DESIGN AND FABRICATION OF A SILICON-BASED MICRO DIRECT METHANOL FUEL CELL STACK

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Abstract

This paper presents a silicon-based micro direct methanol fuel cell (μDMFC) stack with compact stacked structure and a unique shared anode plate. The μDMFC stack consists of two fuel cells in electrically parallel connection, while the fuel transport is arranged in series. Experimental results show that the μDMFC stack generates a power density of 12.71mW/cm^2, almost twice as much as that of a single cell, when fed with 1M methanol solution at room temperature.

Keywords: μDMFC stack, Flow structure, MEMS, Micro power source

1 - INTRODUCTION

Micro direct methanol fuel cells (μDMFC) have drawn increasing attention recently as a promising micro power source (MPS) for applications of portable electronic products, wireless communication systems, and sensor networks, due to its advantages of high energy density, low pollution, convenient fuel storage, and operation under room temperature, etc. [1-2]

Although great progress has been made in the membrane electrode assembly (MEA) research and flow structure optimization, there is still a great gap between the state-of-the-art technical results and the practical applications. One of the most critical challenges is that when a DMFC achieves its maximum power density the voltage remains around 0.2-0.4V, much lower than the requirement of common electronic devices. Moreover, the highest voltage that a single DMFC can achieve is represented by the thermodynamic predicted voltage, which is 1.12V under room temperature, limiting the μDMFC in relatively high-voltage applications. Besides, the maximum output current density is around 10mA/cm^2 under room temperature, indicating that large area is needed to meet the current requirement of micro systems. In one word, although the μDMFC presents many significant advantages, combining μDMFCs together is a must to satisfy the voltage or current requirements of most electronic applications. The micro fuel cell array with planar structure was reported in literature [3-4], with the advantages of easy electrical interconnection and assembly. However, this structure takes up large area and may cause severe lateral ionic conduction as a result of the common proton exchange membrane (PEM).

This paper presents the design and fabrication of a μDMFC stack. The stacked structure of the prototype avoids the lateral ionic conduction and the related parasitic loss. Both the anode and cathode silicon plates were fabricated on the same wafer by micro fabrication technology. The whole μDMFC stack was assembled with PDMS and aluminum holder.

2 - STRUCTURE DESIGN

2.1 - stacked structure design

The designed μDMFC stack consists of two cells which are electrically connected in parallel as shown in Figure 1. A single fuel cell with the

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conventional sandwich structure is presented schematically following the μDMFC stack to visualize the structure evolvement. Three plates and two MEAs are stacked alternately in the prototype. The middle plate which has flow patterns on both sides acts as the shared anode of the two cells, whereas the upper and lower plates act as the cathodes which have the usual flow channels only on one side. Compared to the planar structure, this stacked structure needs much smaller area, and is expected to have a better performance with no parasitic lateral ionic conduction effects due to the separate MEAs.

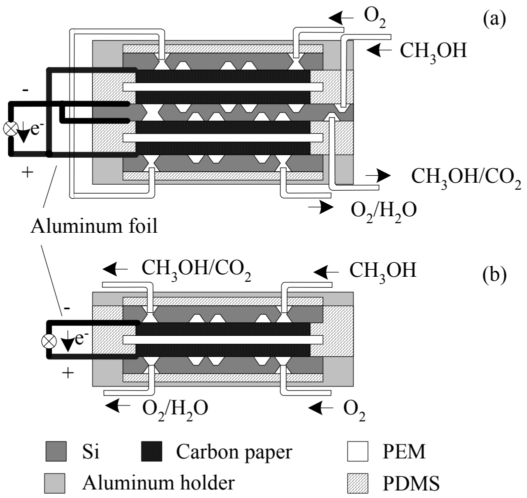

Figure 1. Schematic of (a) the μDMFC stack, (b) the conventional single μDMFC.

2.2 – Flow patterns design

Figure 2 illustrates the structure of the shared anode plate. The serpentine flow channels on both sides of the wafer are designed to be parallel placed. The leading channels, which allow the methanol solution flow to the effective channel area contacting to the MEA, are at one end of the flow channels. The other ends of the flow channels are connected through an etch-thru hole. In the anode, the methanol solution flows into the μDMFC stack through the front-side leading channel from a feeding tube, travels across the front-side flow field and reaches the back side via the connecting hole. Then the fuel flows throughout the back-side flow patterns, moves to the back-side leading channel and finally leaves the fuel cells from another feeding tube. The leading channels actually act as the extension of the feeding tubes.

