DESIGN, FABRICATION AND TESTING OF A POLYMER-BASED MICRO DIRECT METHANOL FUEL CELL

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Abstract: In this paper, an air-breathing micro direct methanol fuel cell (μDMFC) based on polymer is designed, fabricated and tested. The stainless steel plate is fabricated as current collector using micro wire cutting and laser cutting technology. A layer of Au is sputtered onto the surface of the current collector to avoid the electrochemistry corrosion and reduce the contact resistance. The μDMFC is tested at different operating parameters. The results show that the peak power density can reach to 13.37mW/cm^2 under 5mol/L methanol concentration and the μDMFC can steadily work under the high methanol concentration for a long time. It is meaningful for the future applications due to the advantages such as low weight, mass production and high-energy density.

Key words: Micro direct methanol fuel cell, air-breathing, polymer

INTRODUCTION

Direct Methanol Fuel Cell (DMFC), which is a new environment-friendly energy source, provide significant performance such as portable, energy density, simplicity, start-up and room temperature operation compared with other types of fuel cells. μDMFC also has advantages for military use. It is able to meet the requirement for power in the military working for its high efficiency, polyfunctionality, long working-life and noiseless features [1]. In recent years, with the development of MEMS, MEMS-based DMFC has received considerable research attention all around the world [2-5].

The bipolar plates of conventional μDMFC have been fabricated mostly with the silicon, metal and polymer. Most of the researchers had focus on the silicon or metal based μDMFC and achieved some positive results [6-8]. However, as polymer material is weak in electrical conductivity, studies on polymer based μDMFC achieve few improvements and the performance of polymer based μDMFC is relatively weak. Cha et al. [9] reported a μDMFC with bipolar plates made by SU-8 and layers of Pt sputtered onto the surface of the plates, yielding a maximum power density of 8 mW/cm^2. Ito et al. [10] developed photosensitive glass based μDMFC stack with an active area of 1cm^2 but the power density was low. N.Hashim et al. [11] fabricated a μDMFC stack with the bipolar plates made by PMMA and the current collector made by stainless steel mesh, which achieved a maximum power density of 2.2mW/ cm^2

In this paper, an air-breathing μDMFC based on polymer (ABS) is designed and fabricated. The current collector which is made by stainless steel and specially processed to avoid the electrochemistry corrosion is employed. The fuel cell has been tested in different conditions and shows a high applicability on portable energy source because of its simplicity and the feasibility of production in batch.

DESIGN AND FABRICATION

(a) Anode and cathode plate (b) current collector
Fig.1: Photo of plate and current collector

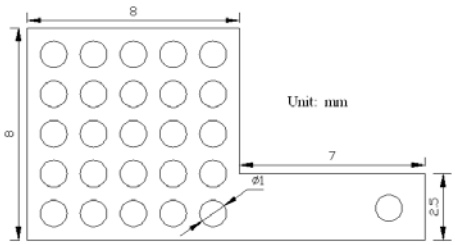

Fig.2: Illustration of current collector

The active area of the MEA is 0.49cm^2. The membrane is consisted of Nafion® 117 produced by DuPont©. Catalyst loading on the anode side is 4.0mg/cm^2 of Pt-Ru/C (proportion 1:1), while the catalyst loading on the cathode side is 4.0mg/cm^2 of Pt/C. The carbon papers (produced by Toray Industries, Japan) are used as the diffusion layer both on the anode and cathode sides. Beside the polar plates, silicone mat are used to avoid the leakage of liquid and act as buffers for the mechanical package with the screws. Both of the polar plates are made by ABS (Fig.1 (a)), which can significantly reduce the weight of the fuel cell. Micro-process technology is employed to cut the anode plate into parallel channels whose channel width and the depth are both 1mm and the rib width is 500μm. On the cathode side, parallel windows, opposed to the channels on the anode side, are made to allow the air approaching the diffusion layer. The stainless steel plate is fabricated as current collector. Using micro wire cutting and laser cutting technology, holes are placed on the collectors uniformly as shown in Fig. 2. A layer of Au with the thickness of 1μm was sputtered onto the surface of the current collector to avoid the electrochemistrical corrosion and reduce the contact resistance. The photograph of the current collector is shown in Fig. 1 (b). Ultimately, the MEA is sandwiched between anode current collector and cathode current collector, and then the screws are used to create an integrated cell. The assembling process of μDMFC and the prototype photo are shown in Fig. 3 and Fig. 4, respectively.

