EFFECTS OF ANODE FLOW FIELD DESIGN ON THE PERFORMANCE OF MICRO DIRECT METHANOL FUEL CELL

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Abstract: In this work, we presented the design and fabrication of the Micro direct methanol fuel cell (μDMFC). A novel encapsulation method with PDMS was designed and introduced to help the MEA contact with the current collectors tightly. Moreover the performance of the μDMFC with different flow field structures was tested, and the results showed that serpentine flow field had the optimal performance. It was also found that the single cell had the best performance when the open ratio of single serpentine flow field (SSFF) was 47%. The peak power density of single cell was 13.2 mW/cm^2.

Keywords: Micro direct methanol fuel cell; Silicon-based technology; Encapsulation; Serpentine flow field

INTRODUCTION

In recent years, with the wide application of portable and wireless consumer devices, the demands on micro power sources for high performance, compactness and low weight have been increased quickly. Micro-direct methanol fuel cell (μ-DMFC), with advantages of high energy density, cleanness, easy operating condition, convenience in storing fuel, is acknowledged as the promising candidate for conventional micro batteries [1-4]. Silicon is commonly used as the material for the current collector of μDMFC [5-7]. With the rapid development of MEMS technology, it provides a new approach to implement the design and fabrication of μDMFC [8-9]. The MEMS technology based on silicon material (include oxidation, photolithography, etching, sputtering, etc.) is very mature, and silicon-based MEMS fuel cell is easily integrated. But the silicon material is brittle and difficult to encapsulate. So in this paper, a novel encapsulation approach, which not only resolved the sealing of Encapsulation effectively but also helped the current collector contact the MEA tightly, was presented. In addition, μDMFCs with different flow fields were designed, and their performances were tested to find the optimal flow field.

EXPERIMENT

Layout design and fabrication of current collector plate

In this work, the selected 3 inches 480μm-thick twin polishing monolithic silicon wafers was processed by the MEMS techniques. And then these accomplished silicon wafers were used for anode and cathode current collector plates. Based on the current silicon micromachining technology, the fabrication process of the silicon-based current collector was designed, as shown in Fig. 1.

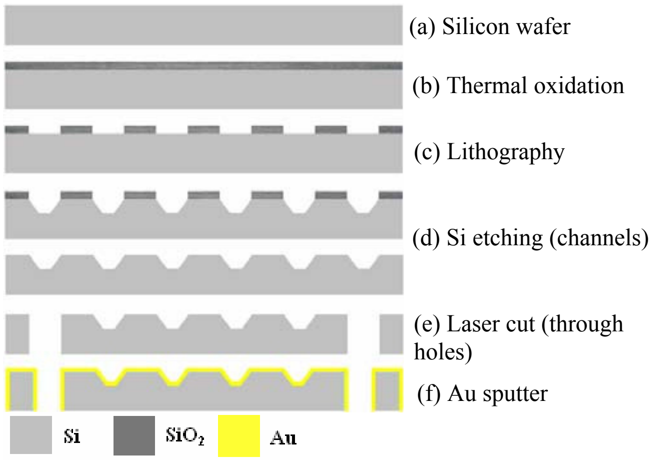


Fig. 1 Schematic of the fabrication process of the silicon-based current collector

Encapsulation of silicon-based μDMFC

The encapsulation is key factor for silicon-based μDMFC. PDMS have the advantage of non-toxic, easy processing and low cost. On the basis of application advantage of PDMS, PDMS was put into the encapsulation of silicon-based μDMFC, which could resolve effectively the sealing of encapsulation and make current collectors contact closely with MEA. The process was given in Fig. 2.

