FULLY INTEGRATED SYSTEM OF MICRO PEM FUEL CELL WITH NABH$_4$ HYDROGEN GENERATOR

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Abstract: A complete system of micro fuel cell with $NaBH_4$ hydrogen generator was developed for micro power sources in this paper. The micro fuel cell system consists of two main components; one is a micro PEM fuel cell and the other is a microreactor for hydrogen generation. The micro PEM fuel cell was fabricated with glass wafers as bipolar plates due to its light weight and corrosion resistant. The microreactor was fabricated to generate hydrogen using a catalytic hydrolysis from $NaBH_4$ solution. All of BOP such as a $NaBH_4$ fuel cartridge, a micro pump, and an auxiliary battery were integrated for a complete micro power device.

Keywords: Micro fuel cell, Microreactor, $NaBH_4$, Hydrogen, Micro power sources

INTRODUCTION

Micro fuel cell has drawn attention as a primary candidate for a micro power source because the energy density is higher than that of batteries [1-2]. At the beginning of research, a direct methanol fuel cell (DMFC) has been mainly studied due to its simple structure and easy refueling of methanol. However, the development of DMFC has reached deadlock due to a fuel crossover phenomenon that gradually degrades the cell performance. Recently a proton exchange membrane fuel cell (PEMFC) has been studied as an alternative micro fuel cell because it is not suffered from the fuel crossover and has higher power density than that of DMFC. There are considerable research works which are focused on the realization of micro fuel cells in the literatures. However, the high density hydrogen storage is required to meet the overall energy density for micro power sources.

Until now micro reformers have been mostly developed to provide hydrogen to micro fuel cells [3-5]. However, the development of micro reformer is still problematic at the several technical points. First the reformer is very complex device including a vaporizer, heater, reactor, combustor, heat-exchanger, and CO remover, which makes it difficult the reduction of weight and volume of total system [4]. The methanol used as a fuel for micro reformer generates inherently carbon monoxide as a byproduct. Though it is extremely small, the carbon monoxide should be reduced below 100 ppm to prevent the deactivation of fuel cell catalysts. Palladium micro membrane and preferential oxidation (PROX) may be perfectly able to remove the carbon monoxide but making the micro reformer more complex and bulky. In addition the reformer needs a thermal isolation to be integrated with a micro fuel cell due to its high operating temperature. A vacuum packaging technology can be used but it is difficult and expensive in micro scale. From above problems of micro reformer, it is seen that a new micro device for hydrogen generation is needed, which has to be simple and operated at low temperature.

Recently, chemical hydrides have attracted a great attention for a new hydrogen generation method. Of various hydrides, sodium borohydride ($NaBH_4$) is stored in liquid phase, and is a stable and non-flammable alkaline solution. In addition, it has relatively high hydrogen content, and is a renewable and environmentally friendly fuel. It is easy to control the hydrogen generation rate and pure hydrogen can be obtained by hydrolysis reaction given below [6].

$$NaBH_4 + 2H_2O \rightarrow NaBO_2 + 4H_2 \quad (1)$$

The hydrogen is only gas product in the reaction and therefore pure hydrogen can be obtained after separating the borate, which can be recycled into the sodium borohydride. No additional heat supply is required because the sodium borohydride hydrolysis is an exothermic reaction. The hydrolysis reaction can be started at room temperature.

The PEMFC can be a primary candidate for a micro power source if the hydrogen generation device is realized in micro scale. Many researchers have been developed a microreactor using MEMS (Micro-electromechanical Systems) technologies that is a useful tool to reduce a size of the device. However, there are only a few works about a microreactor for hydrogen generation from sodium borohydride in the literatures.

In the present study, we attempted to develop a fully integrated micro fuel cell system. The micro fuel cell system consists of two main components; one is a micro PEM fuel cell and the other is a $NaBH_4$ hydrogen generator. The micro PEM fuel cell has a light weight and corrosion resistant glass bipolar plates [7]. The $NaBH_4$ alkaline solution was used as a hydrogen source and a microreactor was fabricated to generate hydrogen using a catalytic hydrolysis reaction [8]. All of BOP such as a $NaBH_4$ fuel cartridge, a micro pump, and an auxiliary battery were integrated for a complete micro power device.

EXPERIMENTAL

Micro PEM Fuel Cell Design

A PEM fuel cell stack consists of two main components: the membrane electrode assemblies (MEA) and the bipolar plates. The bipolar plates hold nearly the whole volume and weight of the fuel cell stack. The bipolar plates are therefore a key component for power density and cost reduction.