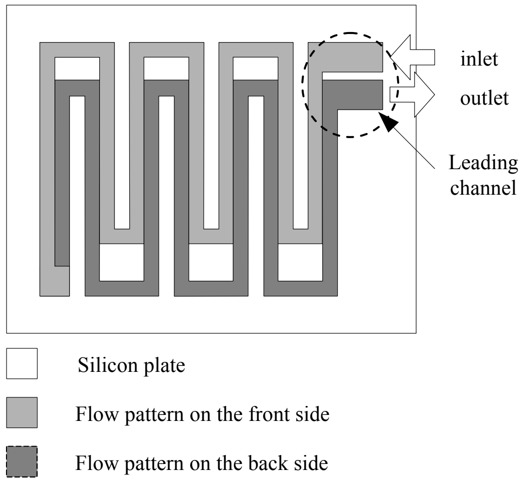

Figure 2. The shared anode plate with double-side flow patterns

2.3 – Other considerations

As indicated in Figure 1, the mass transport is arranged in series, i.e., the reactants flow through the two cells successively, thus only one set of inlet and outlet is needed for fuel and oxygen gas each. The series mass supply mode has the advantages of high flow velocity, efficient product removal, and easy operation.

Parallel electrical connection is adopted in this paper. However, the stacked structure is also applicable for the series electrical connection. In that case, the two sides of the middle plate should be insulated with insulation layers like Si_3N_4. Another solution is to keep the two sides electrically conducted while making the flow patterns on the two sides completely separated, and feeding fuel and O_2 to each side, respectively.

The middle plate is used as the shared anode because mass transport of the anode is more critical than that of the cathode in DMFC. Modeling and simulations have been performed to optimize the anode flow patterns design. The results show that increasing the channel and rib width within the sub-millimeter scale can improve the μDMFC performance. Thus, the channel and rib width are increased from 200μm to 400μm. The detailed geometry information is listed in Table 1.

Table 1. Dimensions of the μDMFC stack (unit: mm)

Total Size (including holders)	22.8×25.0×6.0
Plate area	22.8×15.9
Channel area	6.8×8.0
Channel width	0.4
Channel depth	0.2
Rib width	0.4 / 1.2

3 – FABRICATION

3.1 – Silicon plates

Micro fabrication techniques are used to fabricate the silicon plates. The processes of the anode and cathode plates are presented in Figure 3. The detailed steps are as followed:

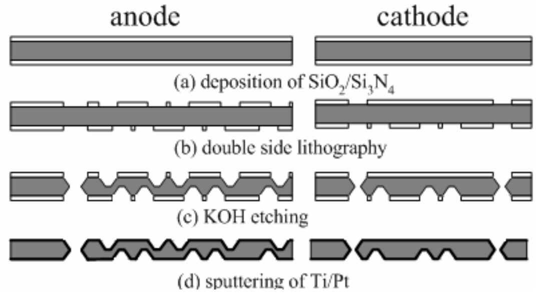

Figure 3. MEMS fabrication processes of the anode and cathode silicon plates.

1) Si_3N_4 films were deposited as the mask layers on both sides of a 400μm thick double-polished <100> silicon wafer by thermal oxidation and LPCVD;
2) The flow patterns were formed by double-side lithography. For the anode plate, the flow patterns include flow channels, leading channels, and the connect hole on both sides. For the cathode plates, the flow patterns include flow channels on the front side and feeding hole on the back side. RIE was used to remove the Si_3N_4 mask under the developed photoresist;
3) The flow structures were etched using KOH timed etching.
4) Ti/Pt layers were sputtered for current collection with the thickness of 2000Å on both sides of the silicon wafer.

The anode and cathode plates were formed on the same wafer, as their processes were exactly the same. Moreover, different and more complicated patterns can be easily accomplished for the two sides of the anode, although they are the same in this paper. With the help of double-side lithography, the two-sided flow structure can be manufactured at one time and halve KOH etching time. Fabricated silicon plates and SEM photos are shown in Figure 4.

