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Performance enhancement of polymer electrolyte fuel cells by combining liquid removal mechanisms of a gas diffusion layer with wettability distribution and a gas channel with microgrooves

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HIGHLIGHTS

- A novel PEFC with a combination of new types of GDL and gas channel was proposed.
- GDL with planer distributed wettability to keep oxygen diffusion paths was adopted.
- Gas channel with slanted micro-grooves to remove excess water from GDL was adopted.
- Current density limit and maximum power density were improved by the combination.
- The stability of the cell voltage was markedly improved.

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ABSTRACT

Although polymer electrolyte fuel cells (PEFCs) are commercially available, there are still many problems that need to be addressed to improve their performance and increase their usage. At a high current density, generated water accumulates in the gas diffusion layer and in the gas channels of the cathode. This excess water obstructs oxygen transport, and as a result, cell performance is greatly reduced. To improve the cell performance, the effective removal of the generated water and the promotion of oxygen diffusion in the gas diffusion layer (GDL) are necessary. In this study, two functions proposed in previous reports were combined and applied to a PEFC: a hybrid GDL to form an oxygen diffusion path using a wettability distribution and a gas separator with microgrooves to enhance liquid removal. For a PEFC with a hybrid GDL and a gas separator with microgrooves, the concentration overvoltage of the PEFC was reduced, and the current density limit and maximum power density were increased compared with a conventional PEFC. Moreover, the stability of the cell voltage was markedly improved.

1. Introduction

Moisture management is critical for improving the performance of a polymer electrolyte fuel cell (PEFC). At high current density, the generated water accumulates in the gas diffusion layer (GDL) and gas channels on the cathode side of the PEFC. The cell performance is greatly reduced by the excess water, which obstructs oxygen transport. To improve the cell performance, an effective removal of the generated water is necessary. Past studies have examined methods to improve moisture control and liquid water removal performance on the cathode side to control the water accumulation in a PEFC. Approaches have included surface treatments, or finishing, of the GDL and the use of gas channels. For example, studies have considered using hydrophobic materials, such as polytetrafluoroethylene (PTFE) and fluorinated ethylene propylene (FEP), for the hydrophobic treatment of the GDL [1–4]. The effects of a microporous layer (MPL), PTFE content [5–7], and component fractions of hydrophobic and hydrophilic materials [8–10] on cell performance have also been examined. Moisture control using GDLs perforated with laser-cut holes [11,12] and multiple

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hydrophobic and hydrophilic MPLs [13,14] have also been tried. To enhance oxygen gas diffusion, control of the liquid water movement using a GDL with a different wettability in the planar direction has been considered [15,16]. Changes to the gas channel, such as channel configuration, have been examined for their effect on PEFC performance. Various flow channel types, such as parallel, serpentine, interdigitated, and hybrid channels, have been investigated [19–28]. Other studies related to the configuration of the flow channel have considered passive water removal by capillary droplet actuation [29] and channel wall wettability [30,31]. To increase the removal of liquid water, Okabe and Utaka [32] proposed arranging microgrooves inside gas channels and experimentally demonstrated the effectiveness of the microgroove arrangement. Koresawa and Utaka [33] applied microgrooves to a real PEFC and demonstrated enhancements to the current density limit. In the present study, two methods were applied to enhancing the performance of a real PEFC, i.e., combining the use of a GDL with a different wettability in the planar direction [15,16] and a microgroove arrangement inside a gas separator [32,33].

2. Summary of previous reports and objective relevance to this study

To improve the oxygen diffusion characteristics of liquid water, Utaka et al. [15] proposed a new configuration where two porous media with different wettabilities (i.e., hydrophobic and hydrophilic) were alternately arranged in the planar direction of a GDL (i.e., a hybrid configuration). Liquid water was moved from the hydrophobic medium to the hydrophilic medium due to capillary pressure originating from the difference in wettability. Voids in the hydrophobic medium were aligned in the direction of oxygen diffusion, enhancing oxygen diffusion. Water distribution profiles in the microporous media were visualized by X-ray computed tomography and oxygen diffusion characteristics were measured by Galvanic cell oxygen absorber apparatus [17,18] simultaneously, and the high oxygen diffusivity mechanisms were examined using model apparatus for the hybrid GDL, which was thicker (2.5 mm) than a conventional GDL.

