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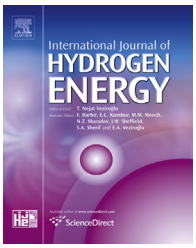

Systematic study on the functions and mechanisms of micro porous layer on water transport in proton exchange membrane fuel cells

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ABSTRACT

Though it is well known that adding micro porous layers (MPL) in proton exchange membrane fuel cells (PEMFC) can improve fuel cell performance, durability and stability, their functions and mechanisms on water transport are still not fully understood. To determine the functions and the mechanisms of MPL on water transport, systematic experiments have been conducted on fuel cells with and without MPL under wide range of operating conditions. Besides overall cell performance, current density distribution along gas channel and electrochemical impedance spectroscopy are used in the analyses. The experimental results show that the functions and mechanisms of MPL depend on the humidity level and operating temperature. At low and medium temperature, MPL can significantly enhance cell performance under both high and low humidity conditions. Under high humidity conditions, adding an MPL can effectively reduce flooding of the catalyst layer by preventing the formation of liquid water in its much smaller pores than in the GDL. Under low humidity conditions, MPL reduces the loss of water to the gas channels as well as enhances back diffusion, thus reduces membrane dehydration. MPL also reduces Joule heating and further reduce membrane dehydration. At high temperature, the effectiveness of MPL is much reduced under both high and low humidity conditions due to the different mechanism of water transfer.

Introduction

Introducing a micro-porous layer (MPL) between cathode catalyst layers (CL) and gas diffusion layers (GDL) is believed to be able to significantly improve PEMFC performance, durability and stability due to three possible roles: decreasing contact resistance, preventing membrane from been punctured by carbon fibers in GDL, and improving water

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management [1–3]. Water management is a very important and complicated issue. A balanced water management in a fuel cell can ensure enough water for high membrane ionic conductivity as well as low liquid saturation level for good reactant gas transport [4]. Thus, much work has been conducted on how MPL affects water management. Though there are some general consensus on the functions of MPL, such as preventing PEMFC from serious flooding or drying [5,6] and reducing fluctuation of water removal [7], serious inconstancies still exist in the understanding of both the functions and mechanisms of MPL in PEMFCs.

Location of flooding reduction by MPL

Although it is generally believed that MPL enhances mass transfer by reducing liquid water saturation in high humidity situations, there is still a debate on where flooding is reduced. Some researchers [8–13] claimed that MPL reduced flooding in the CL while others [14–19] claimed that MPL reduced flooding in the GDL.

Pasaogullari and Wang [8] claimed that MPL reduced water saturation in the cathode CL. Sasabe et al. [10] visualized water distribution in PEMFC by soft X-ray radiography and suggested that MPL acted as capillary pressure barrier which prevented liquid water in the GDL from contacting the CL or forming a water film on the CL surface. Oberholzer et al. [12] claimed that MPL showed no significant impact on liquid water saturation level in the GDL. The reduction of mass transfer loss was attributed to flooding reduction in the CL and/or at the CL|DM interface. Kitahara et al. [13] claimed strong hydrophobic MPL hindered condensed water to transfer back to the CL.

In contrast, Weber and Newman [14] simulated the experimental results reported by Qi and Kaufman [1] and claimed that MPL enhanced water drainage to anode side and eased flooding in the cathode GDL. Malevich et al. [15] used electrochemical impedance spectroscopy (EIS) to compare the time constants and claimed that the decrease of mass transfer resistance reflected reduced flooding in the cathode GDL rather than in the CL. Lu et al. [17] visualized liquid water breakthrough the GDL with and without MPL and suggested that liquid water could only get to the GDL through the cracks in the MPL and thus adding an MPL could reduce liquid water saturation in the GDL. Similar views were also held by Wu et al. [18] and Medicsi and Allen [19] through pore network models.

How MPL reduces flooding

Many believed that MPL affected water transfer by acting as pressure valve [14] or pressure barrier [20], by limiting the liquid water injection sites of GDL to the cracks in MPL [17–19,21,22], and/or by increasing water transfer resistance [6,23]. However, Owejan et al. [24] conducted both *ex situ* and *in situ* experiments and claimed that the main driving force in GDL was not capillary pressure but temperature gradient. It was believed that the generated water can be removed in vapor form under temperature gradient, and the main role of MPL was preventing condensed water from flooding the CL rather than improving capillary-driven flow.

Functions of MPL under dry condition

Yau et al. [23] measured the net water transfer coefficient *in situ* and found that the net water transfer coefficient difference between PEMFCs with and without MPL was not significant in well humidified case but significant in dry cases. They suggested that MPL prevented dehydration of the membrane electrode assembly under dry conditions [8,13,23]. However, Nishiyama et al. [11] reported that PEMFC without MPL shows better performance under dry air inlet conditions.

As reviewed above, there are obviously many disagreements and contradictions in both the functions and the mechanisms of MPL in a PEMFC. The different results and conclusions may be due to the different operating conditions used. Besides, even if the overall operating conditions are the same, local conditions in different parts of the same fuel cell could be very different, causing the true functions of MPL at the specific location being covered up by the overall effect on the fuel cell. It is well known that local conditions and performance can vary significantly in a PEMFC [25–27]. Therefore, the objective of this work is to determine the functions and mechanisms of MPL in a PEMFC by systematically studying the effects of MPL under various operating temperatures and humidification levels, and by measuring local current density variations.

Experimental

Fuel cell test systems

In this study, a single cell with an active area of 16 cm^2 was used. As shown in Fig. 1(a), graphite plates with serpentine flow fields were symmetrically placed at the anode and cathode sides. The serpentine flow field had a single channel and both the channel and land has 1 mm × 1 mm cross-sectional area. The total length of the serpentine flow channel is 80 cm, with 20 channels each 4 cm long. Catalyst coated membrane (Pearl Hydrogen Technology) with Nafion 212 membrane and Pt loading of 0.4 mg cm^{-2} on both cathode and anode sides was used. In the anode side, Toray™ TGP-H-60 carbon paper treated by 10% PTFE was used as the GDL. In cathode side, the same treated GDL with and without a 20%wt PTFE MPL were used as DM, respectively. The thickness of the MPL and the GDL were about 50 μm and 190 μm, respectively. The MPL was knife-coated on the carbon paper.

An automated test station (FCTS-16, Fuel Cell Technologies) was used to control gas flow rate, humidification temperature, cell temperature and back pressure. An electrochemical work station (Bio-Logic SA) was used to monitor or control cell voltage and current. Local current densities were measured by a current density distribution measurement gasket [27,28]. The measurement gasket was a printed circuit board with the same size gold-plated copper strips as the lands, as shown in Fig. 1(b). In this study, the measurement gasket with 21 measuring strips was placed between the anode GDL and the flow field plate (Fig. 1(a)). From the inlet to the outlet, the strips are numbered from 1 to 21, collecting local current along the gas channel separately. Currents collected by strips #1 and #21 were not used in the