Energy 144 (2018) 587—593

Contents lists available at ScienceDirect

Energy

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

A bipolar passive DMFC stack for portable applications

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ARTICLE INFO

Article history:

Keywords:
Direct methanol fuel cell stack
Bipolar
Passive
Portable applications

ABSTRACT

A bipolar passive direct methanol fuel cell (DMFC) stack for portable applications is designed, fabricated and tested. Stainless steel sheet is chosen to fabricate the current collectors by using the traditional wire cutting and laser beam cutting techniques. A 3.5 μm Au layer is deposited on the current collectors using electroplating method to prevent electrochemical corrosion. A novel design of the current collectors is proposed, which makes internal and external electrical connections be seamlessly integrated so that the resistance loss can be reduced. The maximum power density of the passive stack is 18.7 mW cm^{-2} at 3 M methanol concentration. The effect of the passive DMFC stack placement mode is studied. The results indicate that the passive DMFC stack in mode B (vertical cathode air channels) exhibits better and more stable performance than its counterpart in mode A (parallel cathode air channels) in discharging of high currents. Finally, the bipolar passive DMFC stack proves its good performance in powering the experimental fan in 100 days while performance deterioration behaviour is also detected.

1. Introduction

Fuel cell as environment-friendly energy conversion device can directly convert chemical energy into electricity. Direct methanol fuel cells (DMFCs) are one sort of the fuel cells that have various advantages in respect of high energy density, easy methanol storage and free of charge by comparison to conventional batteries. Therefore, DMFCs are considered to be the most promising power source candidate to replace Li based batteries for portable applications [1—6]. Based on the supply of the reactants, there are two types of DMFCs: active and passive. In active DMFCs, external devices (e.g., pumps, blowers or fans), which deliver the reactants and remove the products, lead to higher complexity and lower specific energy density for the system. For passive DMFCs, which do not require auxiliary supplying devices but instead utilize diffusion and natural convection to supply the reactants and remove the products, are a better choice for portable power applications because of their simple structure, low weight, and limited parasitic power losses [7—12].

In portable applications, a single passive DMFC is hardly to be used alone because the output voltage of a single cell is limited. Therefore, it is essential to investigate the passive DMFC stack to fulfill the practical applications. In the study of the passive DMFC, there are still many barrier issues to limit the industrialization of DMFC, such as methanol crossover, slow anode kinetics reaction, heat and water management, durability and stability and so on [13—15]. For passive DMFC stack, the connection design and structure are also important issues which have an great impact on the above issues because a well-designed structure can not only improve the stability and the performance of the passive DMFC stack, but also reduce the parasitic loss and save the cost. The primary consideration in the stack structure design is internal connection since most stacks are in-series connected. According to the arrangement of unit cells, in-series stacks can be classified into two types: bipolar and monopolar. Usually, passive DMFC stacks adopt the monopolar arrangement because this arrangement could make the cathode exposed to the ambient air to maximize the transport of oxygen and water [12]. Chan et al. [16] reported a monopolar passive DMFC stack with 6 cells connected in series, which could generate a peak power density of 10.3 mW cm^{-2} with 6 M methanol. Zhu et al. [17] also designed a monopolar 8-cell twin-stack by using TiN-plated mesh to decrease the internal resistance and increase the performance, in which a peak power density of 16.9 mW cm^{-2} was achieved with 4 M methanol. For design of monopolar arrangement, the limit on the cell number in a stack is a salient issue since too many unit cells in a stack can

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https://doi.org/10.1016/j.energy.2017.12.039
0360-5442/

seriously weaken the stability and reliability of the system. To solve this problem, Wang et al. [18] recently developed a 4-cell modular passive DMFC stack, which could be freely combined and applied to various electronic devices. The PCB based accessories had been designed for electrically connecting and mechanically assembling the 4-cell modules.

Because the bipolar arrangement may lead to water flooding at the cathode, which is more suitable for active DMFC stack, few researchers adopt the bipolar arrangement to design the passive DMFC stack. Hashim et al. [19] designed and fabricated a PMMA (polymethyl methacrylate) based micro-DMFC stack with six cells by using stainless steel mesh as current collectors. Such a micro-DMFC stack may greatly save the cost of entire DMFC stack but lose the performance that only 12.05 mW was achieved by 6-cell stack.

The main objective of this study is to develop a high-performance bipolar passive DMFC stack for portable applications using cheap fabrication procedure that can break through traditional structure restrictions that difficult bipolar design for passive DMFC stack. A novel design of the current collectors is proposed, which makes internal and external electrical connections be seamlessly integrated so that the resistance loss can be reduced. The bipolar passive stack is fabricated and tested. The effect of the methanol concentration on the performance of the passive stack is also investigated. In addition, the effect of the DMFC stack placement mode is studied. Finally, the stable testing and deterioration analysis of the bipolar passive DMFC stack is carried out.

