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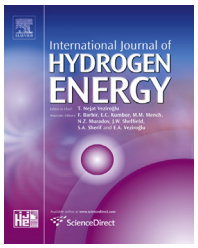

Effect of through-plane polytetrafluoroethylene distribution in a gas diffusion layer on a polymer electrolyte unitized reversible fuel cell

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ABSTRACT

The relationship between through-plan polytetrafluoroethylene (PTFE) distribution on a gas diffusion layer (GDL) and unitized reversible fuel cell (URFC) performance was investigated. Titanium (Ti) - felt was used for the oxygen-side GDL and treated with 10wt.% PTFE dispersion to enhance hydrophobicity. The dependence of PTFE distribution on the PTFE drying conditions was examined using scanning electron microscopy (SEM)-based energy dispersive X-ray spectroscopy (EDS) imaging. The EDS image maps revealed that the PTFE distribution strongly depended on the drying condition of the PTFE; drying under atmospheric pressure yielded a highly non-uniform PTFE distribution in the through-plane direction, whereas drying under vacuum pressure yielded a relatively uniform PTFE distribution. The cell performance of URFCs was then evaluated based on measured current–voltage characteristics during both electrolysis and fuel cell operation modes. Results verified that compared with non-uniform PTFE distribution, a uniform distribution in the Ti-felt GDL improved the fuel cell performance under the fully wet condition (relative humidity = 100%). By applying the Ti-felt GDL with uniform PTFE distribution in the through-plane direction, the current density at the cell voltage of 0.6 V was increased by a factor of about 1.9 compared with the Ti-felt with non-uniform PTFE distribution.

Introduction

Polymer electrolyte-based unitized reversible fuel cells (URFCs) are electrochemical cells that can operate either as an electrolyzer or fuel cell in a single unitized device. URFCs have the potential to be simpler and more compact to construct, compared to the more traditional systems that have separate electrolyzers and fuel cells (i.e., two separate units). A URFC

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with a hydrogen storage apparatus can be compared to a secondary battery. Its advantage over a secondary battery, however, is its capability to store large quantities of energy (in the form of hydrogen) without either self-discharge or oxygen as a side-product [1].

Fig. 1 shows the transport of gases (H_2 and O_2) and water in a polymer electrolyte-based URFC during both electrolysis and fuel cell operation modes. An important component in this cell is the gas diffusion layer (GDL), which plays vital roles in water management and reactant distribution during both modes [2–4], because mass transfer phenomena occur across the GDL. In the electrolysis mode of a URFC (Fig. 1a), the reactant water is supplied from the flow channels of bipolar plates to the catalyst layers (CL) via the GDL (porous current collector), and the two gases (H_2 and O_2) formed during the electrochemical splitting of water are transferred from the CL to the flow channels through the GDL [5]. In the fuel cell mode of a URFC (Fig. 1b), the reactant gases (H_2 and air/O_2) are supplied from the channel through the GDL, which simultaneously provides the primary water removal route from CL. In particular, excess liquid water at high current density and consequent flooding of the oxygen-electrode GDL limits the performance [6,7]. Therefore, effective pore structure and water management ability of the oxygen-electrode GDL is essential for both fuel cell and electrolysis operation modes in a URFC.

In a proton exchange membrane fuel cell (PEMFC), the cathode, which corresponds to the oxygen electrode of a URFC, has been comprehensively investigated. For a cathode GDL of a conventional PEMFC, a hydrophobic microporous layer (MPL) is generally coated onto a basal substrate of GDL, which is often called gas diffusion backing (GDB) and is typically carbon paper or cloth. In this case, the GDL is composed of GDB and coated MPL. The MPL is usually a mixture of fine carbon particles and a hydrophobic agent. The effect of the MPL components and properties on PEMFC performance has been investigated experimentally [8–18]. A GDL equipped with MPL exhibits hydrophobicity due to the hydrophobic agent such as polytetrafluoroethylene (PTFE) in the MPL. In addition, the GDB is usually treated with a hydrophobic agent prior to the MPL coating. Several studies on PEMFCs [19–23] have focused on the effect of PTFE content in a GDL without an MPL (i.e., GDB) on the cell performance. Park et al. [19] reported that PTFE loading on a carbon paper GDL degrades the cell performance. In contrast, Lim and Wang [20] found that 10wt.% PTFE loading is optimal for a carbon paper GDL. Park and Popov [21] determined that approximately 20wt.% is the optimal PTFE content for a carbon cloth GDL. Although they [19–21] investigated parameters of GDL with and without PTFE (e.g., porosity, absolute permeability, and water contact angle), their estimation of PTFE effect is mostly limited to the relation between overall loading amount and performance.