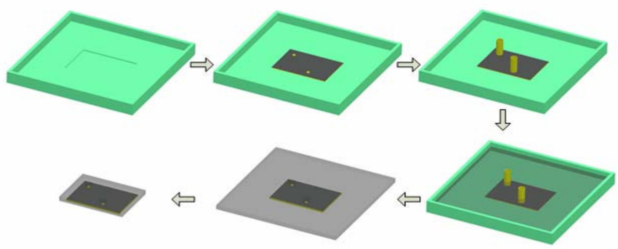


Fig. 2 Schematic of the Encapsulation process using PDMS

Assembly of silicon-based μDMFC

The structure of the silicon-based self-breathing DMFC designed in this work was presented in Fig. 3. The effective area of the membrane electrode was designed as 1.44 cm^2 (1.2 cm×1.2 cm). The diffusion layers of anode and cathode were both carbon cloth. The anode catalyst was 4.0 mg/cm^2 Pt-Ru/C and the cathode catalyst was 4.0 mg/cm^2 Pt/C. Airproof cushions made from silicon rubber were deposited between MEA and polar plates, which was supposed not only to prevent the fuel leaking out but also to protect the MEA effectively. Polar plates were encapsulated under the PDMS protective film on which there were flow fields fabricated by MEMS techniques. Then the anode was fabricated using the layer boring and the diameter of the hole was 600μm. Ultimately, in order to prevent the corrosion of polar plates and reduce the contact resistance, Au was sputtered on the surface of the polar plates. The finished silicon-based DMFC and SEM images of the polar plates were presented in Fig. 4 and Fig. 5, respectively.

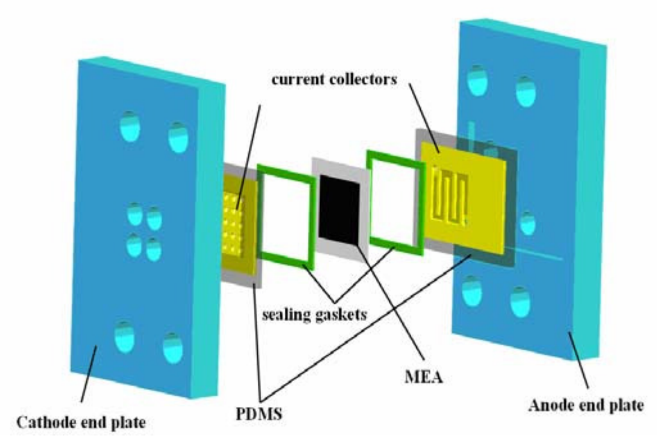


Fig. 3 Schematic of the μDMFC structure

Fig.4 Silicon-based DMFC

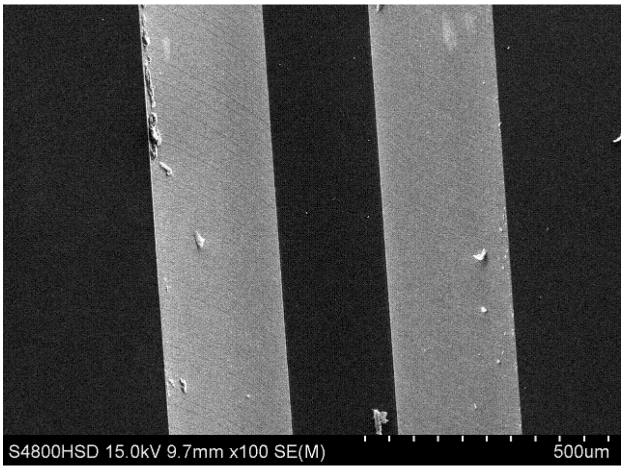


Fig.5 SEM images of the polar plate

PERFORMANCE ANALYSIS OF SILICON-BASED μDMFC

Effects of the anode flow field structure

At room temperature (about 20℃), the performance of micro DMFC was tested. The concentration of methanol solution was 1mol/L, and the flowing speed to the anode was 1mL/min.

