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Performance Evaluation of Micro PEM Fuel Cell through the Numerical Analysis and Fabrication of Micro-Channel

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Abstract

A fuel cell is most interesting new power source because it solves not only the environment problem but also natural resource exhaustion problem. In this paper, hydrogen gas flow in micro-channel was numerically analyzed about various channel shapes to improve the efficiency of micro fuel cell. Flow characteristics with the same boundary condition were simulated in six different shapes of micro-channels which have been already developed and newly designed as well. The result of analysis shows that characteristics of flow such as velocity, uniformity, and flow rate, depend highly upon the channel shape itself. That means it is expectable to increase the efficiency of micro fuel cell through optimal configuration of channel shape for hydrogen gas flow. Finally, actual micro flow channels were fabricated using SU-8 and the performance of PEM fuel cell was also carried out with these micro prototypes.

Keywords: PEM fuel cell(proton exchange membrane), modeling, efficiency, catalyst

1 Introduction

A fuel cell is most interesting new power source because it solves not only the environment problem but also natural resource exhaustion problem. Specially, various researches about micro system are advanced to apply its technology to the fabrication of micro fuel cell with the increasing demands for new portable devices [1]. Due to such advantages as high energy conversion efficiency, longer operation times, as well as rapid recharge turn around cycles, micro fuel cell has received much attention as a leading candidate for portable power of the future than widely used rechargeable Li-ion batteries. However, many problems still exist in the development and commercialization because of high cost and activities of the catalyst packages.

Among various fuel cell types, the DMFC(direct methanol fuel cell) has been mainly studied for micro power source. DMFC has advantages of simple construction, ambient temperature operation and easy storage of liquid fuel. However, it has serious disadvantages such as methanol crossover, which drives to decrease its efficiency.

As new challenges in these days, the integration of high energy density fuel cell in miniature device using silicon based MEMS technologies has been processed. Specially, development of micro fuel reformer drives to fabricate the micro fuel cell with PEMFC (Polymer Electrolyte Membrane Fuel Cell).

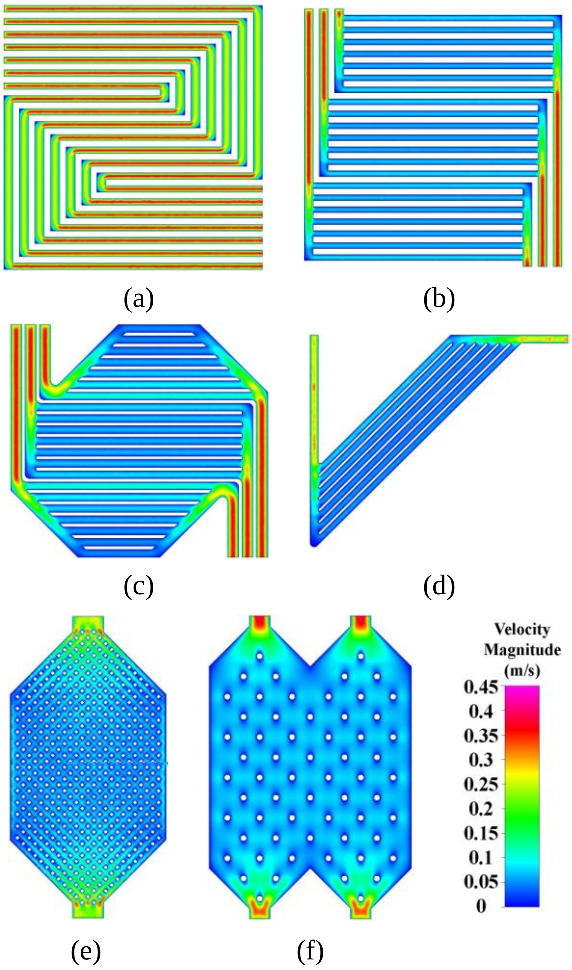

Figure1: Numerical analysis of hydrogen gas flow velocity each model of miniature fuel cell channels.