2. Design and fabrication

2.1. Design and fabrication of bipolar passive stack

The structure of the proposed bipolar passive DMFC stack is shown in Fig. 1. From Fig. 1, it can be seen that this structure can readily assemble multiple cells together in one DMFC stack. This structure mainly consists of bipolar plates, bipolar current collectors and membrane electrode assemblies (MEAs). To reduce the costs, PMMA is selected as the materials of bipolar plates. The structure of the bipolar plate is shown in Fig. 2. On the anode side, a square groove is fabricated as a methanol solution reservoir. On the cathode side, five parallel shaped flow patterns are fabricated to lead the oxygen from the air into the cathode side. Two 300 μm deep grooves in the current collector shape are also fabricated on the both side of the bipolar plate, respectively. Each anode side have a feed hole to inject methanol into the cell.

316 L stainless steel plates with a thickness of 300 μm are chosen to fabricate the current collectors because of the good material characteristics in electric conductivity and electrical corrosion resistance. Firstly, stainless steel plates are cut into small pieces with a specific size required using wire cutting technology. Secondly, 25 circular holes are perforated through the stainless steel plates by laser beam to provide the path for mass transportation, resulting in an open ratio of 44%. Thirdly, the surface of the plates is

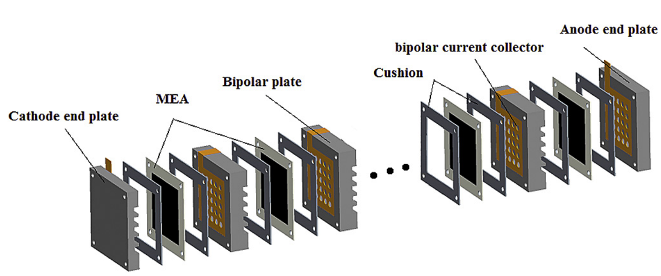

Fig. 1. Schematic of the proposed bipolar passive DMFC stack structure.

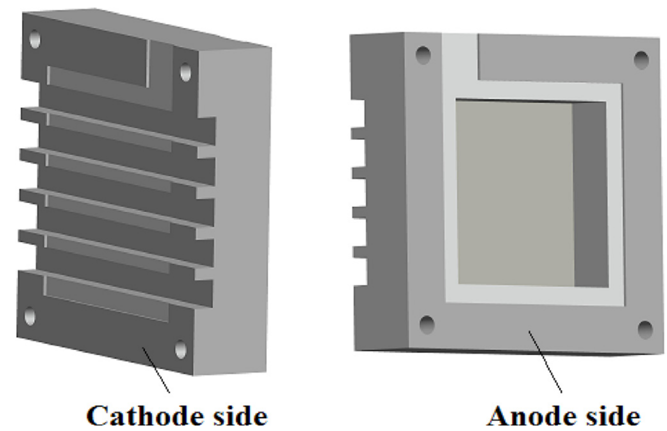

Fig. 2. Schematic of the bipolar plate.

coated with Ni/P and Au layer using electroplating method. Ni/P coating between stainless steel current collector and Au layer can further prevent electrochemical corrosion and compactly cover the circular hole of the stainless steel current collector, which enhance the binding force and prevent Au layer separated from stainless steel substrate. This method is cheap and the stainless steel current collector can be fabricated in a large scale. Finally, the stainless steel current collector is folded twice to form the eventually shape, as shown in Fig. 3. It can be observed that the DMFC stack can be directly connected in series through this current collector design. A salient merit of this current collector design is that internal and

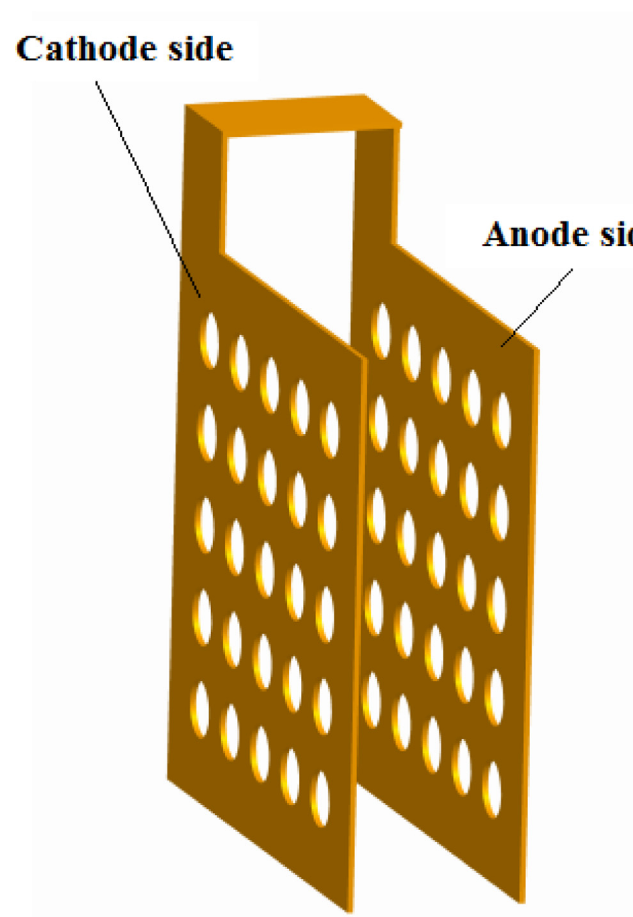

Fig. 3. Schematic of the bipolar current collector.