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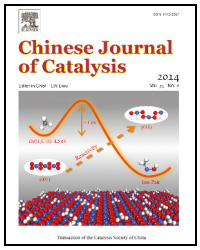

Article

Effect of polytetrafluoroethylene distribution in the gas diffusion layer on water flooding in proton exchange membrane fuel cells

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ABSTRACT

The effect of polytetrafluoroethylene (PTFE) distribution in the gas diffusion layer on water flooding in proton exchange membrane fuel cells was investigated. PTFE was introduced within micropores of carbon papers, to achieve hydrophobicity under different pressures. Carbon papers were subjected to vacuum conditions during immersion in PTFE solution to prepare gas diffusion layers. Residual gas within the carbon papers was eliminated, and PTFE evenly infused within the pores. Cross-sections of the carbon papers indicated that vacuum treatment improved PTFE distribution. The same PTFE content resulted in a decreased water contact angle of the carbon paper because of the greater PTFE content within the micropores. The proportions of hydrophobic and hydrophilic pores within the carbon papers were investigated. The proportion of hydrophobic pores increased during the vacuum treatment. Membrane electrode assemblies (MEAs) were fabricated using the treated hydrophobic carbon papers as gas diffusion layers and were evaluated in a full-sized fuel cell. The uniform PTFE distribution of the carbon paper benefited fuel performance. Electrochemical impedance spectroscopy indicated that the improved MEA possessed favorable resistance to water flooding.

1. Introduction

Proton exchange membrane fuel cells (PEMFC) are devices that convert chemical energy into electricity through electrochemical reaction. PEMFCs are efficient, with fast startup, and produce no emission. They have been applied in vehicles, power stations, uninterruptible power system, and aircraft.

To fully commercialize such fuel cells, their durability must be prolonged, their performance improved, and their cost reduced [1]. The membrane electrode assembly (MEA) performs the core functions of a PEMFC. The MEA consists of two catalytic electrodes and gas diffusion layers (GDLs) on each side of a proton exchange membrane, respectively, for the anode and cathode. Each component of the MEA is optimized to improve the performance, durability, and robustness of the overall PEMFC [2–5]. The GDL sandwiched between the catalyst layer and gas flow channel is an important component concerning the water management of the MEA.

Liquid water in MEAs arises from condensed humidified vapor and as a product of oxygen reduction, some of which is necessary for maintaining the ionic conductivity of the membrane and catalyst layer (CL). Excess water may occlude active sites for electrochemical reaction and affect the gas permeability [6–8]. Most water is transported out of the cathode CL and

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accumulates at the interface between the CL and GDL before draining from the MEA through the GDL by capillary action [9].

GDLs commonly consist of a substrate and microporous layer (MPL). To achieve water removal and gas diffusion, the substrate is typically waterproofed by introducing polytetrafluoroethylene (PTFE) within micropores. This prevents the GDL surface and pores from being clogged with liquid water and facilitates gas transport to the CL. The treatment process normally results in inhomogeneous PTFE distribution across the GDL substrate, with higher concentrations at the surface. Neutron radiography reportedly indicated that water concentrates in the center of the carbon paper when the fuel cell is operating [10–12], reflecting the fact that GDLs are easily flooded.

In the current study, hydrophobization treatment was used to achieve an even PTFE distribution in carbon paper. By vacuumizing the residual gas within carbon paper pores, PTFE solution can more effectively penetrate the pores. The resulted homogeneous hydrophobic pores exhibit favorable anti-flooding properties.

2. Experimental

2.1. Carbon paper hydrophobization

PTFE was introduced within the micropores of carbon paper (Toray, Japan, TGP-H-060) for hydrophobization. Carbon papers were immersed in PTFE solution, and excess solvent was removed by drying, leaving PTFE remaining in micropores. Carbon papers were treated by this process at pressures of 0, −0.08, and −0.05 MPa, with the resulting samples named CP-1, CP-2, and CP-3, respectively. The PTFE contents of the three carbon paper samples were controlled to ensure that they were constant. The resulting carbon papers were sintered at 240 °C for 30 min and then at 340 °C for 30 min in a N_2 atmosphere.

2.2. Physical characteristics

2.2.1. Hydrophobicity test

The water contact angle of the carbon paper surface was measured using the KRÜSS DSA100 Drop shape analysis system. A total of 3 ml of distilled water was dropped onto the surface of the carbon paper at room temperature. The contact angle image was recorded 5 s after the drop was placed. The contact angle was analyzed using the tangent method of Sessile Dropfitting.

2.2.2. Porosity test

A 3 cm × 3 cm section of carbon paper was removed and weighed after hydrophobization. The paper was vacuumized and immersed in water at 20 °C for 2 h. The surface was wiped dry, and the total weight of the paper and water within hydrophilic pores was recorded. This process was repeated until a constant weight was achieved, from which the hydrophilic pore volume was calculated. Residual water was removed from the pores by drying at 90 °C under vacuum, and the paper was immersed in dodecane under vacuum at 20 °C for 2 h. The subsequent procedure was the same as for that above, and the total pore volume was calculated. The porosity of the carbon paper was measured by the mercury intrusion method with a Poremaster GT60 instrument (Quantachrome).

2.3. MEA fabrication

Pt/C (Johnson Matthey, 70 wt%), Nafion® solution (DuPont 5 wt%), and isopropyl alcohol were ultrasonically mixed to prepare the catalyst ink, which was sprayed onto a Nafion® 211 membrane to form the catalyst coated membrane (CCM). Carbon powder (XC-72), PTFE solution, and ethanol were mixed to form a homogeneous ink, which was painted onto the carbon paper. The GDL was prepared after sintering at 240 °C for 30 min and then at 340 °C for 30 min in a N_2 atmosphere. GDLs were fabricated using CP-1 and CP-2.

A CCM was sandwiched between two GDLs, and two MEAs were hot-pressed, which were relevant to CP-1 and CP-2, respectively (Fig. 1). The active area of the MEAs was 270 cm^2.

2.4. Fuel cell stack test

A short stack was assembled with a graphite flow field and two stainless steel bipolar plates. Evaluation of green light (G100) with a temperature, gas flow rate and pressure controlled system was used to test the cell performance. *i-V* curves were measured under an electronic loading (Kikusui, PLZ1004&PLZ2004). Electrochemical impedance spectra (EIS) were measured with a Kikusui KFM2150 instrument.

3. Results and discussion

3.1. SEM characterization of PTFE distribution

The carbon papers were characterized after hydrophobization treatment. Cross-sectional SEM images of fresh and treated carbon papers are shown in Fig. 2. The straight line indicates the analyzed cross-section, and the flexural curve indicates the elemental F distribution measured by an electron probe. Fresh carbon paper contained carbon fibers and organic materials, with F distributed across the entire section. Introducing PTFE within micropores did not change the morphology of the cross section, but the F distribution was influenced by

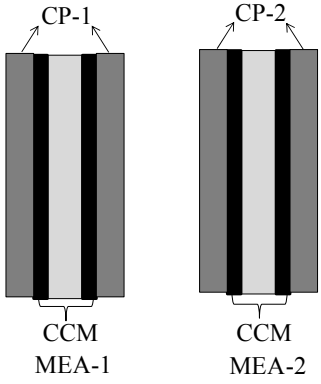

Fig. 1. Sketch map of the MEAs.