DESIGN AND FABRICATION OF FULLY ENCLOSED MICRO PEM FUEL CELL USING NOVEL GLASS BIPOLAR PLATES

Bosun Jang[1*], Jongkwang Lee[2], Sejin Kwon[1]
[1]Department of Aerospace Engineering, KAIST, Korea
[2]Samsung Electronics LCD R&D Center, Youngin, KOREA
*Presenting Author: bosun@kaist.ac.kr

Abstract: A fully enclosed micro PEM fuel cell using glass bipolar plates has been fabricated. Glass bipolar plates are advantageous over silicon bipolar plates in terms of high chemical resistance, light weight, low fabrication cost, and easy manufacture. The MEMS fabrication process of glass - namely, anisotropic etching, UV bonding, sputtering, etc. - has been fully established. As an improved version to the previous study, a fully enclosed design of a micro PEM fuel cell has been realized so as to be integrated into a micro portable device. Multi cell stacking and parameter study has to be performed.

Keywords: Micro PEM fuel cell, Glass bipolar plate, MEMS fabrication process

INTRODUCTION

Background

The development of contemporary microelectronic devices such as MAVs, mobile phones, lab tops, etc. has driven the development of power sources which have a capability of long operation. Moreover, as these kinds of devices become more and more sophisticated and integrated, the required power density for operation is as well becoming higher. In short, the development of a power source having high energy and power density for mobile applications is indeed in demand.

Micro fuel cells are a good candidate for such applications. The direct conversion of chemical energy into electrical energy is the basis of their high efficiency than conventional combustion engines such as Otto motors, diesel motors, or gas turbines which go through an additional energy conversion process [1]. Compared with secondary batteries such as Li-polymer or Ni-Cd batteries, micro fuel cells generally have a higher energy density per unit volume and weight. Also, their bi-product is only water which makes them a green energy source as well. Due to these advantages, micro fuel cell development is gaining more attention among alternative energy research groups.

The most common types of micro fuel cells include μ-SOFCs, μ-DMFC, μ-PEMFC, etc. depending on how hydrogen is supplied to the fuel cell system. SOFC (Solid oxide fuel cell) is advantageous in terms of high energy density compared with DMFC or PEMFC, but is limited by its high operation temperature thus limiting its use for mobile applications [2]. DMFC (Direct methanol fuel cell) is advantageous in terms of easy and convenient refueling, but there are still issues such as low current density that have to be resolved [3]. PEMFC (Polymer electrolyte membrane fuel cell) is advantageous in terms of silent operation, simple structure, etc. making it especially suitable for mobile applications. In this research, a fully enclosed μ-PEMFC using glass wafer was successfully fabricated.

Glass Bipolar Plates

One of the many factors influencing the performance of a micro fuel cell is the micro channels and the wafer in which they are made. These micro channels are usually fabricated using MEMS technology, so a material suitable for such a process should be used. Commonly, silicon is used as the base material for micro fuel cell bipolar plate fabrication since the MEMS process of it is well established. It is possible to yield high-aspect ratio micro structures using silicon. Yu et. al have fabricated and tested an improved silicon miniature fuel cell using MEMS technology [4]. Other groups as well are doing work on silicon-based micro fuel cells.

However, the high fabrication cost of silicon limits its potential for commercial use. Many groups are thus testing the possibilities for alternative materials for bipolar plates. Lee et. al have tested stainless steel metal bipolar plates to test their potential applications [5]. Wang et. al have tested titanium bipolar plates due to their low fabrication cost [6]. Most materials possess pros and cons when it comes to real application, so a trade-off valuation should be carried out.

Another commonly used material for bipolar plates is graphite. However, although the electrical conductivity of graphite is good, its brittle nature makes it not suitable for MEMS process making it impossible to make micro channel structures.

In this paper, a novel glass bipolar plate for a miniature PEM fuel cell has been proposed. Glass wafer has high chemical resistance, low fabrication cost, and is suitable for MEMS process. The glass used is photosensitive glass in which can be micro fabricated using a photo-lithography process. The characteristics of various materials used for bipolar plates for micro fuel cells are summarized in Table 1.

STRUCTURE

Figure 1 shows the components that consist of the micro PEM fuel cell. As typical fuel cells, the fabricated micro fuel cell consists of an MEA, a channel layer, a sealing layer which prevents reactant gas leak, a supporting layer (middle layer), and a conductive electrode. Once each layer is fabricated, the layers are bonded together through thermal bonding.

Table 1: Characteristics of various materials for bipolar plates

Material	**Characteristics**
Silicon	- Well established MEMS process - High cost
Composites	- High mechanical stress - Non-conductive
Graphite	- Good conductivity - Low cost - Brittle
Glass	- High chemical resistivity - Low fabrication cost - Easy manufacture

Then, the surfaces of the channel layers are made conductive through Ag sputtering to make a path for electron flow. Finally, Teflon tubes are inserted in the circular holes in the middle layer to provide a path for gas flow. Oxygen and hydrogen are fed into both sides of the micro fuel cell. The electrons then flow through the surface silver layer and to the aluminum electrode.

