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Micro methanol reformer combined with a catalytic combustor for a PEM fuel cell

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ABSTRACT

This paper presents the development of a micro methanol reformer for portable fuel cell applications. The micro reformer consists of a methanol steam reforming reactor, catalytic combustor, and heat exchanger in-between. Cu/ZnO was selected as a catalyst for a methanol steam reforming and Pt for a catalytic combustion of hydrogen with air. Porous ceramic material was used as a catalyst support due to the large surface area and thermal stability. Photosensitive glass wafer was selected as a structural material because of its thermal and chemical stabilities. Performance of the reformer was measured at various test conditions and the results showed a good agreement with the three-dimensional analysis of the reacting flow. Considering the energy balance of the reformer/combustor model, the off-gas of fuel cell can be recycled as a feed of the combustor. The catalytic combustor generated the sufficient amount of heat to sustain the steam reforming of methanol. The conversion of methanol was 95.7% and the hydrogen flow of 53.7 ml/min was produced including 1.24% carbon monoxide. The generated hydrogen was the sufficient amount to operate 4.5 W polymer electrolyte membrane fuel cells.

1. Introduction

With the growing attention of micro power sources for micro aerial vehicles, micro robots and portable electronics, a micro fuel cell has drawn attention as a primary candidate for an alternative power source because the energy density is higher than that of the existing batteries [1]. Among various types of the fuel cell, polymer electrolyte membrane fuel cell (PEMFC) and direct methanol fuel cell (DMFC) are suitable to portable applications because of its simplicity and low operating temperature [2]. Early DMFC is more attractive than PEMFC due to its simple structure and easy refueling but the fuel crossover that gradually degrades the performance is not still overcome. Though PEMFC is not suffered from the fuel crossover, the storage of hydrogen is a technical bottleneck in the successful development of PEMFC systems. There are several technologies for the hydrogen storage such as the compressed hydrogen, liquefied hydrogen, reforming of hydrocarbons, metal hydrides, chemical hydrides, and carbon nanotubes. Micro methanol reformer is a device to generate hydrogen from the reforming of methanol [3]. PEMFC can be a primary candidate for a micro power source if the reformer is realized in micro scale [20]. Many researchers have been developed a micro methanol reformer using MEMS technologies that is a useful tool to reduce a size of the reformer [3–5].

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There are a number of reforming techniques available including steam reforming [6], partial oxidation [7] and auto-thermal reforming [8]. Steam reforming was selected for a micro methanol reformer because of its high attainable hydrogen concentration in the reformate gas and the low reforming temperature. The methanol steam reforming reaction consists of two overall reactions; one is a primary process in the steam reforming of methanol and the other is the methanol decomposition to produce carbon monoxide (CO) [9].

Methanol steam reforming reaction:

$$CH_3OH + H_2O \rightarrow 3H_2 + CO_2 \quad (1)$$

Methanol decomposition:

$$CH_3OH \rightarrow 2H_2 + CO \quad (2)$$

The CO emission is relatively small but the amount of CO greater than 10 ppm can deactivate anode catalysts of the fuel cell. The CO in the reformate gas can be eliminated by preferential oxidation (PROX) [10].

Fig. 1 shows the schematic of a fuel cell system that consists of a methanol steam reformer and a fuel cell. The reformer is classified into four components: fuel vaporizer/pre-heater, steam reformer, combustor/heat exchanger, and PROX reactor. First, methanol is fed with water and is heated by the vaporizer. The methanol is reformed by the reforming catalyst to generate hydrogen in the steam reformer. To supply heat to the steam reformer, part of hydrogen that is unutilized in fuel cell anode can be fed to the combustor that generates sufficient amount of heat to sustain the steam reforming of methanol. Typically, the reformate gas includes undesirable byproducts such as carbon monoxides, carbon dioxides, and methane. The fuel cell can be severely poisoned by extremely small amount of carbon monoxide. Therefore, carbon monoxide should be reduced to below 10 ppm by PROX as shown in Fig. 1 [15].

