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Effect of the thickness of carbon electrode support on the performance of PEMFC

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ABSTRACT

Porous conducting carbon paper has been identified as one of the most suitable materials to be used as an electrode support in a polymer electrolyte membrane fuel cell (PEMFC). Carbon paper was prepared following a combined technique of papermaking followed by composite formation. Samples were prepared with varying thickness while maintaining a uniform composition and a constant density of 0.50 g/cc. The effect of the thickness on various properties of carbon paper affecting its performance in the PEM fuel cell and cell efficiency has been discussed. Power density as high as 805 mW/cm^2 has been achieved for PEM fuel cell employing carbon paper sample with 0.028 cm thickness, an increase of more than 55% as compared to 510 mW/cm^2 for 0.046 cm thick sample.

1. Introduction

Fuel cells are considered as a reliable and environmental friendly power delivery devices for the future. Fuel cells are electrochemical energy conversion devices that convert hydrogen and oxygen into water, producing electricity and heat in the process and providing fuel efficiency and reduction in pollutants [1,2]. Hydrogen reacts at the anode giving up electrons while oxygen is reduced at the cathode gaining electrons. The electrons pass through the external circuit doing work. This is shown systematically in Fig. 1. The electrode substrate/support (i.e. the porous conducing carbon paper) plays a critical role in the operation of a fuel cell and performs various critical functions i.e. (i) to provide reactant gases access from flow field channels (etched on the bipolar plate) to catalyst layers and passage for removal of product water from the catalyst layer to flow-field channels; (ii) to provide electronic conductivity from bipolar plates to catalyst layers; (iii) to help in heat removal from MEA to bipolar plates where coolant channels are located, and (iv) to provide mechanical support to the MEA in case of reactant pressure difference between the anode and the cathode gas channels, maintain good contact, and not to compress into the channels of bipolar plate resulting in blocked flow [3]. An electrode must therefore be porous with a uniform pore size distribution, electrically conducting, resistant to poisoning by impurities in the fuel and oxidant streams, having a large surface area, sufficient mechanical strength and reasonable tolerance to vibration and flexural damage. It is rare for a single material to incorporate all the above parameters, since a small change (in composition or processing parameter) introduced to achieve a chosen property may lead to undesired changes in the other.

Use of porous carbon materials as a fuel cell electrode support material is widely mentioned in literature [4–14], as the former has physical and chemical properties which meet the above mentioned requirements with varying degrees of success. A judicious choice of materials and its processing has been adopted by the authors in their previous studies [12–15]. Various characteristics of the carbon paper i.e. density, electrical resistivity, strength, modulus, porosity, pore size distribution etc. were controlled to produce carbon support for high performing PEM fuel cell. The procedures employed had different effects on the thickness of the carbon paper, a parameter often neglected as far as its effect on the fuel cell performance is concerned. In the present study carbon paper samples were prepared with varying thickness while maintaining a uniform composition, identical processing parameters and a constant density. Paganin et al. [16] have shown the effect of the thickness of gas diffusion layer (GDL), which includes catalyst and carbon black layers (coated on top of the carbon support), on the performance of PEM fuel cell. They showed that the PEMFC performance increases as the GDL thickness increases from 15 to 35 μm, but starts decreasing with further increase in thickness. According to the researchers lesser amount of PTFE/C is insufficient to provide electrical contact for current collection due to roughness of carbon support material, while excess of it may increase the diffusion distance. Lin et al. [17] on the other hand have shown the combined effect of varying the thickness of electrode support and the carbon loadings i.e. the GDL. Excessively thin electrodes were

