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Investigations of silicon-based air-breathing micro direct methanol fuel cells with different anode flow fields

Huichao Deng [a], Shengtian Sang [a], Yufeng Zhang [a,b,*], Zipeng Li [a], Xiaowei Liu [a,b]

[a] MEMS Center, Harbin Institute of Technology, Harbin 150001, China
[b] Key Laboratory of Micro-Systems and Micro-Structures Manufacturing, Ministry of Education, Harbin 150001, China

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ABSTRACT

Different anode flow fields of air-breathing micro direct methanol fuel cells (μDMFCs) are investigated to improve the cell performances. The single-serpentine flow field can effectively improve the methanol mass transport efficiency and exhibit higher exhaust resultant (CO_2) rates than other flow fields such as gird, parallel and double-serpentine. Additionally, the effects of open ratios and channel lengths on the cell performance are evaluated to determine the optimal anode flow field structures. The μDMFCs with different anode flow fields are fabricated using silicon-based micro–electro–mechanical systems (MEMS) technologies and are tested at room temperature. The experimental results show that the single-serpentine flow field exhibits a significantly higher performance than those of other flow fields, demonstrating 16.83 mW cm^{-2} in peak power density and a substantial increase in mass transport coefficients. Moreover, for optimum single-serpentine flow field, it is appropriate for the flow channel dimensions to be in the ratio of 2:3:254 for channel width: ridge width: channel length.

1. Introduction

In recent years, micro direct methanol fuel cells (DMFCs) based on MEMS technology possess many advantages, such as high energy conversion, fuel efficiency, room temperature operation, simple structure, and high power density. Therefore, they have reached a breakthrough point and will likely be used in portable and mobile electronic products such as laptops and mobile phones in future [1–5]. Concerning micro DMFC technologies, anode flow field configurations have been paid increased attention to, which is a crucial factor for micro DMFC applications [6–10].

The current collector is an important component of micro DMFCs, which not only supplies a passage for the reactant transport, but also provides the structural supporter for the weak membrane electrode assembly (MEA) and collects the current. The anode flow field design is critical to yield better performances of micro DMFCs. At present, studies of anode flow fields mainly include parameter optimizations and new configuration designs [11–13]. Lai et al. [14] investigated the effect of anode flow fields on the performance of passive DMFC, and the results revealed that the passive DMFC with anode perforated flow fields exhibited rather worse performance than that with parallel ones. Yang et al. [11] investigated the effects of different anode flow fields and parameters on the cell performance, and the experiments indicated that single serpentine flow fields performed better than parallel ones. Similarly, Zhao et al. [10] fabricated a micro DMFC with an active 1.0 × 1.0 cm area to investigate the effects of flow field structures on the cell performance and reached the same conclusions. Furthermore, the channel depths of serpentine flow fields were optimized experimentally. Wang et al. [15] developed a micro DMFC with an active area of 1.625 cm^2 assembled by sandwiching the MEA between two silicon substrates with three-serpentine flow field configuration, in which 750 μm wide and 400 μm flow channels were fabricated using MEMS technology. The results demonstrated a maximum power density of 16 mW cm^{-2} with both 2 and 4 M at room temperature. Zhang et al. [16] presented a self-breathing micro DMFC characterized by an anode structure with tapered single serpentine flow fields to improve the methanol mass transport efficiency and the exhaust resultant (CO_2) rate. Moreover, new anode flow fields were also presented to improve the performance of DMFCs [17–21].

Configurations and parameters of anode flow fields have great effects on the performance of micro DMFCs. Utilizing optimum flow fields, the power density of micro DMFCs can be increased by about 50% [22]. Different flow fields are generally applied in anode configurations of micro DMFCs, such as parallel channel, serpentine channel and spiral channel. Owing to the mass transport shadow region of an under-rib diffusion layer from the channel to the electrode, it results in the fall of methanol transport efficiency and the deterioration of the cell performance. In fact, the

* Corresponding author. Address: Box 328, Harbin Institute of Technology, Harbin 150001, China. Tel.: +86 451 86413451; fax: +86 451 86413441.
E-mail address: yufeng_zhang@hit.edu.cn (Y. Zhang).

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pressure difference between adjacent flow channels of the ribs determines the convection and diffusion of the methanol molecules in the electrodes. If the transport rates increases with an increment of the pressure difference, the methanol transport efficiency to the catalyst layer is improved and the resultant (CO_2) is also exhausted from the flow channels more quickly. Based on the above considerations, we investigate different anode flow fields of self-breathing micro DMFCs, as illustrated in Fig. 1. The single serpentine flow fields can effectively improve the methanol mass transport efficiency and exhibit higher exhaust resultant (CO_2) rates than other flow fields such as gird, parallel and double-serpentine. Additionally, the effects of open ratios and channel lengths on the cell performance are evaluated to determine the optimal anode flow field structures. Using silicon-based MEMS technology, the self-breathing micro DMFCs are fabricated and tested to obtain the optimum structure parameters for single serpentine flow fields.