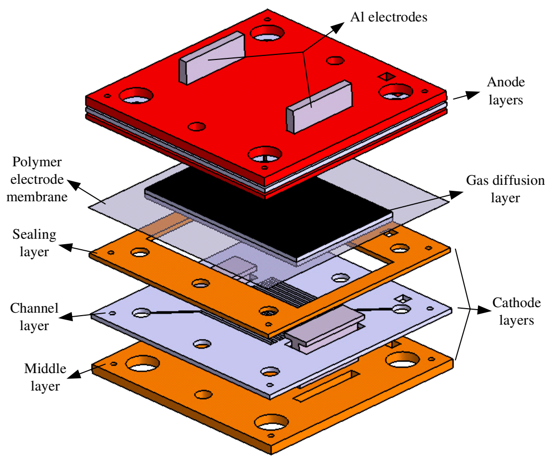

Fig. 1: Schematic of components consisting of the glass bipolar plates and the micro PEM fuel cell

EXPERIMENTAL

Fabrication

The MEMS fabrication process of glass bipolar plates is summarized below in figure 2.

First, a chromium absorber pattern is made on a quartz wafer to selectively permit UV light of wavelength 310 nm (figure 2(a)). The energy lit onto the glass by the UV light is 2 J/cm^2. Then, silver atoms aggregate around the illuminated section through a photochemical process. Afterwards, a heat treatment process is done using a programmable furnace (figure 2(b)). The glass is heated up to a temperature of 500 °C at a ramp rate of 3 °C /min. Subsequently, the glass is heated up to 585 °C at a ramp rate of 1 °C /min and maintained at a constant temperature of 585 °C for 1 hour. Then, the glass is cooled at a cooling rate of 1 °C /min. After the UV exposure and heat treatment processes, the property of the areas where UV light was lit has been changed.

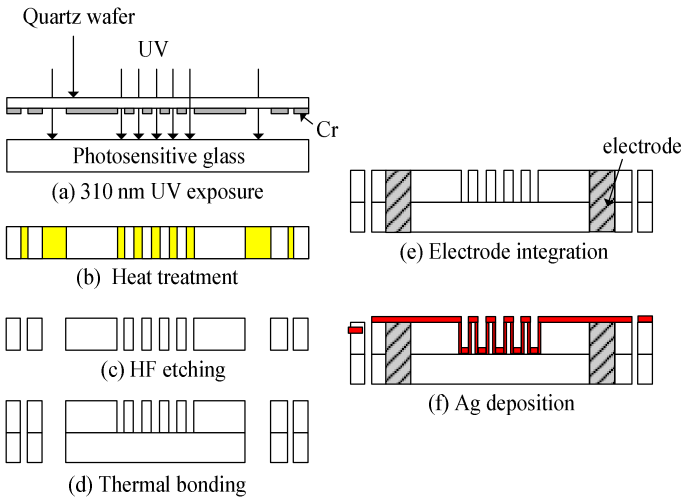

Fig. 2: MEMS fabrication process of micro PEMFC using glass wafer

Photosensitive glass crystallized around the silver atoms during the heat treatment process. This area formed a glass-ceramic region which was 10 times weaker on HF attack. Thus the next step was to simply etch the glass-ceramic region using 10 % dilute HF solution (figure 2(c)). After etching, since the surfaces of the glass wafer became rough after etching, each fabricated glass wafer was polished and cleaned in a piranha solution (H_2SO_4:H_2O_2 = 3:1) for 10 minutes. The corresponding layers where then carefully aligned together and pressed at 1kPa at a temperature of 500°C for 12 hours (figure 2(d). At this high temperature, the surface atoms on the glass wafer diffused into the other wafer forming physical bonds with each other. Then, the Al electrode was inserted and glued using UV curable glue in the bonded glass wafer (figure 2(e). As a final step, since glass is a non-conductive material, a metal layer was sputtered on the surface of the channels to enhance electrical conductivity (figure 2(f). As a seed layer, a chromium layer of thickness 2000 Å was deposited. Afterwards, a silver layer of thickness 1 µm was deposited on both anode and cathode sides of the micro fuel cell.

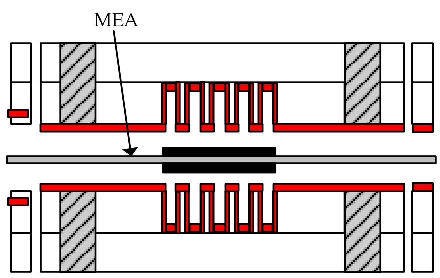

Fig. 3: Integration of bipolar plates and MEA

Integration

The fabricated anode and cathode wafers were carefully aligned with the MEA and glued together using UV curable glue (figure 3). To provide a path of gas flow into the micro fuel cell, two Teflon tubes were prepared and inserted into the glass wafer using UV glue as well (figure 4). It is important to ensure a secure seal between the tube and glass wafer since gas leak might result in performance deterioration.