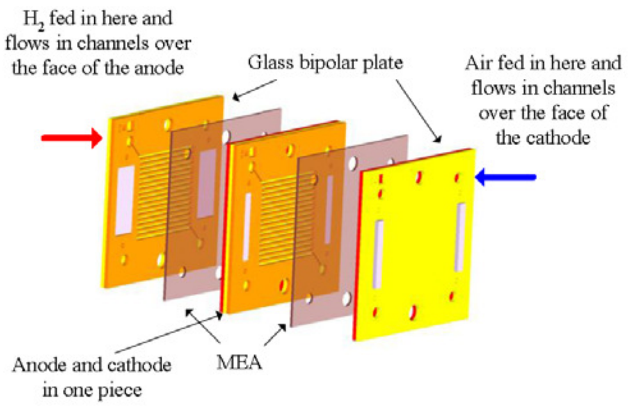

Fig. 1: Schematic of micro PEM fuel cell.

In this paper, we attempted to develop light weight and corrosion resistant glass bipolar plates for the micro PEM fuel cell. Figure 1 shows the schematic of the micro PEM fuel cell stack. The bipolar plate, which consists of three layers and aluminum electrodes, is coated with silver. Silver layer collects the current and Al electrode conduct the current from the anode of one cell to the cathode of the next. Three layers distribute the fuel and the air to the anode channel and the cathode channel separately. A photosensitive glass was chosen as a substrate due to its low fabrication cost, easy manufacture, and chemical resistance [9]. The dimensions of the bipolar plates were 2 mm × 2 mm × 1.5 mm with active area of 1 mm × 1 mm. The width and depth of the micro channel were 300 µm and 500 µm, respectively. The layer of silver 10 µm was sputter deposited onto the surface of the bipolar plate. Figure 2 shows the fabricated bipolar plate [7].

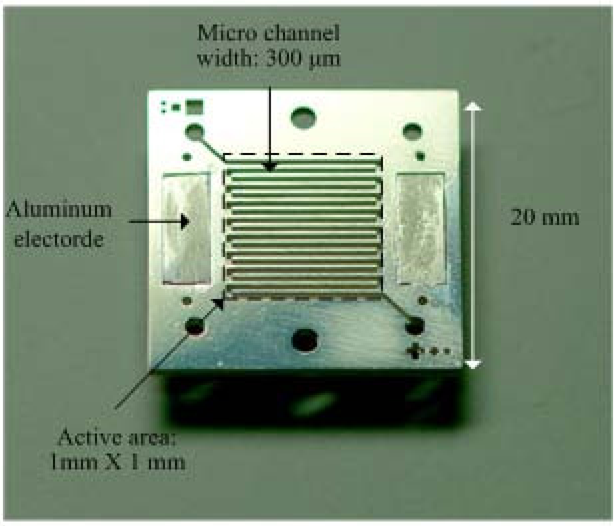

Fig. 2: Fabricated micro PEM fuel cell.

Micro $NaBH_4$ Hydrogen Generator Design

The cobalt-bride (Co-B) was selected as a catalyst for the sodium borohydride hydrolysis reaction in the present study. The cobalt-bride catalyst can be simply synthesized by a chemical reduction method [8]. The catalysts have been mainly used in the form of very fine powders. The power state catalysts are not suitable to be incorporated with a microreactor because they cause a high pressure drop and microchannels clogged. So it is preferred to coat the active catalysts on a support for practical operation of the microreactor. A nickel form was used as a catalyst support in the present study. The used nickel form had the porosity of 90% and the average pore diameter of 200 µm. Electroless plating method was used to coat the cobalt-boride catalyst on the surface of the nickel form support, resulting in Co-B/Ni-form catalyst.

The glass wafer was selected as the substrate of microreactor because it has such superior properties as transparency, hardness and resistance to strong acid. With photosensitive glass wafer (FORTURN®) in particular, etching with high aspect ratio was possible with tight tolerance [5]. The microreactor was made of three photosensitive glass layers; one for a bottom layer, one for a reaction chamber and the remaining for a cover with inlet and outlet ports. The fabrication process for an individual glass wafer included as follows; (1) exposure to the ultraviolet (UV) light with a wavelength of 310 nm under a mask at the intensity of 2 J/cm^2, (2) heat treatment at 585 °C for 1 hour to crystallize the part of the glass that was exposed to the ultraviolet light, and (3) etching the exposed part in the 10% hydrofluoric (HF) solution to result in the desired shape [5]. With above process, a cover and a reactor layer were fabricated, respectively. The reactor layer was bonded on the bottom layer to shape the reaction chamber.

