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Characterization of a high performing passive direct formic acid fuel cell

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Abstract

Small fuel cells are considered likely replacements for batteries in portable power applications. In this paper, the performance of a passive air breathing direct formic acid fuel cell (DFAFC) at room temperature is reported. The passive fuel cell, with a palladium anode catalyst, produces an excellent cell performance at 30 °C. It produced a high open cell potential of 0.9 V with ambient air. It produced current densities of 139 and 336 mA cm^{-2} at 0.72 and 0.53 V, respectively. Its maximum power density was 177 mW cm^{-2} at 0.53 V. Our passive air breathing fuel cell runs successfully with formic acid concentration up to 10 and 12 M with little degradation in performance. In this paper, its constant voltage test at 0.72 V is also demonstrated using 10 M formic acid. Additionally, a reference electrode was used to determine distinct anode and cathode electrode performances for our passive air breathing DFAFC.

Keywords: Direct formic acid fuel cell; Portable power; Reference electrode

1. Introduction

Recently, there has been considerable interest in the use of miniature fuel cells as replacements for batteries in portable electronics. The advantages of using miniature fuel cells over conventional batteries are that the miniature fuel cells have a much higher stored energy density, and the ability to be immediately recharged by replacing the fuel cartridge [1]. Most investigators are exploring direct methanol fuel cells (DMFCs) for this purpose [2,3], but our previous paper showed that direct formic acid fuel cells (DFAFCs) are quite interesting for portable power applications [4–8].

Formic acid is a liquid, but unlike methanol it has a low crossover through the Nafion® membrane and a high kinetic activity. These unique characteristics of formic acid allow to operate DFAFCs at higher voltages than DMFCs. Methanol has the higher theoretical energy density than formic acid. However, because fuel cells run more efficiently at higher voltages, in practice DFAFCs have about the same energy density as DMFCs. Furthermore, DFAFCs have about a factor of three to six higher power density than DMFCs and can operate well at room temperatures [4–8]. Thus, DFAFCs have advantages over DMFCs.

In the previous study, the passive air breathing DFAFC with PtRu black anode catalyst produced a maximum power density of 33 mW cm^{-2} [6]. This power output is very promising and far better than that of most reported passive DMFCs, but it still needs a significant performance improvement in order to compete with the conventional batteries. In order to bring such improvement, we need to develop more active catalysts for oxidizing formic acid. This catalytic improvement would increase cell efficiency and power density while reducing overall precious metal loadings.

Recently, noble Pd catalysts were found which produced unusually high performances in active DFAFCs. Until now, Pd catalyst has never been tested for passive DFAFCs. Like active DFAFCs, we expect to find a similar significant performance enhancement in passive DFAFCs with Pd black catalyst. In this study, we characterize the performance of the passive air breathing DFAFC with Pd black catalyst. To determine its distinct anode and cathode electrode performances, a reference electrode is used. The performance of the passive DFAFC is also compared to that of the active DFAFC.

