

Porous current collectors for passive direct methanol fuel cells

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Abstract

A passive direct methanol fuel cell (DMFC) with its cathode current collector made of porous metal foam was investigated experimentally. The measured polarization curves, constant-current discharging behavior and EIS spectra showed that the passive DMFC having the porous current collector yielded much higher and much more stable performance than did the cell having the conventional perforated-plate current collector with high methanol concentration operation. It was demonstrated that the improved performance for the porous current collector was attributed to: (i) the enhanced oxygen transport on the cathode as a result of a larger specific transport area, (ii) the increased operating temperature as a result of the lower effective thermal conductivity of the porous structure, and (iii) the faster water removal as a result of the capillary action in the porous structure. The experimental results also revealed that the porous current collector with a smaller pore size yielded higher performance as a result of the lower cell resistance.

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1. Introduction

The high energy density of liquid methanol as well as simple and compact power systems make the direct methanol fuel cells (DMFC) a promising power source for portable electronic devices. Over the past decade, extensive efforts [1–8] have been made to the study of the DMFC with the fuel fed by a liquid pump and oxidant fed by a gas compressor. In order to make the DMFC more competitive with conventional battery technologies, however, it is essential to eliminate some auxiliary devices such as liquid pumps and gas fans/blowers so that the overall DMFC system becomes much simpler and much more compact. For this reason, the concept of a passive DMFC without external pumps and other ancillary devices has been proposed and studied [9–18]. A typical passive-feed DMFC consists of a fuel reservoir, an anode current collector, a membrane electrode assembly (MEA), and a cathode current collector. Methanol is introduced to the active layer primarily by diffusion without any external means of liquid transport and oxygen is taken passively from the ambient air without any means of air movement. This type of passive DMFCs not only offers the advantage of simple

and compact systems but also makes it possible to eliminate the parasitic power losses for powering ancillary devices required in active DMFCs. Because of these advantages, the passive DMFC has received much more attention. Chen and Yang [10] investigated the effect of operating conditions on the power density of an air-breathing DMFC. Liu et al. [11] studied sintered stainless steel fiber felt as the gas diffusion layer in an air-breathing DMFC. The effect of methanol concentration was also studied in this work. Kim et al. [12] fabricated and tested a single cell and monopolar DMFC stack operating under passive and air-breathing conditions. Shimizu et al. [13] reported their activities regarding the research and development of DMFCs that operated passively at room temperature. Park et al. [15] reported the optimal methanol solution appeared at 4.0 M in passive DMFCs. Kho et al. [17] investigated the variation in the open circuit voltage (OCV) and the cell temperature with time as a consequence of the methanol crossover.

The previous studies have indicated that the passive DMFC usually has to be operated with higher methanol concentration, as the methanol transport from a built-in fuel reservoir to the anode catalyst layer in this type of passive fuel cell relies on diffusion. Since there is plenty of room up to pure methanol, methanol transport on the anode is actually not a problem. Rather, higher methanol concentration offers the advantage of increasing the energy density of the fuel cell, provided that the

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rate of methanol crossover can effectively be reduced. In contrast, the problem of mass transport of oxygen and water on the cathode is more challenging, as this type of fuel cell operates on the air-breathing mode and there is no external means to enhance oxygen transport and water removal. As a result, the passive fuel cell frequently operates under the oxygen-starving and water-flooding conditions. In addition, it was recently found that passive DMFCs operate at near room temperature and it is important to increase the cell operating temperature so that electrochemical kinetics of both methanol oxidation and oxygen reduction reactions can be improved [18,19]. In summary, on the constraint without any external means of air movement, it is critical to design and optimize the architecture of the passive DMFC to ensure higher oxygen transfer and water removal rates as well as a higher cell operating temperature.