Teflon tubes were connected on the inlet and outlet ports of the microreactor with epoxy glue. The microreactor was fixed in an aluminum holder to facilitate the experiment on the performance measurements. Figure 3 shows the fabricated microreactor with the aluminum holder and the Teflon tube connectors [8].

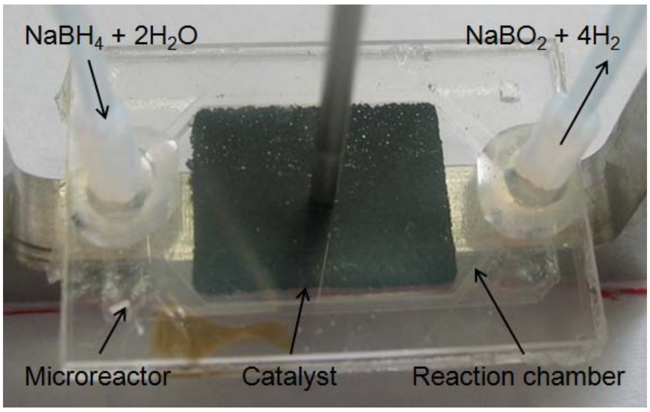

Fig. 3: Micro $NaBH_4$ hydrogen generator.

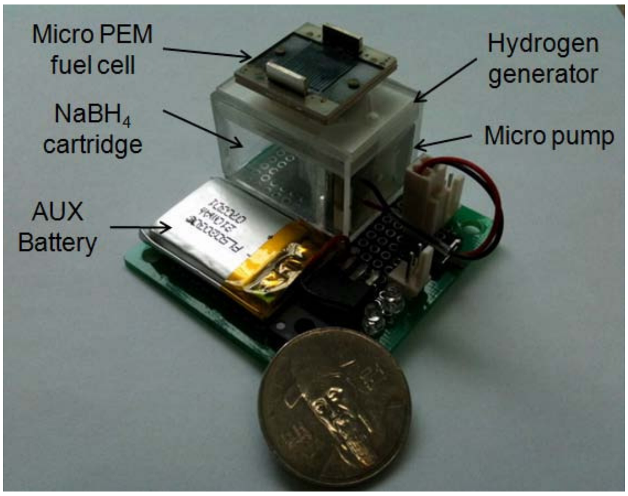

Fig. 4: Fully integrated micro PEM fuel cell system.

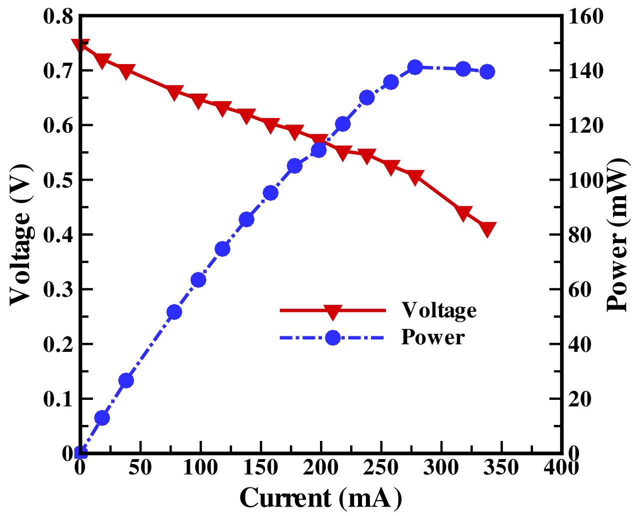

Fig. 5: Polarization and power density curves of micro fuel cell.

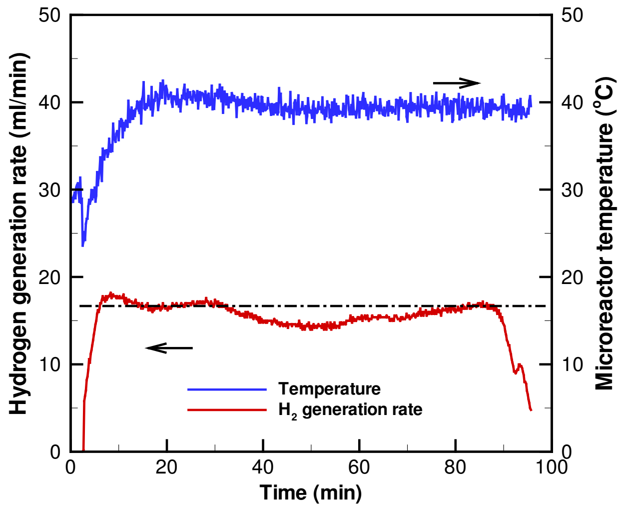

Fig. 6: The hydrogen generation rate and the microreactor temperature as a function of operating time.