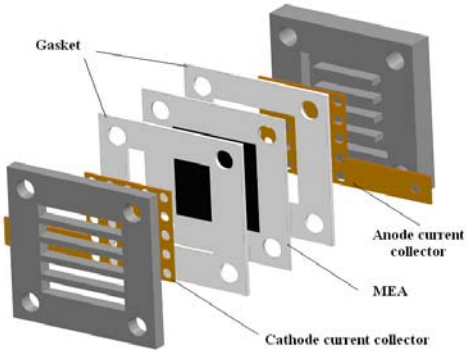

Fig.3: Schematic of μDMFC

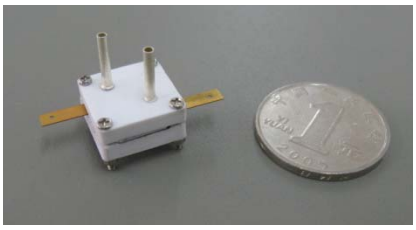

Fig.4: Prototype of μDMFC

RESULTS AND DISCUSSIONS

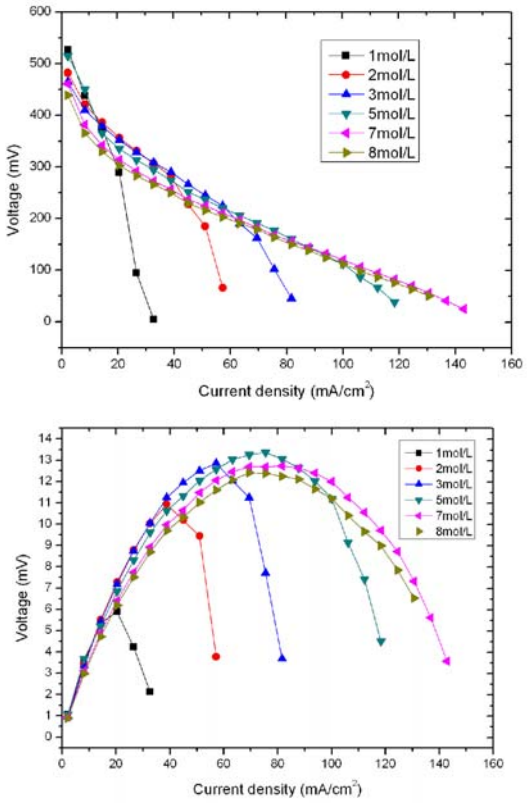

Fig.5: Effect of methanol concentration on the performance of μDMFC

Fig. 5 shows the performance of the μDMFC operated under room temperature (20℃) with various methanol concentrations from 1.0 to 8.0 M. The flow rate is 0.5ml/min. Power density of the cell sharply decreases operating at a high current density when the

concentration increases from 1.0M to 3.0M and concentration polarization occurs. This decreasing power density is caused by that the methanol supplement cannot fit the electrochemistrical reaction rate. As a result, the cell does not exhibit a stable performance with a heavy current. The peak power density can reach to 13.37 mW/cm^2 under 5.0M methanol concentration. The performance has not a large degradation when the concentration changes around 6.0M to 8.0M. The cell shows a poor performance under the low methanol concentration is caused by the osmosis of methanol will produce a high cathodic mixed overpotential when the cell works in a small current density. While working in the high current density, the diffusion and consumption of methanol tend to balance in the reaction region and the osmosis of methanol is reduced. The water, produced in the cathode and blocking the transfer of O_2, becomes the main factor affecting the performance. The best concentration is 7.0M in this situation. This result is different from the traditional passive DMFC which the best concentration is around 1.0M to 2.0M. It is because that the methanol transfer rate of the fuel cell in this paper is much lower than the passive cell, which makes the concentration gradient higher. As a result, this structure is more suitable for the high-concentration methanol fuel.