In general, the size of PEMFC becomes larger than DMFC because it has a fuel reformer in the fuel cell system, but it has an advantage of higher current density than DMFC, what is more, methanol crossover does not occur. Therefore our final goal is to accomplish the micro DMFC device through silicon based MEMS technology.

It is known that the efficiency of a PEMFC is affected by many parameters such as operating temperature, pressure and humidification of the gas. And the flow geometry of channel is very important factor to control efficiency of fuel cells [2-5]. The structure of micro channel shape is one of the key elements which control the flow rate, pressure and velocity of fuel. In this work, hydrogen gas flow in micro-channel was numerically analyzed about various channel shapes to improve the efficiency of micro fuel cell. Flow characteristics with the same boundary condition were simulated six different shapes of micro-channel which have been already developed and newly designed as well. The result of analysis shows that characteristics of flow such as velocity, uniformity, and flow rate, depend highly upon the channel shape itself. That means it is expectable to increase the efficiency of micro fuel cell through optimal configuration of channel shape for hydrogen gas flow. Finally, actual micro flow channels were fabricated using SU-8 and the performance of PEM fuel cell was also carried out with these micro prototypes.

2 Modeling of Channel

In this study, numerical analysis is performed about 4-types of conventional channels already developed and 2-types of newly designed channel shapes, as shown in Fig. 1. Total reaction area of each types of channel is designed up to almost 4 cm^2 (or less in case of type-3 and 4). The cross sectional area of one channel is 0.5 mm × 0.5 mm at rectangular shape in type-1 to 4, and each pole structure's dimension has 0.3 mm in diameter and 0.5 mm in height of type-5 and 6, respectively. Figure 1 shows the numerical analysis results of various channel shapes. Figure 1(a) ~ (d) are the conventional arrays of pipe-like channel shape which are already exist, and fig. 1(e) ~ (f) are newly designed channel shapes to increase the efficiency of fuel cells. The newly designed models consist with the same dimension of pole structure arrays inside of box channel to distribute uniform gas flow.

It was assumed that fluid is pure hydrogen gas and is incompressible. Velocity of fluid at inlet was kept of 0.2 m/s with the laminar flow in our consideration. Boundary condition of outlet is free. Temperature was also kept of 300 K, and the effect of gravity ignored during this simulation.

3 Numerical Results

Figure 1 and 2 shows the distribution of velocity magnitude and the fitted graph of its velocity magnitude of conventional channel types 1 ~ 4 in (a) ~ (d) and newly designed channel types 5 ~ 6 in (e) ~ (f), respectively. The numerical results show that the flow characteristics are highly dependent upon the structure of channel shape.

Figure 1 (a) shows the type-1 of model shape has uniform flow in all area of channel arrays. The result of velocity characteristics in each channel of type-1 is comparatively the same. However, (b) ~ (d) indicate that the velocity of inside from each channel, which has the shape of divided with several sections, is different according to the relative distance from root of inlet (type-2 to 4). Even the same kind concept of channel structures such as type- 2 to 4, the uniformity of flow speed in each channel inside is relatively good for the type-2, as shown in fig. 1(b). It means the flow rate becomes different in the branched each section of channel. If flow-rate is not uniform in reactant channel like the branch-off sections, the efficiency of micro fuel cell decreases at last.

Figure 1(e) ~ (f) is the results from the novel channel shapes. In case of type-5, the effect of boundary layer is increased due to the structure of inlet, outlet and the numbers of poles in channel, as shown in fig. 1(e). It also will decrease the performance efficiency of fuel cells. The model of type-6 is finally optimized for this boundary layer. Type-6 is designed to decrease the effect of boundary layer different to type-5. Figure 1(f) and fig. 2 (b) shows that channel shape of type-6 has the most uniform flow characteristic in all area of channel. When it has the uniform gas flow in all area of channel, the efficiency of micro fuel cells is expected to increase such as cases of type-1 and type-6.