Micro Fuel Cell System Integration

Figure 4 is a picture of a fully integrated micro fuel cell system. The micro system included a micro fuel cell, a hydrogen generator and every BOP components such as a $NaBH_4$ fuel cartridge, a micro pump, and an auxiliary battery.

The performance of the micro fuel cell system was measured at various operating conditions. The experimental setup consisted of two parts; one is for the measurement of the flow rate of hydrogen generated by the microreactor and the other is for the measurement of the power output of electricity generated by the micro fuel cell. A syringe pump was used to provide the sodium borohydride solution to the microreactor. The hydrolysis reaction generated hydrogen gas with sodium metaborate ($NaBO_2$) as a byproduct of the hydrolysis reaction. The sodium metaborate was filtered through the separator and the pure hydrogen only entered a flow meter to measure the flow rate. A temperature sensor was placed on the middle of microreactor to measure the reactor temperature during the reaction. The hydrogen flow from the microreactor was supplied to the micro fuel cell and the power output was measured with an electric load. The micro fuel cell was tested with a pure hydrogen gas to compare to that with hydrogen generated by the microreactor.

RESULTS AND DISCUSSION

Performance of Micro Fuel Cell

Single cell prototype micro PEM fuel cell was tested. Pure hydrogen and air were used as reactant gases on the anode and cathode sides. Figure 5 shows the polarization and power density curves. The open circuit voltage was 0.79 V which is lower than that of typical fuel cells. This loss resulted from the waste of fuel passing through the electrolyte. This is a major problem to be solved. The maximum power density was 140 mW/cm^2. The present study established the fabrication method of the light weight, corrosion resistant glass bipolar plate and demonstrated the feasibility of the glass bipolar plate [7].

Performance of Micro Hydrogen Generator

The hydrogen generation rate and the microreactor temperature as a function of operating time are presented in Fig. 6. The hydrogen generation rate was 15.6 ml/min; this amount of hydrogen can give 1.3 W electric power on a typical PEM fuel cell. The total amount of generated hydrogen was 1,430 ml for 85 min. The average of conversion efficiency was 93% during the reaction [8].

Figure 7 shows the continuous power generation from the micro fuel cell with the microreactor for hydrogen generation. This test consists of two parts; one is for the increasing electric-load and the other is for the constant electric-load. It can be seen that the power output of micro fuel cell reasonably follows up the given electric load conditions. The fluctuation of power output was caused by the unstable hydrogen generation rate and the water formation in the cathode channel of micro fuel cell.

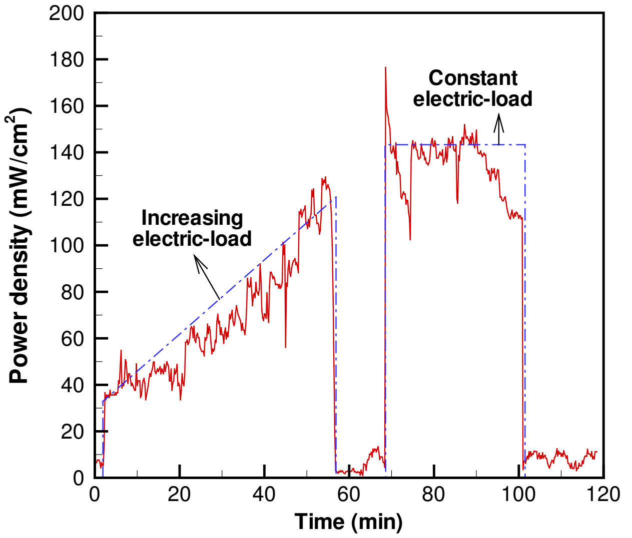

Fig. 7: Continuous power generation from micro fuel cell system.

CONCLUSION

A fully integrated micro fuel cell system was developed in the present study. The micro fuel cell system consists of two main components; one is a micro PEM fuel cell and the other is a $NaBH_4$ hydrogen generator. All of BOP such as a $NaBH_4$ fuel cartridge, a micro pump, and an auxiliary battery were integrated for a complete micro power device. The volume and weight could be reduced by MEMS fabrication, increasing the energy density of the fuel cell system.

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