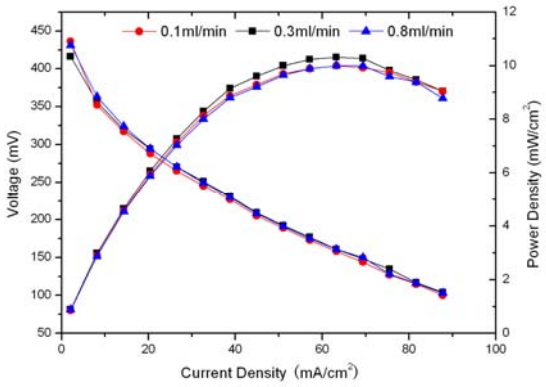

Fig.6: Effect of methanol flow velocities on performance of μDMFC

Fig. 6 presents the effect of various methanol flow velocities on performance of μDMFC with the methanol constration of 5.0M under room temperature (20℃). It can be found that the performance of the cell is steady when the flow velocity rises from 0.1ml/min to 0.8ml/min. This is because that the transfer of methanol in this structure depends on the fuel diffusion. The presure of the anode flow field will be impeded by the current collectors, whose influence to the transfer is greatly reduced. Therefore, if enough fuel is provided, the methanol flow velocities will have little effect on the μDMFC. Although the velocity is low, the performance will not be degraded with the methanol constration of 5.0M.

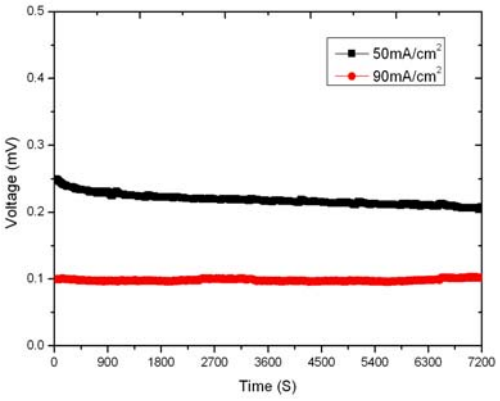

Fig.7: Two-hour performance at 50mA/cm^2 and 90mA/cm^2 using 7mol/L methanol with 0.1ml/min flow velocity

Fig.7 shows two-hour performances at 50mA/cm^2 and 90mA/cm^2 using 7.0M methanol with 0.1ml/min flow velocity. We can find that the μDMFC can steadily operate under the high methanol concentration for a long time. The performance of μDMFC decreases slightly after a two-hour working at 50mA/cm^2 while that increases after working at 90mA/cm^2. The reason of this variation is that the electrochemistrical reaction tends to be stronger when the fuel cell is working at a higher current density which makes the operating temperature rise to the balance temperature and improves the performance to some extent. We can also find in the figure that the osmosis of methanol which caused by the high fuel concentration shows little effect on the performance when the μDMFC is working at a high current density. The water which is produced in the cathode is the main reason of the performance degradation.

CONCLUSIONS

In this paper, an air-breathing μDMFC based on ABS has been designed and fabricated. Comparing with the μDMFCs based on silicon or metal, this design has the advantages of low cost, light weight and possibility for mass production. Micro process

technology such as micro wire cutting and laser cutting are employed to process stainless steel current collectors. The tests made in various conditions show that the peak power density of 13.37 mW/cm^2 has been achieved which is equivalent to the level of metal-based μDMFCs. We can find in the stability test that this μDMFC works steadily using a high methanol concentration (7.0M) and a low flow velocity (0.1ml/min). This has a practical value to the portable power devices, meeting the demand of high energy density.

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