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A PEM fuel cell with metal foam as flow distributor

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ABSTRACT

In this work, we report our experimental results of the PEM fuel cell with metal foam as flow distributor. These experimental results show the characteristics of the PEM fuel cell with the metal foam as flow distributor and extend our understanding of the relation between cell performance and mass transport properties into a region of parameters that the conventional PEM unit cell cannot provide. The comparison in polarization curve is made between the PEM unit cell with different metal-foam properties and the PEM unit cell with graphite flow channel plate as flow distributor. The experimental results show that the PEM fuel cell with metal foam as flow distributor possesses some unique characteristics compared with the conventional PEM unit cell with flow channel plate as flow distributor. The unique characteristics are listed in this paper with our preliminary analysis. Due to the high porosity of metal-foam (as high as 95%) plus convective flow through the metal-foam, mass transport limitation phenomenon is not as pronounced as in the case of conventional PEM unit cell with flow channel plate as flow distributor. Another interesting phenomenon is that electrical conductivity of metal-foam plays a significant role in performance, which is seldom the case in the conventional PEM unit cell with flow channel plate as flow distributor. Although there are several technical challenges to be overcome for the current form of metal-foam to replace flow channel plates, the unique mass-transport properties of metal foam plus its light weight are very attractive.

1. Introduction

A PEM fuel cell is an electrochemical device in which the free energy of combustion of hydrogen is converted into electrical energy. Oxygen from air is used as oxidant. It produces more electricity per mass of fuel than any other non-nuclear method of power production. It is a key technology to realizing hydrogen economy and reducing green house gas emissions from automobiles [1]. It has been under intense development for the past 30 years for applications such as powering cars and portable electronics. These applications pose very strict requirements on the PEM fuel cell in terms of cost, durability and power density (power per volume and per weight) as well.

A conventional PEM fuel cell (a single cell) consists of a membrane-electrode-assembly (MEA) and two bipolar plates. On the bipolar plates there are flow channels, which can be obtained through machining or sheet-metal forming. The essential functions of the bipolar plates are to collect electric current, distribute oxygen and hydrogen gases to catalyst layers and transport product water and heat out. Different configurations of the flow channels have been developed such as single serpentine, double serpentine, and inter-digitated [1–6]. However, there are issues associated with the flow channels. Due to the existence of ribs and channels on the bipolar plates, the concentration distribution of reactants and also temperature distribution inside electrodes are not uniform in MEA plane [7–14], leading to uneven rate distribution of electrochemical reactions. As a consequence, it reduces catalyst utilization and durability. Second, it is costly to machine flow channels on the bipolar plates [15]. Third, the bipolar plates occupy a large portion, up to 50%, of the total weight and the total volume of the single cell.

In an effort to reduce weight and volume of the PEM fuel cell, Kumar and Reddy [16,17] proposed to use metal foam as flow distributor, replacing the function of the flow channels on the bipolar plates. The metal foam with different configurations is commercially available. For this specific application metal foam comes in a sheet form with thickness of a couple of millimeters. The metal foams' mechanical strength, porosity, thermal conductivity, and electric conductivity can be tailored to meet specific needs. One possible disadvantage of metal foam is its corrosion resistance. This may require further investigation in the future. On the other hand, the most unique feature about metal foam is that it can be

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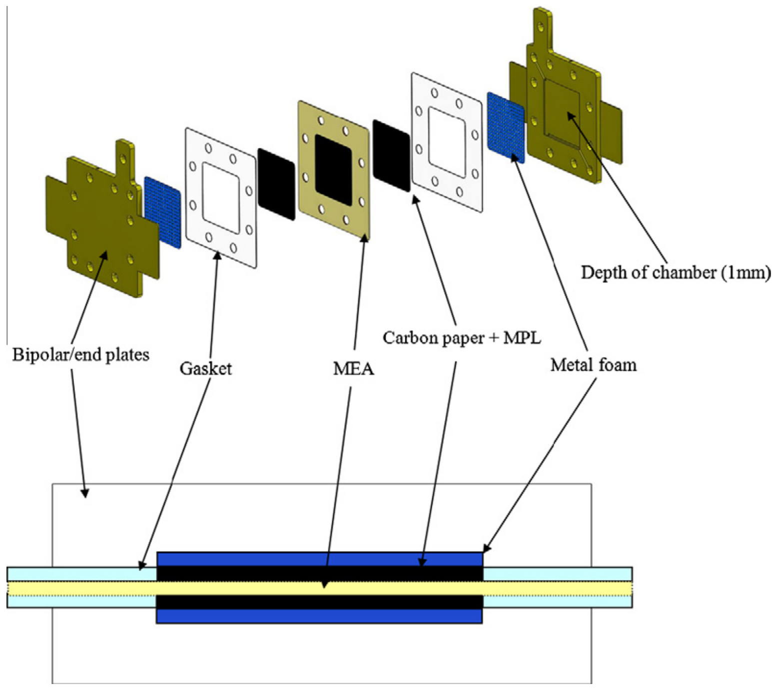

Fig. 1. Schematic of PEM fuel cell with metal foam as flow distributor.