2. Fabrication and assembly

In this work, the anode current collectors with different flow patterns were fabricated using bulk-silicon MEMS technology. The silicon wafers with ⟨1 0 0⟩ crystal orientation were utilized as anode current collectors, including grid, parallel, single-serpentine and double-serpentine channels. First, clean the silicon wafer by ultrasonic and a 0.8-μm-thick Si_3N_4 layer was deposited on the silicon substrates with low pressure chemical vapor deposition (LPCVD). Photolithography was applied to pattern microchannels on the Si_3N_4 layer. The flow channels depth of 240 μm were etched using an anisotropic etching process of 40% KOH solution at 40 °C, then Si_3N_4 layer was removed by reaction ion etch method. Considering portable applications, the cathode current collectors with air-breathing perforated structure were employed to fabricate the self-breathing openings with a radius of 0.3 mm on the silicon wafer by laser cut. In fact, the program radius which is set on the laser machine should be a little smaller than 0.3 mm because the remnant heat can increase the radius of opening. To collect current and minimize contact resistance, a Ti/Au (0.05/1.0 μm) layer was sputtered on the current collectors as shown in Fig. 2. During the laser ablation, the incisions on the silicon is burnt by the high energy of laser (Lumonics JK702 Nd: YAG laser, made in the UK), however, this Ti/Au layer sputtered process can repair the electrical conductivity of incisions.

A piece of 5-layered MEA with an active area of 0.8 × 0.8 cm fabricated by the catalyst coated membrane (CCM) method was employed in the silicon-based micro DMFC. The hydrophilic catalyst layer was prepared utilizing the decal transfer method to form

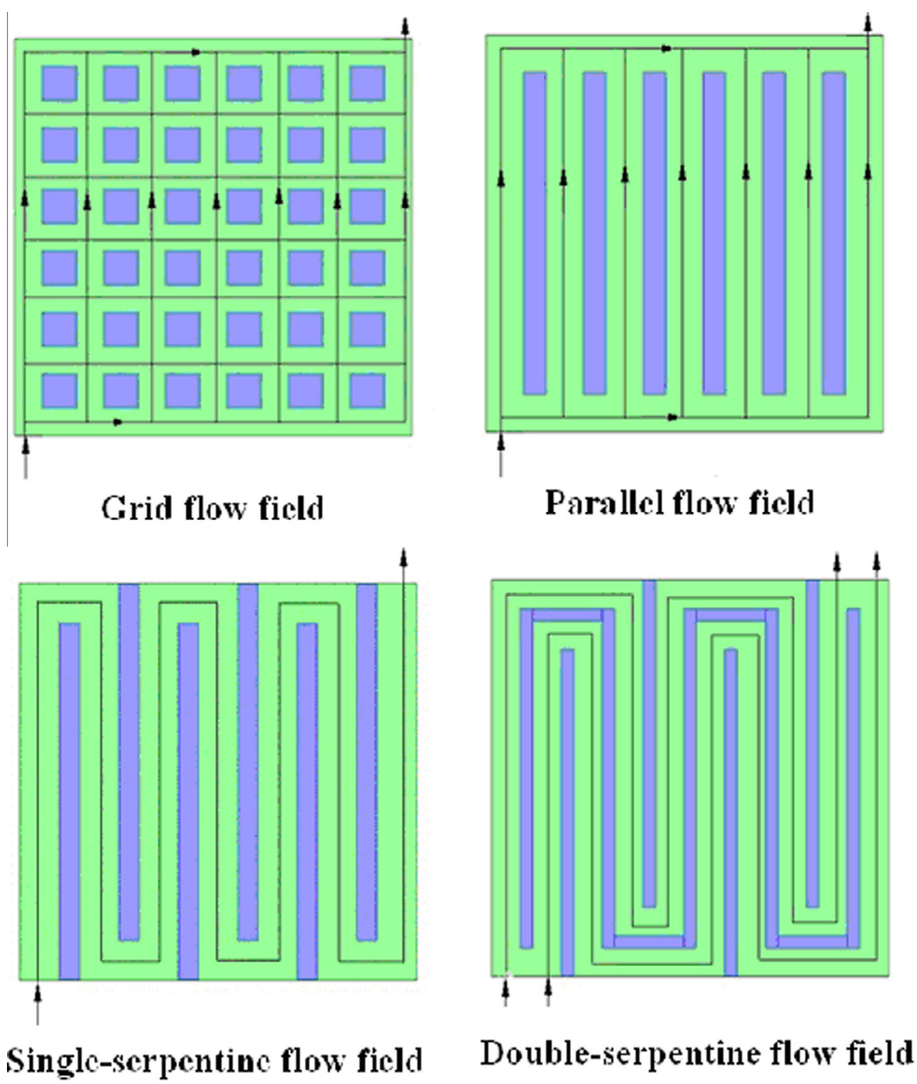

Fig. 1. Design of the anode flow fields.