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Fabrication and performance evaluation for a novel small planar passive direct methanol fuel cell stack

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ABSTRACT

In this paper, several practical operating performances were evaluated with a novel small passive direct methanol fuel cell (DMFC) stack in different potential application conditions. Combined with a DC–DC convertor, the fuel cell can realize a much more stable constant voltage output; combined with super capacitors, it can provide a large current pulse discharge. After a reproducible operation of approximately 300 h at 60 mA with five times of refueling fuel, the Faradic efficiency and energy efficiency were a little decreased and the maximum performance degradation was approximately 8%. As increasing the operating time, the methanol crossover and produced water at the cathode could cause the fuel cell performance degradation. Before realizing the portable application of passive DMFC, the stability of the cell for a long-term operation as well as the increase of the energy conversion efficiency is an important problem to be solved.

1. Introduction

The direct methanol fuel cell (DMFC) as a promising power source for portable applications has attracted more and more attention due to its high energy density, long operation time, no need for charging and the simple system design [1–6]. Many efforts have been made to study the passive DMFC. For instance, Chu and Jiang [7] investigated the effect of operating conditions on the performance and energy efficiency of a small passive DMFC. Liu et al. [8] studied sintered stainless steel fiber felt as the gas diffusion layer in an air-breathing DMFC. Bae et al. [9] investigated the effect of methanol concentration, catalyst loading and reactants supply modes on the performance of a passive DMFC. Shimizu et al. [10] reported their activities regarding the research and development of DMFCs operated passively at room temperature. However, over the past decades, most of previous investigations concerning the passive DMFC were focused on single cell [11]. In fact, fuel cells do not operate as a single-unit; they are connected in series to achieve a great and more useful potential [12–14]. Therefore, in order to realize the commercial application, the development of the passive DMFC stack is required. Several studies on the development of DMFC stacks have been reported. For example, Chang et al. [15] reported a DMFC stack with 12 cells connected in series. The active area of each cell in the stack was 2.0 cm^2. The DMFC stack can provide a peak power output of 560 mW at 2.8 V. Chen and Yang [16] developed an air-breathing DMFC stack that consisted of four cells with a maximum power output of 342 mW at 1 V. Lu et al. [17] fabricated an 8-cell air-breathing DMFC stack which produced a maximum output power of 1.33 W at 2.21 V at room temperature. Guo et al. [18] developed DMFCs on printed circuit board and obtained a power output of 21 mW. Chan et al. [19] developed a DMFC stack for a seagull display kit with a power output of 350 mW at 1.8 V. Baglio et al. [20] fabricated a three-cell DMFC stack with a power output of 225 mW with the power density of 20 mW cm^{-2}. In addition, Zhu et al. [21] developed a twin stack containing eight DMFCs and obtained a power output of 545 mW.

However, the details of the stack design and fabrication are not addressed in the literatures and several technical issues still remain to be overcome in order to enter the portable energy market with successful commercial application. Most of the researches employed a small reservoir; therefore, the fuel cell operated only several minutes or hours and the result was not enough for the practical application. Due to the short operation time, some of the results were not helpful for the long-term operation of the fuel cell. Therefore, in this paper, a passive DMFC stack was designed and assembled; the stack was operated completely at room conditions. In order to check the long-term operation, a much bigger reservoir was employed. The constant current discharge, the constant voltage output and pulse discharge ability were tested. In addition, the Faradic conversion efficiency and the energy conversion efficiency were evaluated. At last, a reproducible operation of the whole operation time of about 300 h with five times of refueling

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fuel was also conducted to evaluate the stability and reproducibility of the stack at all ambient conditions. The results have potential contribution for the development of passive DMFCs.