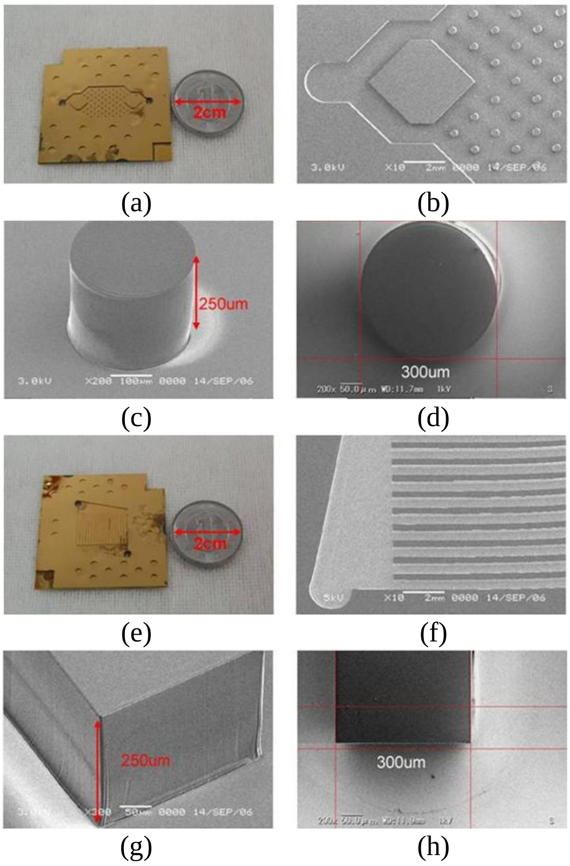

Figure2: Fabricated anode((a)~(d)) and cathode((e)~(h)) channel with Si/SU-8 for micro PEM fuel cell

4 Experimental Set-up and Procedure

Micro channels are fabricated based on numerical analysis results. It is difficult to fabricate complicated channel shapes with mechanical process and has limit of minimum size [7, 8]. Fuel cell channels are fabricated on silicon wafer using SU-8 (epoxy type negative photo-resist) which is easy to make complicated channel shape on micro scale. Figure 3(a) and (e) show manufactured PEMFC channels of anode and cathode. Especially, anode and channel is embodied in the same as type-6 which shows the most uniform characteristic for hydrogen gas flow. The whole size of channel is 3cm × 3cm, and the active area is 1cm × 1cm. Figure 3(b) ~ (h) is SEM image of micro channels. Anode is formed of structure whose radius is 300μm, and cathode is formed of 300μm channel whose width is 500μm as shown fig. 3(d) and (h). Micro channels were manufactured with SU-8 100 on the silicon board whose thickness is 280μm, and height of channel is 250μm as shown fig. 3(c) and (g). Anode and cathode channels are plated with Cr (60nm) and Au (130nm) to use for electrode by sputtering process. Fuel cell test was performed using fabricated Micro Channel. Figure 3 shows the photograph of the micro PEM fuel cell prototype which used 5L standard MEA based on Nafion 112. Silicone was used in sealing for prevent gas (hydrogen and oxygen) leaking.

Gases (hydrogen and oxygen) were got through electrolysis of H_2O using 500mW PEM electrolyser and supplied hydrogen and oxygen directly. Outlet of gas is opened for removing the pressure effect of gas on the performance of fuel cell. Temperature of hydrogen and oxygen are measured at inlet of channels with K-type thermocouple and maintained 25 ℃.

