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Stainless steel fiber felt as cathode diffusion backing and current collector for a micro direct methanol fuel cell with low methanol crossover

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HIGHLIGHTS

- Stainless steel fiber felt was used as cathode current collector and backing layer.
- Methanol crossover was lowered obviously.
- Higher fuel utilization ratio and energy efficiency were achieved.

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ABSTRACT

In this paper, a membrane electrode assembly (MEA) with novel structure is designed and fabricated for a micro direct methanol fuel cell (DMFC), which used stainless steel fiber felt (SSFF) to replace the current collector and the backing layer at cathode. Result data shows that the novel structure can reduce the methanol crossover dramatically, as a result, achieves a better performance with a higher methanol concentration, a higher fuel utilization ratio and energy efficiency. In addition, the novel MEA also presents an improved water management at room temperature, allowing it to achieve a better performance. To elaborate the effect of the novel structure on anode or cathode electrode process, a reference electrode is built inside the single cell. The electrochemical results of half-cell test show that the novel MEA has a greatly reduced cathode polarization and a slightly increased anode polarization.

1. Introduction

Direct methanol fuel cell (DMFC) is an attractive and a leading candidate power source for portable and micro-power devices due to its simple structure, high specific energy, and instantaneous recharging time [1,2]. In order to make the DMFC more competitive with conventional battery technologies, it would be optimal to operate the DMFC in a passive mode, which has no auxiliary liquid pump and gas blower compressor but relies on diffusion and natural convection to supply the fuel and oxygen.[3]. Although the passive design greatly simplify the cell structure, the power density from passive systems is not as good as those running in an active mode due to poor transport. To achieve the commercialization of a passive DMFC, various passive DMFCs have been proposed and extensively investigated to improve the cell performance over the past decade [3].

Methanol crossover is one of the main challenges that restrain the performance of a passive DMFC [4,5]. The oxidation of methanol transporting from anode to cathode leads to a mixed potential and thus reduces the overall cell voltage. This problem can be solved by developing an alternative proton exchange membrane with high proton conductivity and low methanol permeability or modifying Nafion membrane to lower its methanol crossover [6–8]. Another way to lower methanol crossover is to optimize the MEA structure, the material of the gas diffusion layer (GDL) and even the structure of the current collector and reservoirs. By increasing the methanol transportation resistance from reservoirs to anode catalyst layer or adopting a pervaporation membrane, a passive DMFC can be operated at high methanol concentration or neat methanol with a low methanol crossover [9–13]. Moreover, methanol crossover can

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also be reduced by enhancing water back diffusion from cathode to anode, which can be achieved by increasing the liquid pressure inside the cathode catalyst layer [14–18]. However, there are few researches that can reduce methanol crossover dramatically by optimizing the MEA structure.

In recent years, metallic porous materials, such as stainless steel fiber felt (SSFF), metal foam, have shown great potential to replace conventional carbon-based fiber products as backing layer of gas diffusion electrode due to high mechanical strength and good ductility. It was shown that SSFF GDL has larger compressive modulus, tensile modulus and ductility which is of great benefit to the transport ability under assembly compression and durability under the running conditions of shock and vibration [19]. By adopting SSFF as anode gas diffusion backing, an air-breathing DMFC gives better performance than that uses common carbon paper [20]. Because of its high electronic conductivity, porous metal foam can be used as both gas diffusion backing and current collector, which not only simplifies the cell structure but also gives better oxygen transportation than conventional gas diffusion layer [21]. But there is not a detailed study about how the electrode process is affected by this novel structure of membrane electrode assembly.

In this paper, a 316L stainless steel fiber felt was used as cathode gas diffusion backing and current collector to fabricate a MEA for DMFC. To evaluate effects of this novel MEA structure on cathode or anode electrode process, a half-cell measurement system was built by introducing an Ag/AgCl reference electrode. The fabricated micro DMFC was tested by polarization at different methanol concentrations, temperatures, constant-current discharging and electrochemical impedance spectra (EIS) tests in half-cell measurement system, comparing with a normal DMFC as reference.