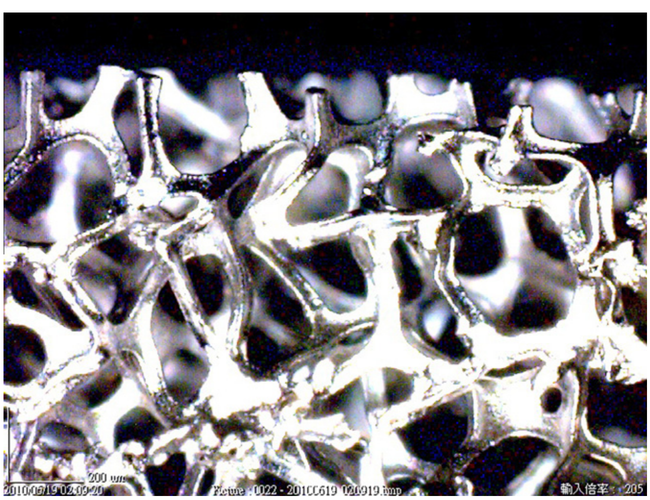

Fig. 2a. Side view of metal foam without PTFE coatings.

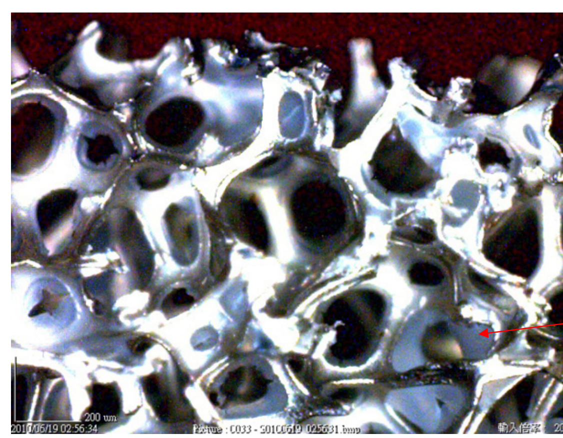

Fig. 2b. Side view of metal foam with PTFE coatings.

made extremely porous, up to 95% porosity, thus being very light, excellent medium for transporting gases, and still having enough thermal and electric conductivity. These properties encourage us to try it for replacing the flow channels on bipolar plates.

Recently we have conducted an extensive experimental study on the PEM fuel cell with metal foam as flow distributor. Our objective is to gain understanding of the PEM fuel cell with metal foam as flow distributor. In this paper, we report our experimental results, which include the effects of metal foam's hydrophobic treatment, porosity, and operation conditions on the performance of the fuel cell.

2. Experiments

Fig. 1 shows the schematic diagram of the PEM fuel cell with metal foam as flow distributor. The metal foam we have used in this work is made of nickel with pore size of about 580 μm. Its density, usually described by its weight per geometrical surface area, is about 500 and 600 g/m^2. Because of corrosive environment in the PEM fuel cell, metal foam needs to be coated with corrosion-resistant material, similar to metal bipolar plates in that coating is needed [18–20]. In addition, metal foam is required to facilitate water-removal and thus needs to be hydrophobic, similar to gas diffusion layers (GDLs) [21]. In this work, metal foam is coated with PTFE [22] to enhance water removal and corrosion–protection as well. The metal foam as supplied from a vendor has porosity in the range of 95–98%. In order to enhance electric conductivity, the metal foam is compressed and as a result, its porosity is reduced slightly. After compression, metal foam is further treated with PTFE solution to make it hydrophobic. As a result, the porosity decreases a little bit further. The microstructure of metal foam can be seen from Fig. 2a (before PTFE treatment) and Fig. 2b (after PTFE treatment). In Fig. 2b, PTFE can be clearly seen on the surface of metal struts. The properties of metal foam are summarized in Table 1.

Commercially available catalyst-coated-membranes (CCM) from Gore Ltd. are used in the experiments. The size of the CCM's