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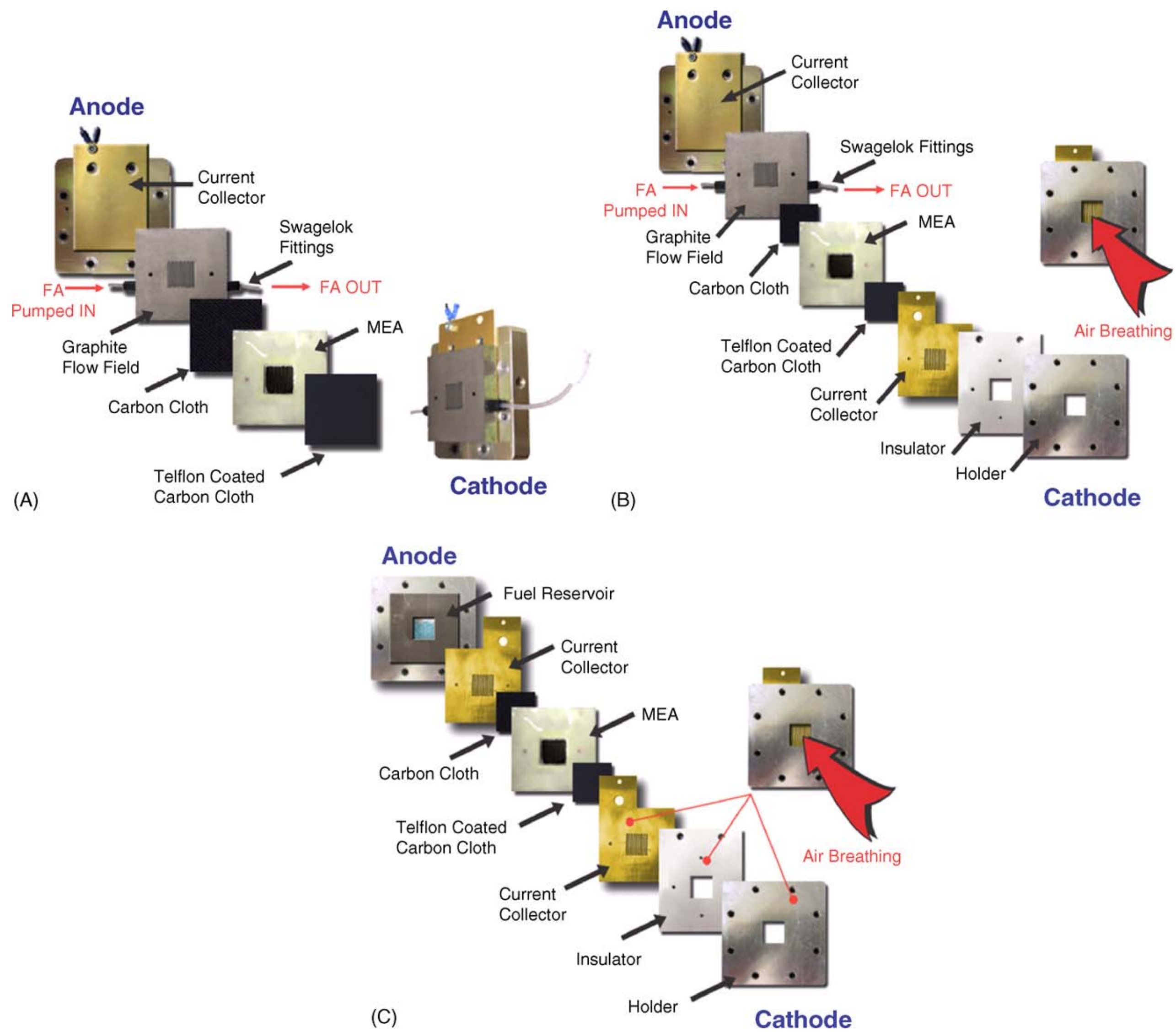

Fig. 1. Diagrams of (A) the active, (B) the active air breathing, and (C) the passive air breathing DFAFCs.

2. Experimental

The membrane electrode assemblies (MEA) were fabricated in house using a 'direct paint' technique as it is described elsewhere [4–6,8]. The active area is 4 cm^2. The 'catalyst inks' were prepared by dispersing the catalyst powders into appropriate amounts of Millipore water and 5% recast Nafion® solution (1100EW, Solution Technology, Inc.). Then both the anode and the cathode 'catalyst inks' were directly painted onto either side of the Nafion® 115 membrane. A commercially available platinum black (HiSPEC™ 1000 from Johnson Matthey) was used for the cathode catalyst layer at a loading of 8 mg cm^{-2}. Pd black (High Surface Area from Sigma–Aldrich) was used for the anode catalyst layer at a loading of 8 mg cm^{-2}. The final catalyst layers contained 15% Nafion® by weight.

As Fig. 1 shows, three different types of DFAFC were used in this study: active DFAFC, active air breathing DFAFC (air breathing DFAFC), and passive air breathing DFAFC (passive DFAFC). In the active DFAFC, both formic acid and air were supplied to the catalyst layers through flow fields using a liquid syringe pump and a compressed gas cylinder. For the air breathing DFAFC, the cathode flow field was removed from the active DFAFC and the cathode was exposed to the ambient air. For the passive DFAFC, both the anode and cathode flow fields were removed from the active DFAFC and a fuel reservoir was placed at the anode. Formic acid was delivered from the fuel reservoir to the anode catalyst layer by a simple diffusion and capillary action in the passive DFAFC. Both a heating cartridge and heating tape were used to maintain the operating cell temperature at 30 °C. Formic acid from Fluka® was diluted with the Millipore water to give a final concentration ranging from 3 to 15 M. The membrane was used without any prior conditioning.

Both cell polarization curves and constant voltage test were acquired using a fuel cell testing station (Fuel Cell Technologies, Inc.). An Ag/AgCl reference electrode from Fisher® mounted in the fuel reservoir in Fig. 1(B) was used to measure the anode