2. Experimental

2.1. Fuel cell design and test

Graphite plate or conductive metal was usually used as the pole plate to collect the current in a single cell. However, for a planar fuel cell stack, each single cell should be separated from the neighbors; or else, the cell stack will become a big single cell. Here, the unsaturated polyester plate with high rigidity and insulation was used to fix the current collectors. The schematic illustrations of several components are shown in Fig. 1. Take three single cells in the same side for example, the fuel cell body of a window frame is shown in Fig. 1a. It was made of polycarbonate, which can provide an enough rigidity to support the unit cells. The anodic side support plate (Fig. 1b) was a whole plate, but the cathodic side support plate (Fig. 1d) was separated individually. For this design, it is easy to fix the membrane electrode assembly (MEA); if one single cell does not work well, it is easy to check or replace the MEA with a new one. The parallel channels in the anode support and the circle open in the cathode support were machined. The anode channel with large open space in the anode support plate was used to transport the methanol to the anodic side of MEA and the circle open in the cathode support plate were used for air diffusion, respectively [14,22]. The flow fields in the anode and cathode were concave and the depth depended on the thickness of MEA and current collectors. The current collectors were made from 0.5 mm of 316L stainless steel mesh and the surfaces were electro-deposited by Au to decrease the contact resistance with MEA. Before use, two current collectors were connected together according to the Fig. 1c. One current collector was used in the anode for a single fuel cell and the other one was used in the cathode for the neighboring single fuel cell; in this sequence, the single fuel cell can be connected in series through the current collector. When the MEA was fixed between the anodic and cathodic support plate, the cell was held together by means of a set of four retaining bolts positioned at the periphery of the single cell. The gaskets and the adhesive–sealant silicone were used to prevent methanol leakage from the reservoir. All the tests of the passive DMFC stack were performed with a Fuel Cell Test System (Arbin Instruments Co.) at ambient conditions.

2.2. MEA preparation

The electrodes were fabricated as follows. Carbon papers (Toray) with 10 wt.% PTFE wet-proofing treatment were used as the backing support layer. Then, a micropore layer (MPL) consisted of carbon black (Vulcan XC-72) and PTFE was applied onto the carbon papers. The PTFE content and carbon loading of MPL for the diffusion layers were 20 wt.% and 2 mg cm^{-2}, respectively. The catalysts for anode (Pt–Ru black, HiSpec 6000) and cathode (Pt black, HiSpec 1000) were purchased from Johnson-Matthey Co. and used as-received. The catalyst loading on the anode and cathode was 8.0 mg cm^{-2}. The Nafion ionomer (5 wt.%, DuPont, USA) loading in the catalyst was 10 wt.% for the cathode and 15 wt.% for the anode, respectively. A Nafion 117 membrane (Dupont Co.) was used as the polymer electrolyte membrane. The pretreatment process of the membrane 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 catalysts were then mixed with Nafion solution (Dupont Co.), water and isopropyl alcohol to form a catalyst ink. The catalyst ink was applied onto the gas diffusion medium. The Nafion membrane sandwiched between the anodic and cathodic electrode was hot-pressed at 3.5 Mpa and 130 °C for 150 s. Surface area of each electrode was 5 cm^2 and the total area of the stack was 50 cm^2 with 10 single cells connected in series.

3. Results and discussion

For the purpose of obtaining the best performance, the polarization curves as well as the power and power density curves with different methanol concentration are shown in Fig. 2. The feature of the curves was consistent with the results published elsewhere [9,13,14]. Simply, the cell performance increased with increasing methanol concentration up to 4 M and then decreased; the maximum power reached about 1.3 W (26 mW cm^{-2}) using 4 M methanol solution. The output power was lower than 1 W for 2 M methanol solution due to the methanol transport limitation at high current density. Although there was no mass transport limitation for 5 M methanol solution, the higher methanol concentration would cause larger methanol crossover to cathode, where the

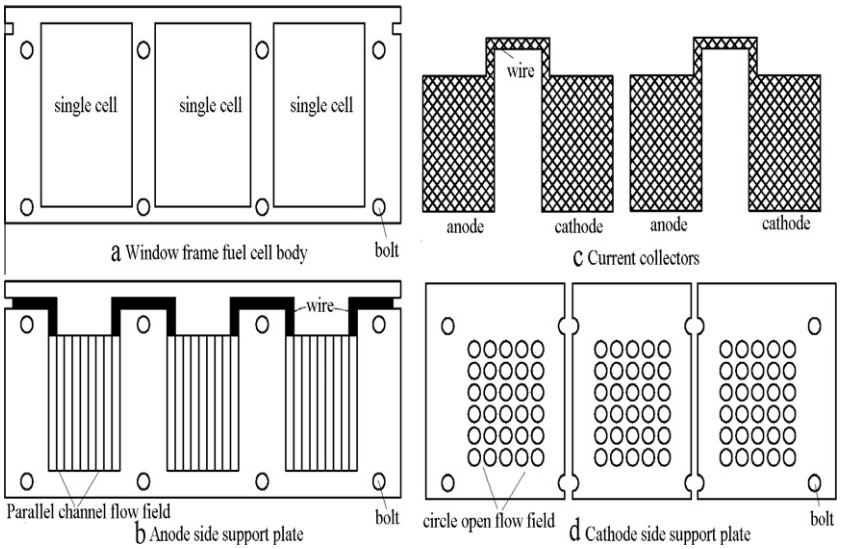

Fig. 1. The schemes of the fuel cell body, current collector, the anodic and cathodic support plate.