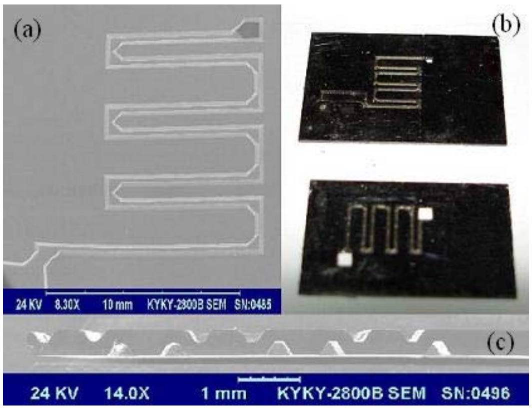

Figure 4. Photos of anode/cathode plates.

(a) Flow pattern on one side of the anode plate;
(b) Fabricated anode and cathode silicon plates;
(c) Cross section of the anode plate.

3.2 - MEA

The MEA was fabricated using hot pressing two catalyst-coated (anode: 4.0mg/cm^2 Pt-Ru, cathode: 1.5mg/cm^2 Pt) wet-proof carbon papers together with the PEM, Nafion 117 in between.

3.3 – Assembly

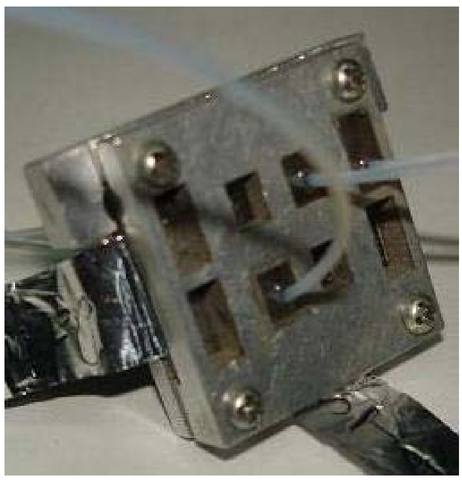

Figure 5. Final assembled μDMFC stack.

PDMS and Aluminum holders were used to protect fragile silicon plates and keep the fuel cell hermetic [5]. The assembled µDMFC stack is shown in Figure 5.

4 – RESULTS AND DISSCUSSION

The assembled µDMFC stack was tested on an electrochemical interface, Solartron SI1287 under room temperature and pressure. The performance curves including the output voltage and the power density versus the current density are plotted in Figure 6. The experiment results show that the prototype has an open circuit voltage of 0.47V and the maximum power density of 12.71 mW/cm^2, when fed with 1M methanol solution at 0.40ml/min and pure oxygen at 20ml/min. The power density of the µDMFC stack almost doubles that of a single µDMFC fabricated by our team previously using similar fabrication technologies [5], while the volume of the µDMFC stack is far less twice than that of the single cell. The prototype also has a better utilization factor of fuel because the µDMFC stack has a larger reaction area and consumes more reactants than the single cell, although the dilution of methanol solution and oxygen gas might have impaired the stack performance. No leakage was found during the daylong testing, demonstrating the reliability of the PDMS assembly method.

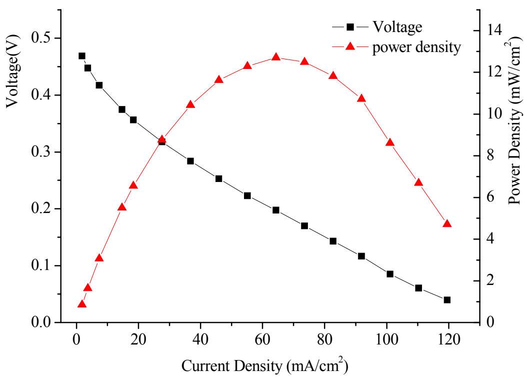

Figure 6. Performance of the µDMFC stack tested with 1M methanol at 0.4 ml/min and pure O_2 at 20ml/min at room temperature (25℃).

5 – CONCLUSIONS

A silicon-based µDMFC stack with stacked structure has been designed, fabricated, and characterized. Micro fabrication technology was used to implement both the anode and cathode silicon plates on the same wafer. Experiment results show that the prototype generates a power density of 12.71mW/cm^2 which almost doubles that of the single cell, and an open-circuit potential of 0.47V. The stacked structure and PDMS assembly technology are also applicable for stacking more cells to meet the demand of high-power electronic devices.

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