Journal of Power Sources 273 (2015) 375–379

Contents lists available at ScienceDirect

Journal of Power Sources

journal homepage: www.elsevier.com/locate/jpowsour

Short communication

A water management system for metal-based micro passive direct methanol fuel cells

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HIGHLIGHTS

- Aluminum alloy is used to fabricate cathode end plate with perforated flow filed.
- Water-collecting channels and PEO coating are fabricated on cathode end plate.
- Air-breathing holes can be free of water accumulation.
- Water flooding of cathode flow field can be prevented.

ARTICLE INFO

Article history:
Received 22 January 2014
Received in revised form
6 September 2014
Accepted 8 September 2014
Available online 16 September 2014

Keywords:
Direct methanol fuel cell
Water flooding
Plasma electrolytic oxidation
Current collector

ABSTRACT

A novel water management system for micro passive DMFC is fabricated and characterized in this paper. This system consists of both a cathode current collector made of a 316L sintered stainless fiber felt (SSFF) and an aluminum-based end plate fabricated with a perforated flow field. Besides, some water-collecting channels were fabricated on the surface of the cathode end plate and then covered by the plasma electrolytic oxidation (PEO) coating. The results show that the PEO coating plays crucial roles in the water management system. Because of the highly hydrophilic property of the coating, the channels work well in collecting the liquid water from the current collector, and water accumulation along the air-breathing holes can be well prevented, which improves the stability of the micro DMFC.

1. Introduction

With the rapid development of portable electric devices, there has been an ever-increasing demand on micro power sources with high energy density. Direct methanol fuel cell (DMFC) is an attractive candidate due to its simple structure, instantly recharging and prospective energy density [1–3]. To make it more competitive, DMFC can be operated in a passive mode by eliminating auxiliary devices, relying on diffusion and natural convection to provide fuel and oxygen [4,5]. Such a passive design simplifies the cell structure greatly, but the poor transport makes its performance worse than those running in an active mode [4–6].

Water flooding is one of the key issues that can lower the output power and deteriorate the stability of a micro passive DMFC [4]. On the cathode, water that is generated by oxygen reduction reaction, along with that crosses from the anode, transports through the diffusion layer to the flow field [7]. Unlike those running in an active mode where air flow can take the water away, a passive DMFC mainly rely on gravitational force or wettability gradients to get the liquid water off [4]. Such an operation mode can easily result in accumulation of liquid water inside the diffusion layer, forming a so-called water flooding problem and constraining oxygen transportation [4–7]. Thus, it is quite necessary to optimize the cathode structure to enhance the water removal ability.

In recent years, researchers have developed some methods to release the water flooding problem of a micro passive DMFC [8–12]. Chen and Li adopted metallic porous materials as cathode current collector, and the liquid water can be removed at a faster rate as a result of the capillary action in the porous structure [8,9].

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http://dx.doi.org/10.1016/j.jpowsour.2014.09.059
0378-7753/

Some effective strategies to enhance water removal are achieved on silicon-based micro passive DMFCs [10–12]. Yao et al. fabricated some alternative hydrophilic and hydrophobic holes on the cathode plate [10]. Liquid water can be driven passively into the hydrophilic holes, while the hydrophobic holes provide the oxygen diffusion path. Peng and Zhou fabricated some capillary channels with hydrophilic surface along the ribs of the air-breathing holes [11,12]. The water generated on the surface of cathode diffusion layer can be drawn into these channels by capillary force. Despite the effective removal of water droplets in the aforementioned designs, it is clear that these silicon-based fabrication methods are not suitable for a metallic substrate.

In this communication, we proposed a novel water management system for metal-based micro passive DMFC to reduce the water flooding problem effectively. The system includes a hydrophilic coating, some water-collecting channels and a stainless steel felt fiber. A micro passive DMFC was fabricated with the novel structure and tested by polarization and constant-current-density discharging.

2. Design and fabrication

Fig. 1a schematically shows the structure of the micro passive DMFC. A 316L stainless steel fiber felt with 0.25 mm in thickness was used as cathode current collector. Aluminum alloy LY12 was adopted to fabricate the cathode end plate that had a perforated flow field, as shown in Fig. 1b. At the back side contacting with the current collector, there are several water-collecting channels with 0.3 mm in width and 0.5 mm in depth in the active area between every two rows of the holes. At the front side, several water-collecting channels are also fabricated to go through the plate, connecting with the ones at the back side. To make the liquid water flow fluently in the channels, two additional lines of holes were fabricated respectively on the top and bottom of the flow field.