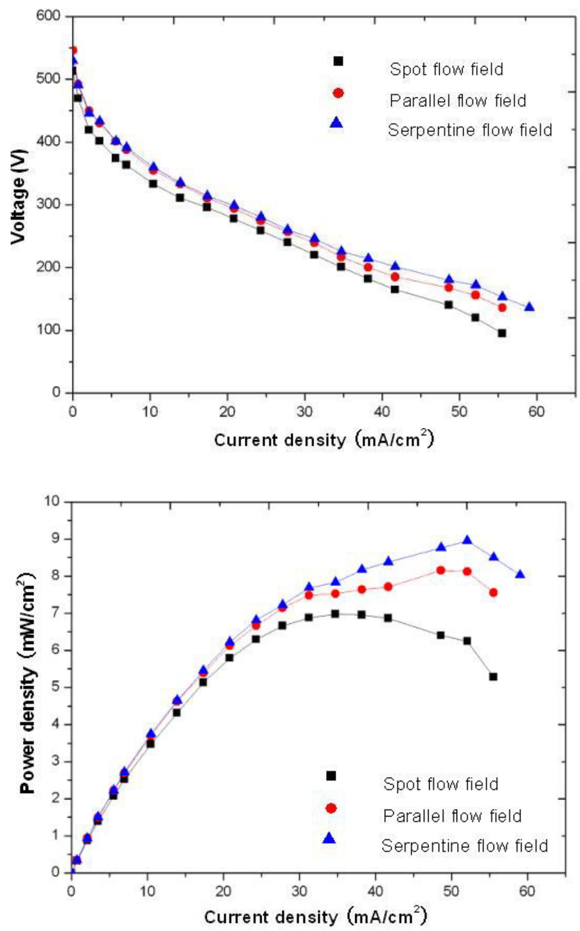


Fig.6 Performance curve of micro DMFCs with different anode flow fields

Table 1 Values of detailed dimension parameters of the designed serpentine flow field

Flow field	Width of flow field (mm)	Width of raphe (mm)	Depth of flow field (mm)	Area of effective coverage (cm2)	Duty cycle (%)
SSFF-1	0.4	0.86	0.3	0.634	38
SSFF-2	0.5	0.75	0.3	0.64	47
SSFF-3	0.8	0.4	0.3	0.64	73
SSFF-4	0.3	0.98	0.3	0.637	29

It can be seen from Fig 6 that the performance of cell is affected by the anode flow field greatly. The performance decreases in the following order: serpentine flow field, parallel flow field, and spot flow field. The main reasons are as follows:

(1) Spot and parallel flow fields can reduce reaction pressure drop, thus slowing down the average flow velocity of fuel, which boosts fuel diffusion to MEA. However, through simulation analysis and visual observation, it can be seen that the fuel distribution of spot and parallel flow field is asymmetric. When it comes to serpentine flow field, the fuel distributes in effective coverage equally, thus accelerating the mass transfer rate of molecule and ensuring average distribution of fuel.

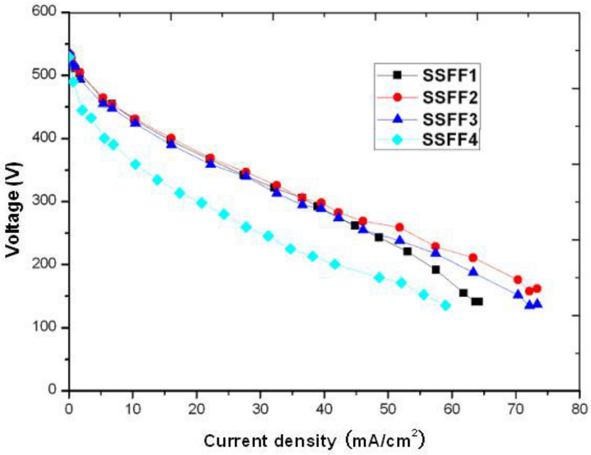
(2) With the same duty cycle, serpentine flow field can increase the length of fuel flow and create great pressure. Thus it increases the speed of fuel flow and boosts the mass transfer.

For the micro DMFC polar plate of small flow field, CO_2 can affect the liquid flow and mass transfer greatly when the cell is under discharge condition, especially at high current density. Thanks to large pressure drop of serpentine field, CO_2 is easier to be swept out. In this way, CO_2 will not inhibit the mass transfer of fuel, and the interface between methanol solution and MEA is increased to improve the mass transfer of fuel.

Optimization of anode flow field dimension

The previous experiment results have shown that the silicon-based micro DMFC with serpentine anode flow field has the best performance. In this section, the performance of SSFF (Single serpentine flow field) with different open porosity is discussed. Detailed dimensions of serpentine flow fields are shown in Table 1.

To compare with each other, experiments are conducted at room temperature. Methanol solution of 1.0mol/L flows into the anode flow field at 1.0ml/min. Experiments results are shown in Fig 7.