The cathode current collector is one of the key components of the passive DMFC, which not only collects the electric current but also offers the passages for oxygen and water transport. Furthermore, since in the passive DMFC, the heat generated within the cell is predominately lost from the cathode current collector, it is essential to employ a material with low effective thermal conductivity as the cathode current collector such that the heat loss can be lowered and the cell can be operated at a higher temperature to achieve better performance. Therefore, in the passive DMFC, the cathode current collector must have high electric conductivity, good mechanical strength, more uniform transport area and low effective thermal conductivity. In this work, a passive DMFC with its cathode current collector made of porous metal foam was investigated experimentally. We show that this type of porous current collector can not only provide a higher oxygen transfer rate and a more effective water removal rate, but also can render a higher cell operating temperature.

As a consequence, the cell having this type of porous current collector yielded significantly higher performance and much more stable operation than did the cell having the conventional perforated-plate current collector.

2. Experimental

2.1. Membrane and electrode assembly (MEA)

A pretreated Nafion 115 membrane with a thickness of 125 μm was employed in this work. The pretreatment procedures included boiling the membrane in 5 vol.% H_2O_2 , washing in DI water, boiling in 0.5 M H_2SO_4 and washing in DI water for 1 h in turn. The pretreated membranes were kept in the DI water prior to the fabrication of MEAs. Single-side ELAT electrodes from ETEK were used in both anode and cathode, where carbon cloth (E-TEK, Type A) were used as the backing support layer with 30 wt% PTFE wet-proofing treatment. The catalyst loading on the anode side was 4.0 mg/cm^2 with PtRu black (1:1 a/o), while the catalyst loading on the cathode side was 2.0 mg/cm^2 using 40 wt% Pt on Vulcan XC-72. Furthermore, 0.8 mg/cm^2 dry Nafion[®] ionomer was coated onto the surface of each electrode. Finally, MEA with an active area of 4.0 cm^2 were fabricated by hot pressing at 135 $^\circ\text{C}$ and 4 MPa for 3.0 min. More detailed information about the MEA fabrication can be found elsewhere [20].

2.2. Single cell fixture

As shown in Fig. 1, the MEA mentioned above was sandwiched between an anode and a cathode current collector. The entire cell setup was then held together between an anode and a

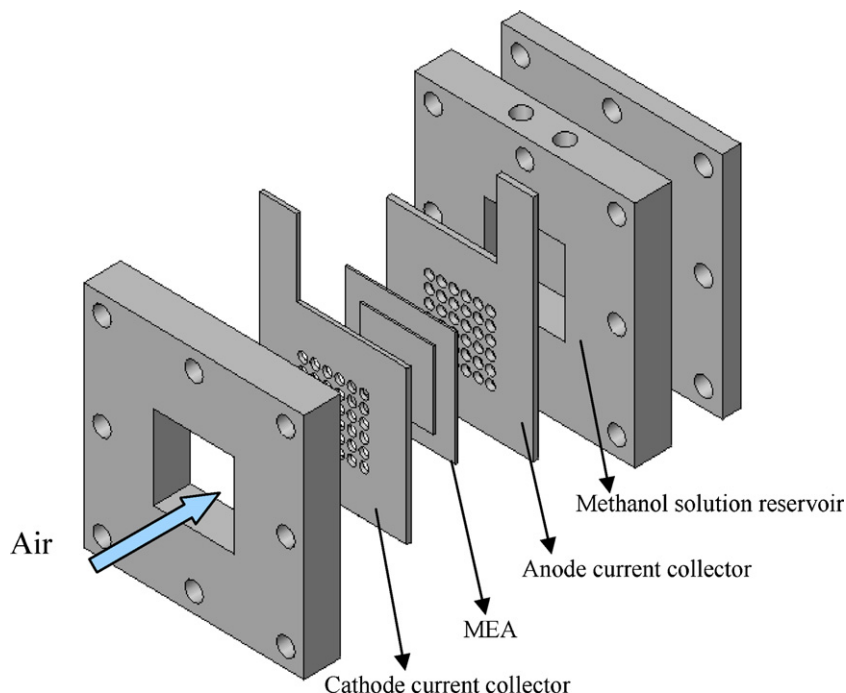


Fig. 1. Schematic of the passive DMFC.

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