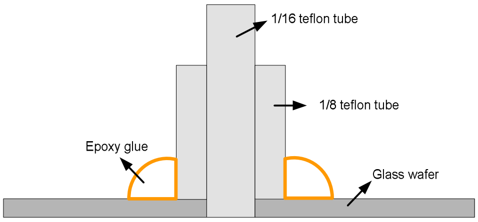

Fig. 4: Cross sectional view of Teflon tube insertion

The fabricated micro PEM fuel cell is shown in figure 5 below. Air and hydrogen are fed from both sides of the fuel cell.

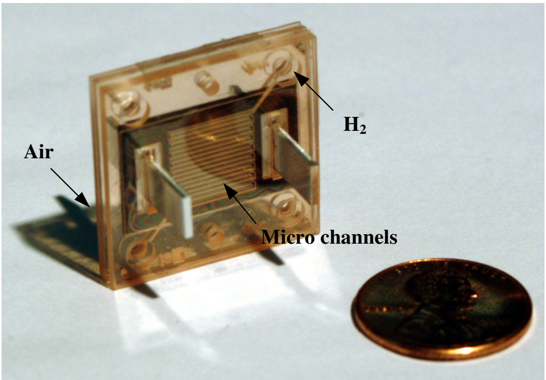

Fig. 5: Fully integrated micro PEM fuel cell using glass bipolar plates

Etch rates of glass wafer

One of the fabrication cautions took in this study was to make precise high-aspect ratio micro channels on the glass wafer. Once the channel shapes are imprinted on the glass by UV light, the glass-ceramic regions are etched using dilute HF solution. It is known by experience that the etch rate of the glass-ceramic region is 10 μm/s in 10% HF solution and the etch rate of the other regions is 1 μm/s [7]. So after the channels were etched according to this time, the width of micro channels were investigated on each step of fabrication – the chrome mask stage, heat treatment stage, and the etching stage. Target channel widths of 200, 250, and 300 μm were selected and the variation of the width according to each fabrication step was taken into account. Figure 6 shows the successive variation of the channel widths according to each fabrication step.

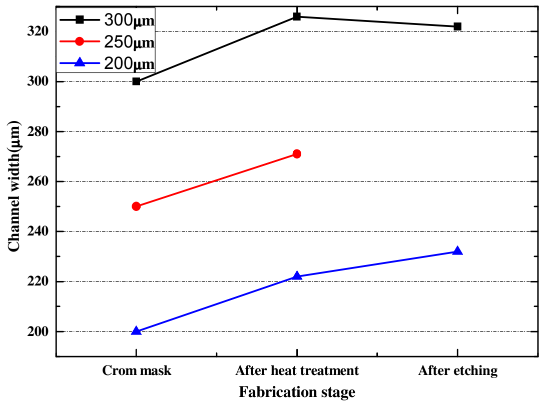

Fig. 6: Channel width variation according to each fabrication step

It turned out that during the crystallization process (heat treatment process), the width of the channels increased to about 10%. During the etching process on the other hand, the width hadn't change much. This data will be used to make precise channel widths during future fabrication work.

And Figure 7 shows the SEM image of the fabricated micro channels in the case of channel width 300 μm.

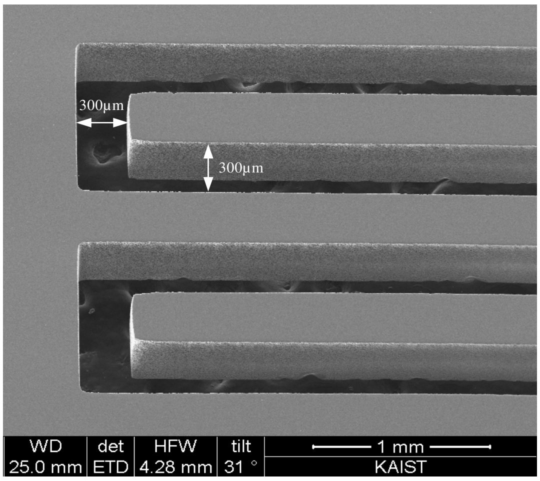

Fig. 7: SEM image of micro channel 300 μm

CONCLUSION

In this study, a fully enclose micro PEM fuel cell using glass bipolar plates was fabricated. The MEMS fabrication process using photosensitive glass was fully established. This process includes the anisotropic wet etching process, bonding process, electrode insertion process etc.

Compared to the previous study [8], the newly designed micro PEM fuel cell was in a compact form in which no end plates are needed and could be directly integrated into a portable electronic system. Future work will consist of performance evaluation, and parameter studies such as varying the amount of metal layer deposition, number of cell stacking, etc. of a single cell. These factors are critical ones that greatly influence the performance of a micro fuel cell system. Once those factors are established, multi cell stacking with 2, 4, 6 cells will be carried out producing a micro fuel cell with a power level of up to 1W. In the case of energy density, it greatly depends on the type of hydrogen generator used together with the micro fuel cell. A micro methanol reformer is being considered to be integrated together.

ACKNOWLEDGEMENTS

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