Several works [7,24–28] have focused on the PTFE distribution in the GDB of carbon material, and reported that the distribution directly depends on the treatment process. PTFE can be applied to the GDB in several ways. The most common technique is the immersion method, where the GDB is first dipped into an aqueous PTFE dispersion, excess dispersion is then allowed to drip off, after which the remaining solvent is removed by oven drying, and finally the PTFE is sintered at above 350 °C. The advantage of this immersion method is that the PTFE loading amount can be controlled by simply adjusting the dispersion concentration. However, uniform distribution of PTFE is difficult to achieve by any PTFE coating method due to the complex micro pore structure of GDB. Mathias et al. [7] reported that PTFE dispersion drying time can affect its distribution. Based on their measurements of PTFE through-plane distribution in relation to PTFE dispersion drying times, they reported that relatively slower drying times yield higher concentrations in the interior of the GDB, whereas relatively faster drying times yield higher concentrations near the surface. Inoue et al. [24] supported these observations by numerical analysis of evaporation and phase change of PTFE during the drying process. Fishman and Bazylak [25,26] measured the PTFE though-plane distribution of carbon paper GDB using microscale computed tomography (μCT) imaging. Comparison of PTFE distribution between GDB samples with and without PTFE treatment revealed that PTFE preferentially accumulated in the through-plane direction locally near the surface [26]. Rofaiel et al. [27] presented measurements of heterogeneous through-plane PTFE distribution for different types of GDB (paper, felt, and cloth) using scanning electron microscopy (SEM)-based energy dispersive X-ray spectroscopy (EDS) imaging. They reported that the morphological features of untreated GDB significantly affect the PTFE distribution.

In PEMFC related literature, a few studies have focused on the relation between the PTFE though-plane distribution in

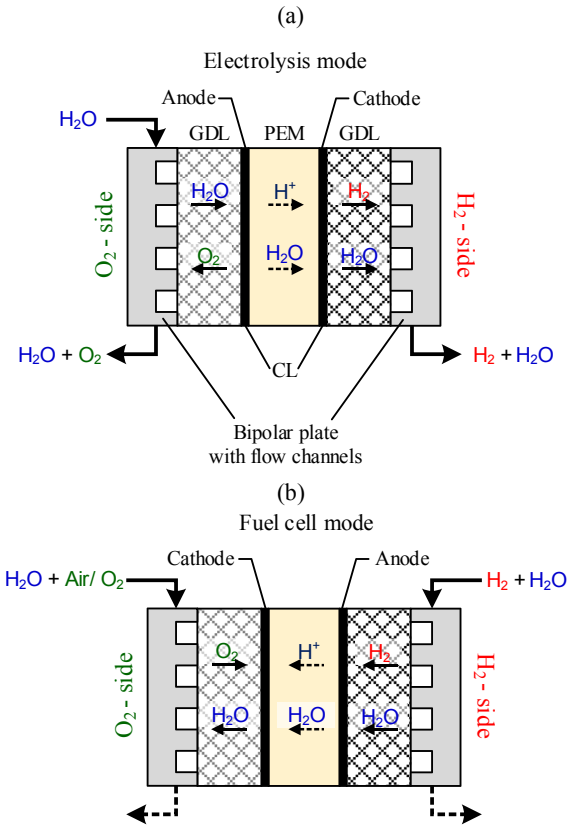

Fig. 1 – Schematic drawing of each operation of URFC: (a) electrolysis mode and (b) fuel cell mode.