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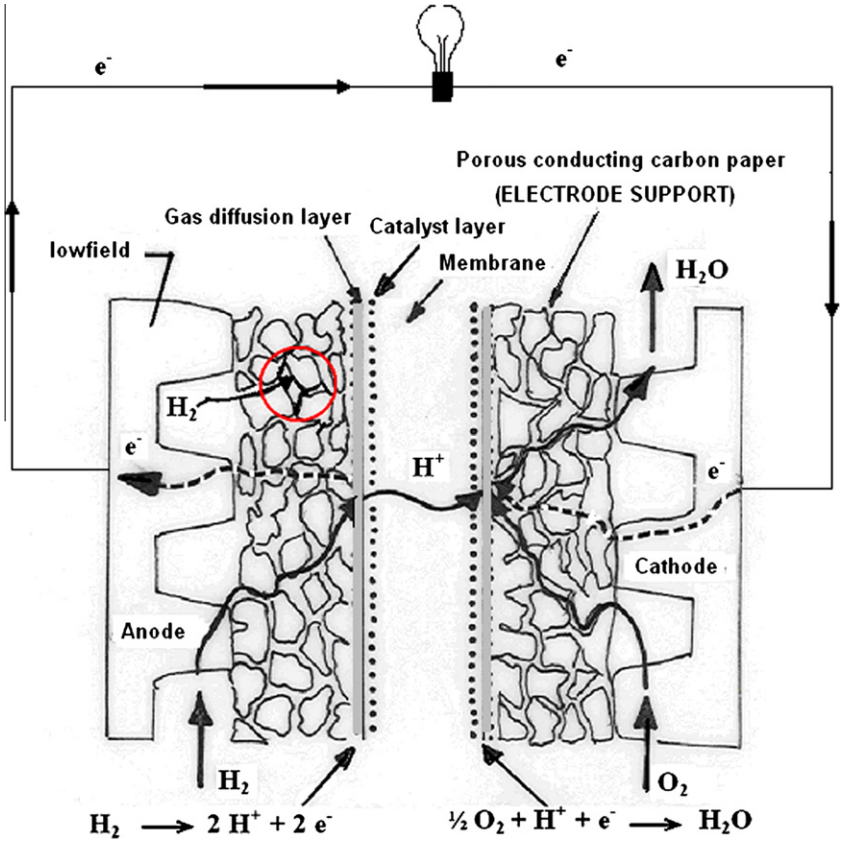

Fig. 1. Schematic of the various transport processes inside the PEM fuel cell. Highlighted area shows an unconnected pore.

found performing poorly that was attributed to the reduced pore size and pore volume of the GDL formed on thin supports. In the present study however the effect of thickness of the carbon electrode support on its various properties and its performance in a PEM fuel cell has been discussed.

2. Material and methods

2.1. Preparation of carbon paper

Polyacrylonitrile (PAN) based T-300 grade carbon fibers were used for making porous carbon fiber preforms. Calculated amounts of carbon fiber (chopped in 1.0 cm length), was dispersed in an aqueous solution and vacuum filtered to form highly porous carbon fiber preform by the well known paper making technique [12]. The preforms thus prepared were impregnated with phenolic resin (obtained from 'IVP India Ltd.') such that the ratio of reinforcement (fiber) to the resin is 1:1 by volume. This ensures adequate wetting of the porous carbon fiber substrate. The impregnated preforms were then molded into sheets by compression molding followed by post-curing at 150 °C for 2 h in air to ensure full curing and cross-linking of the binder material before carbonization. The samples so obtained are known as green samples. These were further heated to 2200 °C in an inert atmosphere with a heating rate of 100 °C/h from RT to 1000 °C; and further at 900 °C/h, and kept on hold for 15 min at the final temperature. In order to prepare sample with different/(increasing) thickness, the amount of raw materials (i.e. carbon fiber and resin) was varied/(increased) and correspondingly the spacing of the die mold (during the molding process) was adjusted/(increased) so as to maintain a constant density (i.e. 0.5 g/cc) of the final samples. The density of the different samples prepared was measured and was found to be identical. The carbon paper samples thus prepared had thickness of 0.046, 0.04, 0.035, 0.031, 0.028 and 0.023 cm after the final heat treatment. These have been designated as samples A–F respectively in the following text.

2.2. Characterization of the carbon paper

The in-plane and through-plane electrical resistivity of the carbon paper was measured using the four-point and two-point probe technique respectively. Keithley 224 programmable current source was used for providing current. The voltage drop was measured by Keithley 197A auto-ranging microvolt DMM.

The porosity and pore structure was determined using mercury intrusion porosimetry analyzer (model: Poremaster (33/60), P/N 05060; obtained from Quantachrome instruments, USA). In this method, mercury (Hg) with its very high surface tension (4.80×10^{-5} J cm^{-2}) is forced into the pores of the sample. The amount of Hg uptake as a function of pressure allows one to calculate the effective porosity, pore tortuosity and the pore size distribution.

Flexural strength and flexural modulus of the carbon paper samples was measured on the INSTRON machine model – 4411, by three point bending technique according to ASTM: D 1184-69. The crosshead speed was maintained at 0.2 mm/s.

Gas permeability of the carbon paper samples was determined on the set-up designed as per the Indian Standard Method IS: 11056-1984 for "Determination of Air permeability of Fabrics".

2.3. Formation of membrane electrode assembly and fuel cell performance

The carbon paper samples of size 4 cm^2 were teflonised and gas diffusion layer (GDL) was prepared by coating 1.5 mg/cm^2 of carbon black (Vulcan XC-500 obtained from Cabot Corporation, USA)