Furthermore the hybrid configuration was applied to carbon paper used for GDLs [16]. The formation of oxygen diffusion paths was confirmed by X-ray radiography, where voids in the hybrid GDL were first formed in the hydrophobic regions and then spread to the untreated wetting region. The application of a hybrid GDL enhanced the oxygen diffusion characteristics. Although these results show the potential for a hybrid GDL, for the realization of actual power generation applications, liquid water should be effectively removed from the GDL.

At the same time, reduce the accumulation of liquid water on the GDL surface, Utaka et al. proposed an arrangement of thin microgrooves with axes tilted toward the surrounding air flow on the side walls, the upper wall inside the gas channel and isolated their effect by using model apparatus [32]. The water produced from the GDL was discharged along microgrooves facing the top of the GDL by capillary forces and air flow shear. Laser-induced fluorescence was used to measure the water velocity in the microgrooves. It was shown the microgrooves for an inclination angle of 20° were confirmed to be effective throughout a gas channel with a total length of 200 mm. Moreover, Koresawa and Utaka [33] demonstrated the effectiveness of microgrooves for an actual PEFC by applying the configuration to an actual PEFC with a straight gas channel and a total length of 200 mm. The PEFC with microgrooves showed a better performance than the conventional PEFC without microgrooves.

Thus, the combination of a hybrid GDL and a gas channel with microgrooves should facilitate a more effective removal of liquid water. As shown in Fig. 1, an oxygen diffusion path in the hydrophobic region of the GDL was ensured by movement from the hydrophobic region to the hydrophilic region. However, liquid water easily accumulated in the hydrophilic region. The PEFC performance was improved by combining a gas channel with microgrooves and a hybrid GDL to prevent or minimize the accumulation of excessive liquid water on the GDL surface.

The objective of this study was to enhance the power generation of an actual PEFC by applying a hybrid GDL with planar distributed wettability and a gas channel with microgrooves.

3. Experimental apparatus and method

3.1. Experimental system

Pure hydrogen gas and air (approximately 78%, nitrogen, approximately 21% oxygen, and approximately 1% argon) were supplied to the anode and cathode, respectively, from gas cylinders via a mass flow controller to control the flow rate. A humidifier was used to maintain water vapor saturation. To avoid cooling condensation, pipes from the humidifier to the PEFC were heated and covered with an insulating material. To operate the PEFC at a fixed temperature, separators of the anode and cathode were connected to a thermostatic bath, and water was circulated at a constant temperature. The cell voltage was measured with a data logger, and the cell resistance was measured with an LCR meter. The current load on the PEFC was changed in a stepwise fashion based on the electrical load. The results were used to determine the current-voltage characteristics and the cell resistance via the current density.

Fig. 2(a)–(c) show the entire PEFC apparatus, hybrid GDL and microgroove construction, respectively. To evaluate the differences in PEFC performance with and without microgrooves, a separator with a long gas channel was manufactured to mimic the application of this PEFC to an actual PEFC as shown in Fig. 2(a). The gas channel had a rectangular cross-section with width and height of $d_g = h_g = 1.0$ mm and a length of 200 mm. Eleven gas channels were arranged in parallel. The membrane electrode assembly (MEA) of the PEFC had a reaction area of 42 cm^2 (21 mm × 200 mm). For the GDL, carbon paper (Toray Industries, TGP-H-060) was hydrophobically treated and coated with an MPL. For the gaskets, a silicone rubber sheet was used on the anode side, and a silicone sponge sheet was used on the cathode side.

3.2. Structure of hybrid GDL

A hydrophobically treated carbon paper GDL (Toray Industries, INC. TGP-H-060) with an MPL coating on one side was used. The

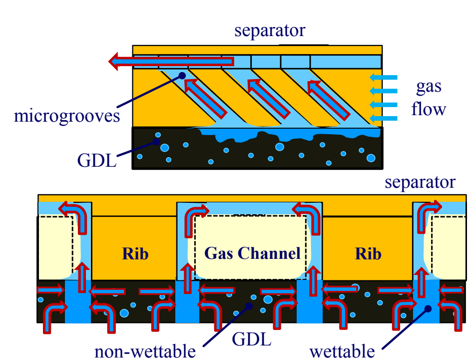

Fig. 1. Schematic of water movement with combined hybrid GDL and microgrooves.