In the design, liquid water produced inside the porous current collector is expected to be drawn into the water-collecting channels and flow down automatically under the gravity. To achieve this purpose, a highly hydrophilic coating (shown schematically in Fig. 1b as a gray part) was fabricated on the surface of the cathode end plate by plasma electrolytic oxidation (PEO) technology [13,14]. The PEO treatment was carried out for about 30 min in a mixed solution of 10 g L^{-1} Na_2SiO_3 and 1 g L^{-1} NaH_2PO_2 by a homemade 5 kW AC power supply with the frequency of 1000 Hz. The as-prepared coating is composed of aluminum silicate and aluminum oxide and possesses a typical crater-like structure resulting from the breakdown [15].

A micro DMFC with the novel structure was fabricated. Commercial anode (Pt loading: ca. 2 mg cm^{-2}) and cathode (PtRu loading: ca. 4 mg cm^{-2}) gas diffusion electrodes, purchased from Johnson Matthey, Inc., were attached to a pretreated Nafion membrane with hot pressing at 135 °C and 10 MPa for 180 s. The as-prepared membrane electrode assembly (MEA) has an active area of 1 cm^2. The anode current collector with some parallel channels and 43.2% open ratio was fabricated with 316L stainless steel. To reduce the contact resistance, all the current collectors were coated with 200 nm Au layer. As references, another two micro DMFCs were also fabricated. One of them (named as reference-a cell for simple description) is a conventional one whose cathode current collector has perforated flow field and is coated with Au layer. The other (named as reference-b cell) has the same configuration as shown in Fig. 1a, but its cathode end plate is covered by Au layer instead of PEO coating. The Au deposition does not cause significant variation to the water management of reference-b cell because the wettability of the end plate does not change a lot with the Au layer [16].

In our micro DMFCs, air was supplied to the electrodes through the open areas only by diffusion, and methanol solution diffused into the anode catalyst layer from a 2.5 mL reservoir that was adhered to the anode fixture. Prior the performance test, the cell

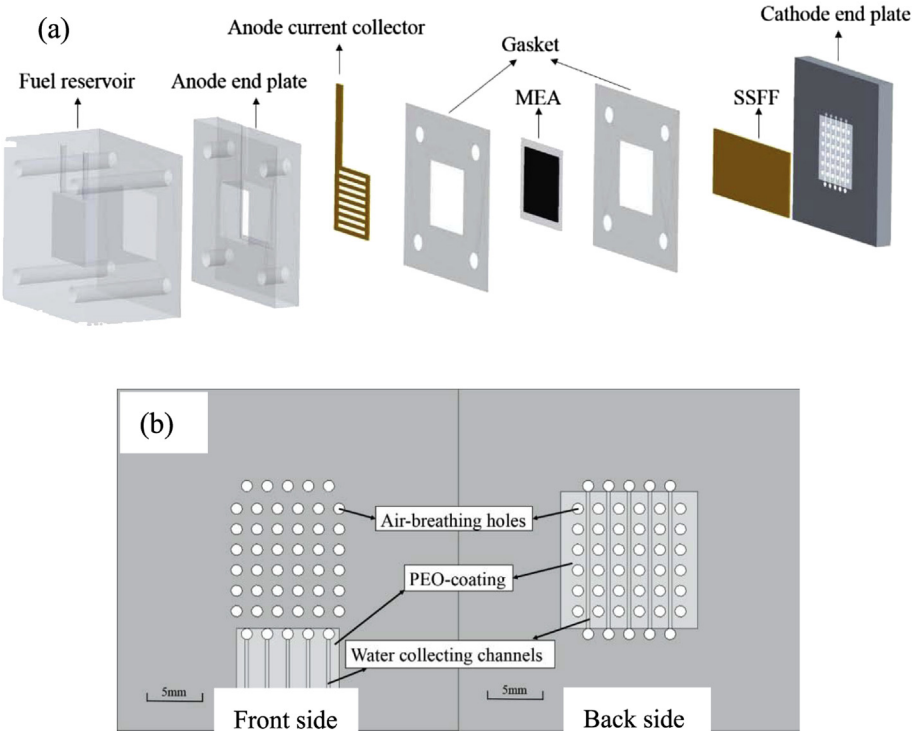

Fig. 1. Schematic structure of the novel micro passive direct methanol fuel cell (a) and the cathode end plate (b).