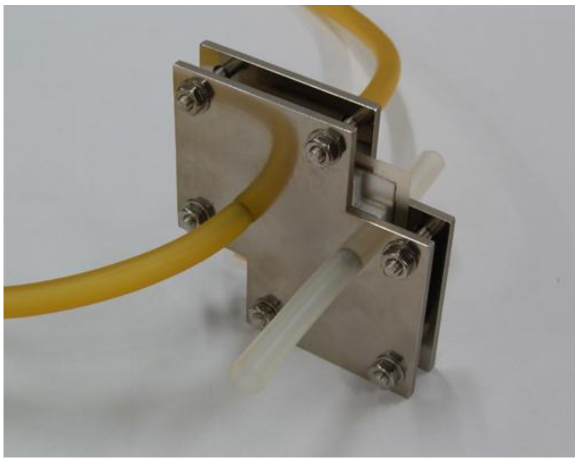

Figure 3: Assembly of micro PEM fuel cell prototype.

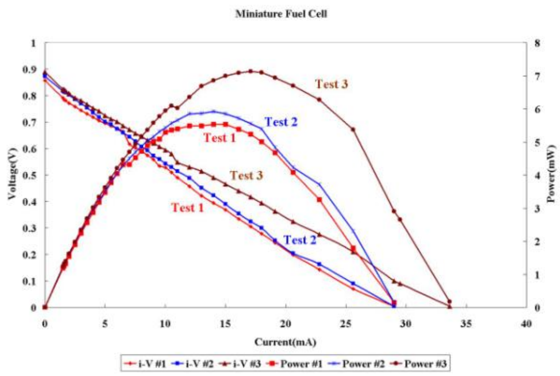

Figure 4: Current-voltage curve and current-power curve of fuel cell performance experiments of micro fuel cell prototype: y-direction of left side is Voltage (V), y-direction of right side is Power (mW).

Performance of fuel cell was measured at 5 minutes later from supply hydrogen and oxygen and performed three times which has interval time of 30 minutes.

5 Experimental Results

Figure 4 shows the experimental result of prototype PEM fuel cell. In fig. 4, x-axis is current (mA), y-axis of left side is voltage (V) and y-axis of right side is power (mW). Figure 4 shows that maximum voltage is 0.857~0.89 V, maximum current is 29~33.6 mA and maximum power is 5.53~7.13 mW. Performance of PEM fuel cell is increased from test 1 to test 3 as shown fig. 4. Especially, the third test shows clearly improved performance of PEM fuel cell. This improvement of performance can be due to humidification of MEA caused by H2O as the product of fuel cell experiment. These experimental results are similar or improved comparing with another studies of PEM fuel cell [7, 8].

On the one hand, after experiment, we found some problem with using SU-8 channel. Adhesion of gold electrode to SU-8 channel has a problem due to the negative influences of thermal and humidified load during fuel cell operation. Figure 5 shows SEM images of MEAs before and after experiment. After experiment, MEA, which has porous media, was clung to the sputtered gold electrode of SU-8 channel.

6 Conclusion

Numerical analysis is performed about 4-types of conventional channels already developed and 2-types of newly designed channel shapes. And Micro channels are fabricated based on numerical analysis results. We performed experiment

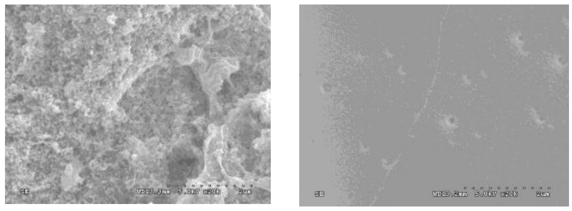

Figure 5: SEM image of MEA (left: before experiment, right: after experiment)

using fabricated micro fuel cell. This study was concluded as in the following:

1. The inside flow characteristic is changing by configuration of micro channel shape. Through the numerical analyses, type-6 shows the most uniform flow characteristic than another conventional channels. The uniform gas flow in all area of channel, the efficiency of micro fuel cells is expected to increase

2. Fuel cell performance was decreased by Adhesion of gold electrode to SU-8 channel. Therefore we need experiment to investigate the optimum materials of electrode and channel of micro PEM fuel cell.

3. Experimental result shows that performance of PEM fuel cell is improved with number of test. Therefore, the improvement of performance can be due to the humidification of MEA caused by H_2O as product from fuel cell.

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