This paper presents the design, fabrication and performance evaluation of a micro methanol reformer. The complete methanol reformer is made of the steam reformer, the catalytic combustor, and the heat exchanger between the two reactors. Two catalysts loaded into a porous ceramic support were prepared; one is Cu/ZnO for steam reforming of methanol and the other is Pt for catalytic combustion of hydrogen. The performance of the micro methanol reformer combine with the catalytic combustor was measured at various test conditions and optimum operation condition was sought.

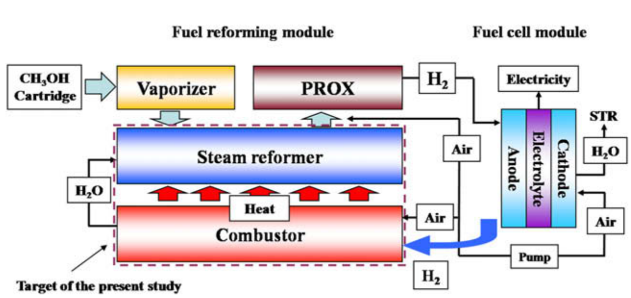

Fig. 1 – Schematic of a fuel cell system integrated with a methanol reformer.

2. Design and fabrication

2.1. Design of micro reformer

Fig. 2 depicts the construction of the micro methanol reformer combined with a catalytic combustor. The mixture of methanol and water enters the steam reformer at the top, and hydrogen and carbon dioxide as the reforming products leave the reactor. The mixture of hydrogen and air flows into the catalytic combustor at the bottom with a counter flow stream against the reforming stream. The heat generated from the catalytic combustion is transferred to the steam reformer through the heat exchanger layer that has micro-fins to increase the surface area and the suspended membrane to enhance the heat transfer. The porous catalyst supports are inserted in the cavity made on the glass wafer as in Fig. 2.

The micro methanol reformer structure was made of five glass wafers; two for top and bottom, one for steam reformer layer, one for catalytic combustor layer and the reminder for heat exchanger in-between. The glass wafer selected as the

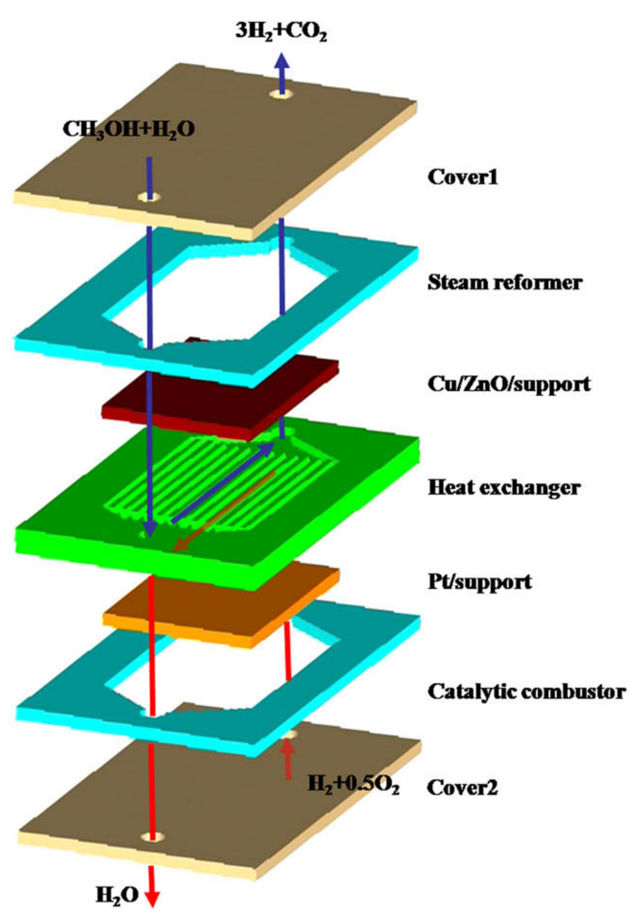

Fig. 2 – The construction of the micro methanol reformer combined with a catalytic combustor.