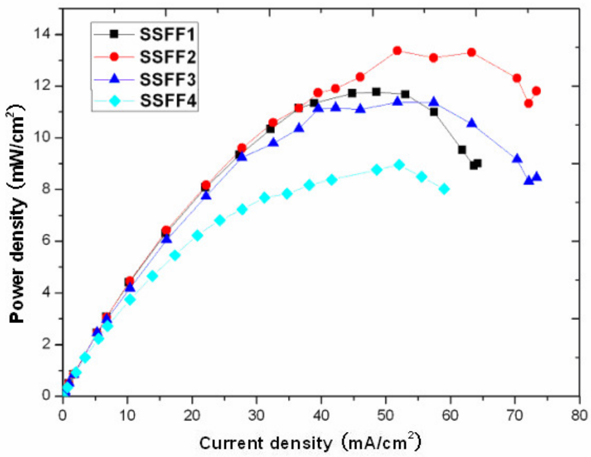


Fig.7 Performance curve of micro DMFCs with different duty cycle

Fig. 7 shows performance curve of micro DMFCs with different duty cycle. The best performance can be obtained at the duty cycle of 47%, and the micro DMFC yields power density of 13.2mW/ cm^2 at the current density of 50mA/cm^2. Higher or lower duty cycle will reduce the cell performance at varying degrees. Specific reasons are as follows. When duty cycle is small, raphe width will be large accordingly, which will asymmetric the distribution of methanol solution in diffusion layer and reduce mass transfer of fuel. Therefore, the cell performance decreases. On the other hand, high duty cycle means wee raphe width. This makes the interface between liquid and diffusion increase so that the contact resistance increases too. Meanwhile, increased interface between methanol solution and MEA will make methanol infiltrate to cathode more, causing mixed potential in cathode, reducing the output characteristic of cell.

It can be seen from the above experiments that SSFF with superior duty cycle will result in methanol infiltration, reducing voltage of cell. But SSFC with less duty cycle weakens mass transfer of methanol. Therefore, optimum design of duty cycle of SSFF plays an important role in cell characteristic. Experiment results show that the best duty cycle is 47%.

CONCLUSION

In this paper, different plate structures of silicon-based μDMFC by bulk silicon MEMS technology is designed and fabricated. Moreover, the assembly between silicon polar plates and other key components is realized using the PDMS technology. Through experiments, the structure of the anode current collector is analyzed by testing the cell performance. The best flow field structure is obtained by optimizing the size of optimal flow field. The optimal SSFF open ratio is 47%, and the peak power density is $13.2mW/cm^2$ at the discharge current density of $50mA/cm^2$.

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REFERENCES

[1] C. K. Dyer 2002 Fuel cells for portable applications *J. Power Sources* 106 31-34

[2] Jingrong Yu, Ping Cheng, Zhiqi Ma, Baolian Yi 2003 Fabrication of miniature silicon wafer fuel cells with improved performance *J. Power Sources* 124 40-46

[3] Shinji Motokaa, Mohamed Mohamedi, Toshiyuki Momma, Shuichi Shoji, Tetsuya Osaka 2004 MEMS-based design and fabrication of a new concept micro direct methanol fuel cell (μ-DMFC) *Electrochem. Commun.* 6 562-565

[4] Mench M M, Wang Z H, Bhatia K and Wang C Y 2001 Design of a micro direct methanol fuel cell *Proc. of the Int. Mechanical Engineering Cong. and Expo.* (New York)

[5] G. Q. Lu, C. Y. Wang, T. J. Yen, X. Zhang 2004 Development and characterization of a silicon-based micro direct methanol fuel cell *Electrochim. Acta* 49 821-828

[6] Kevin G Stanley, Eva K Czyzewska, Tom P K Vanderhoek, Lilian L Y Fan, Keith A Abel, Q M Jonathan 2005 A hybrid sequential deposition fabrication technique for micro fuel cells *J. Micromech. Microeng.* 15 1979-1987

[7] K. L. Chu, S. Gold, V. Subramanin, C. Lu, M. A. Shannon, R. I. Masel 2006 A nanoporous silicon membrane electrode assembly for onchip micro fuel cell applications *J. Microelectromech. Syst* 15 671-677

[8] H. Yang, T. S. Zhao 2005 Effect of anode flow field design on the performance of liquid feed direct methanol fuel cells *Electrochim. Acta* 50 3243-3252

[9] C. W. Wong, T. S. Zhao, Q. Ye, J. G. Liu 2006 Experimental investigations of the anode flow field of a micro direct methanol fuel cell *J. Power Sources.* 155 291~296