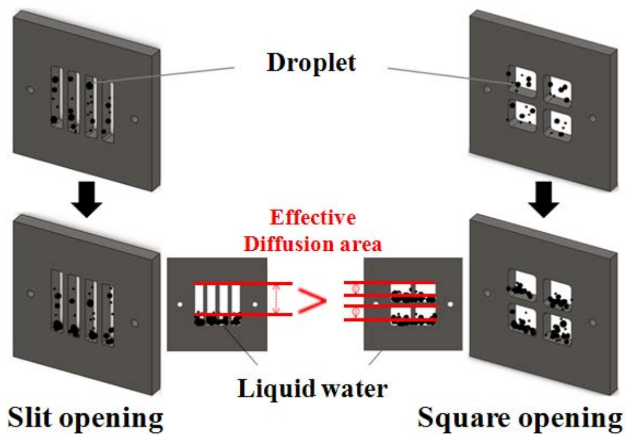


Fig. 8 Mechanism of droplet accumulation on opening type

To validate the feasibility of the synthetic jet air blower, the fabricated synthetic jet air blower was installed on the cathode side (Fig 9). Fig. 10 shows the comparison of cells performance of three different types to supply the air for cathode slit opening ratio of 61%. In the fuel cells installed the synthetic jet air blower and fan, the performance was 40% higher than that of the air- breathing PEM fuel cell. Because the air can be sufficiently supplied to the cathode and generate water can be easily removed from the GDL. Also, the durability was improved 20% compared with that of air-breathing PEM fuel cells due to the water management.

One of the important things in small fuel cells used auxiliary devices is its power consumption. The synthetic jet air blower only consumes 0.3W (3V, 80mA, 550Hz) or less, when the SP4423 EL lamp driver was used as a controller for PZT vibration, while the fan consumes about 1W at 12V, 0.1A. Therefore, the air breathing fuel cell used the synthetic jet air blower shows that the overall system efficiency of fuel cell is better, even though cells performance with fan is higher.

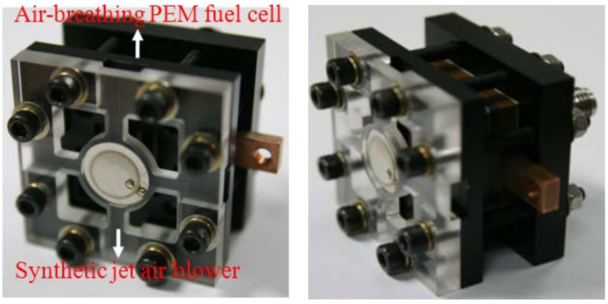
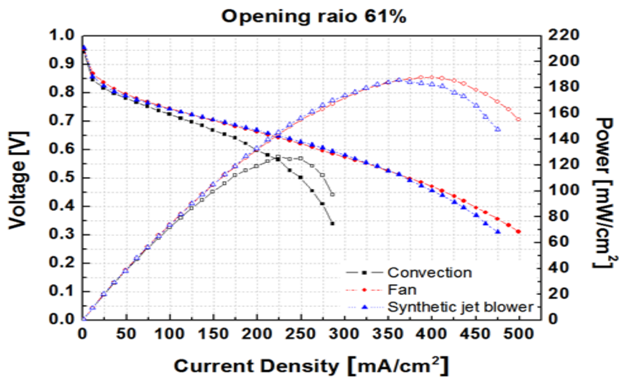
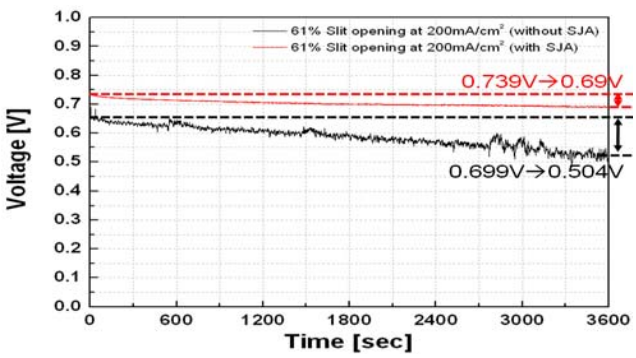


Fig. 9 Photograph of the fabricated air-breathing PEM fuel cell with synthetic jet air blower.



(a)



(b)

Fig. 10 Effect of air-breathing fuel cell on the three different types to supply the air : (a) polarization curves ; and (b) durability tests

IV. Conclusion

The synthetic jet air blower for air supply of air breathing fuel cells was fabricated. We used sine wave as its input to reduce the PZT noise level and maximum flow rate of synthetic jet air blower measured 495cc/min at 650Hz. However, even though the sine wave was used, the noise levels increase dramatically when the operating frequency of the synthetic jet air blower is increased over 600Hz. Therefore, we used the frequency range of PZT that was operated below 600Hz.

The air breathing fuel cell was fabricated. For air breathing designs, the cathode flow field was machined to have various opening ratios (40~72%) with slit and window opening. With increasing the opening ratio, open circuit voltage (OCV) was lowered from 0.95V to 0.9V due to the high contact resistance. On the other hand, at high current range, with increasing the cathode opening ratio, the cell performance increased due to the improved mass transport. The maximum power density of 124mW/㎠ at 250mA/㎠ was obtained for the cathode opening ratio of 61%. In the cathode configuration, the slit configuration shows superior performance because the generated water drained easily.

Also, the performance test of the air breathing fuel cell installed the synthetic jet air blower results in the maximum output of 188mW/㎠ at 0.5V, which was improved more than 40%. The synthetic jet air blower consumes less than 0.3W for its operation.

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