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Development and performance analysis of a metallic passive micro-direct methanol fuel cell for portable applications

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ABSTRACT

Due to the growing interest on miniaturization for application on portable devices, the Micro Direct Methanol Fuel Cells (Micro-DMFC) proved to have great benefits. Passive fuel cells have extra advantages leading to less complex and cheaper systems. In the present work, an experimental study on the performance of a passive Micro-DMFC with an active area of 2.25 cm^2 working at ambient conditions is described. Several commercially available materials for Membrane Electrode Assembly (MEA) are tested including materials with low platinum content to achieve lower prices. The effect of methanol concentration on the cell performance is evaluated. The performance is compared with the one obtained using an active Micro-DMFC with the same active area. A optimized design is proposed corresponding to a maximum power density, 19.2 mW/cm^2, obtained using a Nafion 117 membrane, 3 mg/cm^2 Pt–Ru and 0.5 mg/cm^2 Pt as, respectively, anode and cathode catalyst loading, carbon paper as anode gas diffusion layer (GDL) and Sigracet carbon paper with micro porous layer (MPL) as cathode GDL at methanol feed concentration of 3 M. This result higher than the optimal power obtained with the active Micro-DMFC clearly demonstrates that membranes with low catalyst content could be used in passive MicroDMFC with success. This is an important result bearing in mind the use of micro-DMFCs in portable applications.

Introduction

Fuel cells have been considered a promising power source for transportation and portable electronic devices. Supported by the advantages of the scaling laws, miniaturization promises higher efficiency and performance of power generating devices, and therefore Micro-DMFC is an emergent technology. These cells use liquid fuels without a reforming step and can provide up to ten times the energy density of conventional batteries. Liquid alcohol fuels have high energy density and are easier to transport, store and handle than the hydrogen.

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Methanol is the most frequently used fuel and much progress has been made in the development and optimization of direct methanol fuel cells. Small DMFCs with various degrees of microfabrication have been reported [1]. Regarding design parameters, the materials used as carrier substrate are mainly silicon and stainless steel. Stainless steel leads to higher fuel cell performances, although there are few works using this substrate [2–6] mainly because of its high machining cost.

Concerning the different concepts of fuel delivery, the Micro-DMFCs can be characterized as passive and active. Passive systems do not need moving parts to feed oxidant and fuel to the cell, requiring no power to operate. They use natural convection/diffusion to fuel and oxidant supply without any additional power consumption. This type of system supply has lower costs and higher system energy density, therefore it is more suitable for portable power sources [7–9].

The passive fuel cells, likewise the active ones, have severe methanol crossover when the cell is operated with high methanol concentrations. This leads to losses in the cell performance, since methanol diffuses through the membrane generating heat but no power [10]. Using low methanol concentrations on the anode side could solve this problem. However, low methanol concentrations could lead to an inadequate methanol supply, and polarization of the cell voltage may occur due to the lack of fuel. An additional consequence of the use of low methanol concentrations is that the output of a passive DMFC is not acceptable for real applications. Another important issue is the higher water concentration gradient between the anode and the cathode side: water crossover through the membrane towards the cathode side due to the coupled effect of electro-osmotic drag and diffusion. Moreover, at the cathode side water is produced by the electrochemical reaction. A large amount of water at the cathode resulting from both water crossover and water generated in the electrode could flood the cathode leading to an increased resistance of oxygen transportation and reducing the cell performance [11]. For these reasons, the control of the multiphase flows at the micro scale is a crucial issue.

The great challenge in passive Micro-DMFC systems is how to reduce both methanol and water crossover without sacrificing performance. Based on previous works performed on DMFCs, a viable solution is to use high concentrations of methanol, combined with different membranes, diffusion layer and catalytic layer materials with different thicknesses [12–16]. In Micro-DMFC literature there are some studies with passive cells [17–22] but these are not focused on cell performance evaluation by modifying the type of GDL material or the membrane thickness.

The catalyst content is another issue that should be explored because its reduction on the catalytic layer generates cheaper membranes. There are few works analyzing the effect of anode and/or cathode catalyst loadings. For MicroDMFC, Hashim et al. [23] tested, in a passive stack, Nafion 117 with different catalyst loadings (2, 3 and 4 mg/cm^2) at the anode side using a constant catalyst loading of 2.0 mg/cm^2 at the cathode side. The authors concluded that better fuel cell stack performances (12 mW/cm^2) were obtained for a catalyst loading of 3.0 mg/cm^2. Ahmad et al. [22], in a passive fuel cell of 4 cm^2 active area, tested different anode and cathode catalyst loadings and obtained the best power output (14 mW/cm^2) using an anode catalyst loading of 5 mg/cm^2 Pt–Ru and a cathode catalyst loading of 0.5 mg/cm^2 Pt. Gogel et al. [24] tested, in a DMFC with 25 cm^2 area, a Nafion 105 membrane a 110 °C with cathode catalyst loadings between 1 and 6.3 mg/cm^2 PtB with an anode catalyst loading of 5.4 mg/cm^2 Pt–Ru. The authors concluded that the reduction of platinum loading in the cathode leads to a concurrent decrease in performance. The lowering of performance is gradual down to about 2 mg/cm^2. However, when the platinum content is reduced from 2 to 1 mg/cm^2 the performance is notably diminished by about 300 mV (corresponding to approximately 4 times lower performances).

The effect of methanol concentration and the effect of design parameters, such as membrane thickness and cathode GDL thickness on the cell performance of a passive Micro-DMFC were investigated in this work. MEAs with very low catalyst content at anode side (0.5 mg/cm^2 Pt) and also relatively low platinum–ruthenium content at anode side (3 mg/cm^2 Pt–Ru) are tested to assess if it is possible to use cheaper membranes successfully. The cell performance was evaluated by current–voltage measurements at ambient conditions (atmospheric pressure and ambient temperature), conditions of special interest bearing in mind portable applications. The experiments were performed with a Micro-DMFC with 2.25 cm^2 of active area.

Experiment

The experimental fuel cell is constituted of:

- Two acrylic end plates: the anode one is 1 cm thick with a 1.8 cm^3 methanol reservoir and the cathode one is opened and 4 mm thick;
- Two stainless steel current collectors: the anode one has holes on the active area with diameter of 1 mm and the space between holes is 0.5 mm, the cathode one has holes on the active area with diameter of 1 mm and the space between holes is also 1 mm;
- Two silicon gaskets;
- One MEA

A picture of the passive fuel cell is presented in Fig. 1.

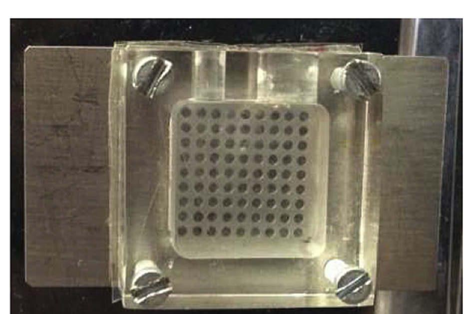

Fig. 1 – Picture of the Passive Micro-DMFC used in the experiments.