2. Experiment

2.1. Fabrication of membrane electrode assembly

The membrane electrode assembly with an active area of 1 cm [2] was fabricated in-house by the following procedures. A stainless steel fiber felt made of 316L was coated with a 200 nm Au layer by magnetic sputtering technology to decrease the contact resistance. A mixture of 90 wt.% XC-72 and 10 wt.% PTFE was sprayed onto the surface of SSFF, serving as micro porous layer with a carbon loading of 4 mg cm^{-2}. Carbon-supported catalyst, 40 wt.% Pt/C, purchased from Johnson Matthey, Inc., was used for the fabrication of cathode catalyst layer. Catalyst ink was prepared by dispersing appropriate amount of catalyst and Nafion solution (Dupont, 5 wt.%) into a mixture of isopropyl alcohol and deionized (DI) water with a volume ratio of 1:1, and it was then sprayed onto the carbon-coated SSFF to get a cathode gas diffusion electrode (GDE). The Pt loading was about 2 mg cm^{-2} with 20 wt.% Nafion as the bonding agent. Along with the manufacture of the novel cathode GDE, a conventional cathode GDE with carbon paper (TGPH060) as backing layer was also made for reference. Some parameters of stainless steel fiber felt (SSFF) and carbon paper (CP) are presented in Table 1. Nafion 117 membrane was used to fabricate the MEA, which was pretreated in deionized water, 3 wt.% H_2O_2, 3 wt.% H_2SO_4, and deionized water again for 1 h in each solution in turn. Commercial anode gas diffusion electrode (purchased from Johnson Matthey, Inc.) and home-made cathode gas diffusion electrode were attached to Nafion membrane by hot-pressing at 408 K and 18 MPa for 180 s to form a MEA. Fig. 1(a) shows the prepared novel MEA. In following the two MEAs fabricated with carbon paper and SSFF were named respectively as CP-MEA and SSFF-MEA for the simplicity of description.

Table 1
Physical property of carbon paper and stainless steel fiber felt.

	Material density (g cm^{-3})	Bulk density (g cm^{-3})	Thickness (mm)	Porosity (%)	Fiber diameter (μm)
SSFF	7.98	2.73	0.36	65.8	10
Carbon paper	1.80	0.49	0.17	73	8

2.2. Single cell assembly

SSFF-MEA has SSFF as cathode current collector, and thus only an anode current collector is needed for single cell assembly, which has parallel channels with an open ratio of 43.2% [22]. For CP-MEA, a cathode current collector is still needed, which has perforated flow field with an open ratio of 40.7% [22]. All the current collector plates were made of 0.45 mm thickness 316L stainless steel, with 200 nm Au layer to reduce the contact resistance. The entire cell was assembled by holding the MEA and current collectors together between two organic glass fixtures. There is no external pump used in our passive DMFC system. Air is only supplied to the electrodes by diffusion through the open areas. A 2.5 mL reservoir is adhered to the anode fixture. Referring to the study of S. H. Yang, [23] an improved half-cell test system was set up. In this system, an Ag/

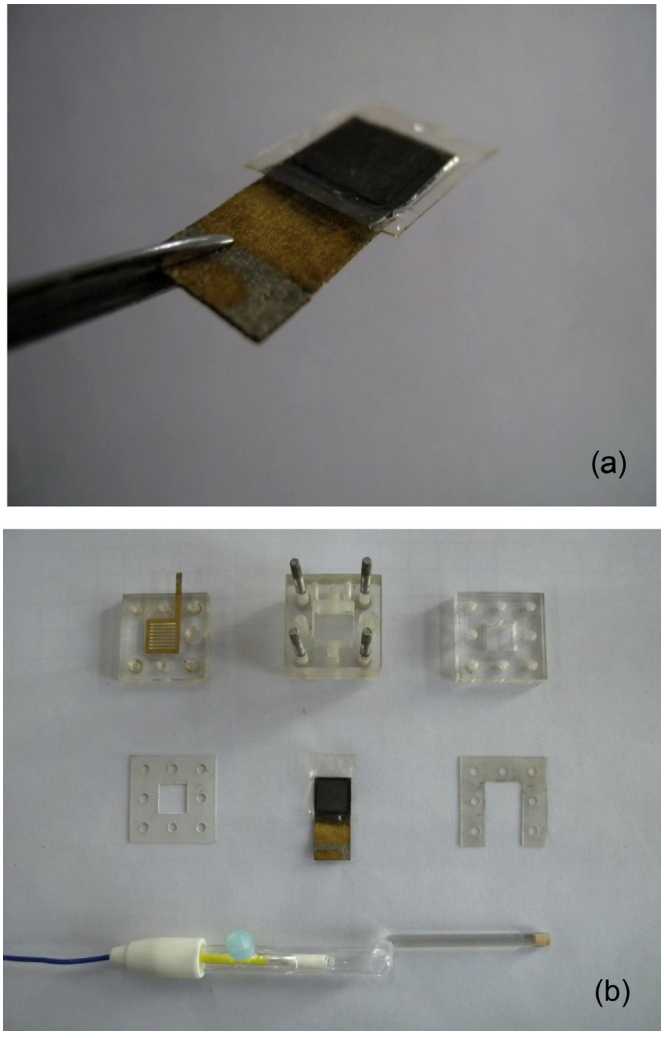

Fig. 1. Photographs of SSFF-MEA (a) and all parts of the single cell (b).