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Proposal and examination of method of water removal from gas diffusion layer by applying slanted microgrooves inside gas channel in separator to improve polymer electrolyte fuel cell performance

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HIGHLIGHTS

- New gas channel with slanted microgrooves was proposed for water control in PEFC.
- Effective water removal was confirmed by water velocity measurement of LIF method.
- Effects of tilt angle of microgrooves, water supply rate and gas velocity were examined.
- Tilt angle of 20° shows best performance of water removal in variation of 20°–45°.

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ABSTRACT

The objective of this study was to improve the management of moisture from the gas diffusion layer (GDL) in the gas channel of a separator for PEFC. At the cathode-side, oxygen is transported as reactant gas from gas channel through GDL. When large quantity of moisture is generated during high power generation, moisture blocks transport of oxygen, and the cell voltage drops drastically. Narrow microgrooves with axes at tilt angle to the air flow were arranged inside channel walls. The water from GDL was discharged along microgrooves to facing top of GDL by forces of capillary and air flow shearing. Laser induced fluorescence method was used to measure water velocity in microgrooves. The effect of air velocity in the gas channel on water velocity in microgrooves was investigated. It was shown microgrooves manufactured inside gas channel worked properly. Water velocity in microgrooves increased with increasing air velocity, and moisture could be discharged from GDL by applying microgrooves. Furthermore, effective length of the microgrooves needed to remove water from the GDL surface increased with decreasing inclination angle of microgrooves in the range of 20°–45°. An effective length of approximately 200 mm was attained, which was overall length of experimental apparatus.
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1. Introduction

Polymer electrolyte fuel cells (PEFCs) are expected to be used as power sources for automobiles, cogeneration power sources for homes, etc. because of their low environmental load, high power density, and ability to operate at low temperatures. As seen in the general structure of a PEFC, at the cathode side, oxygen is transported from the gas channel in the separator through the gas diffusion layer (GDL) to the catalyst layer. Similarly, at the anode side, hydrogen is transported from the gas channel through the GDL to the catalyst layer. The electric power is produced by the chemical reaction of oxygen and hydrogen at the catalyst layer. The cell voltage is reduced by flooding phenomena, dryout phenomena, etc. Flooding occurs as a result of the liquid water produced by the chemical reaction, which accumulates in the microporous media of the GDL and the GDL surface on the gas channel side at the cathode. Finally, the diffusion of the reaction gas is suppressed. On the other hand, the proton conductivity in the polymer electrolyte membrane is decreased by low humidity during dryout. Therefore, moisture management in a membrane electrode assembly (MEA) is very important to improve the performance of PEFCs. Thus, for

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appropriate liquid water management, it is necessary to remove the extra liquid water in the GDL on the cathode side, to prevent an over-accumulation of liquid water in the GDL and GDL surface in the gas channel at the cathode side of a PEFC.

The authors [1] proposed a new GDL configuration, in which two porous media with different wettabilities are alternated (a hybrid configuration). Additionally, the authors [2], [3], [4] confirmed that this hybrid configuration is effective by measuring the apparent oxygen diffusivity in micro-porous GDLs using a galvanic cell oxygen absorber, along with the simultaneous measurement of the effective oxygen diffusivity and X-ray computed tomography visualization of the liquid water in carbon paper-type GDLs. GDLs with a higher oxygen diffusivity and the presence of liquid water, such as the hybrid configuration, can realize a better liquid water management performance by the addition of a gas channel structure, which aims at preventing the accumulation of liquid water on the GDL surface. Focusing on the use of a separator for moisture control, previous studies have tested gas channels such as a parallel type or serpentine type. Tanigawa et al. [5], [6] examined the effect of a gas channel on the condensate behavior using numerical simulations of serpentine-type separators with different rib widths. Konomi et al. [7], [8] developed a hybrid separator that combined the interdigitated type [9] and parallel type to improve the performance of a PEFC. As mentioned above, various studies have been performed to examine different gas channel configurations. However, problems have been found. For instance, liquid water accumulates within the GDL just below the rib and near the point of contact between the side wall of the channel and the GDL surface. Thus, it is necessary to avoid the accumulation of water near the rib. Kumbur et al. [10] examined the behavior of a liquid droplet, such as the contact angle and departure diameter. Zhang et al. [11] reported that liquid water can easily accumulate at the channel corner. Palan et al. [12] investigated the removal of liquid water using acoustic and vibrational methods. Further, Mench et al. [13] examined the effect of wettability on the inner surface of a channel by the visualization of liquid water using neutron radiography, and showed that the water removal performance is enhanced by combining a hydrophilic inner surface and hydrophobic GDL. Synchrotron X-ray tomography was used by Krüger et al. [14] to visualize the water distribution in the GDL and flow field channels of a PEMFC subsequent to operation. Visualizations of the water droplets and wetting layer formations in the flow field channels were shown. However, few studies have investigated ways to enhance liquid water removal by the configuration of the channel wall, as intended in this study.

In this study, in order to reduce the accumulation of liquid water on GDL surface, the authors proposed a method where thin microgrooves with axes at a tilt angle to the air flow were arranged at both the side and upper walls inside the gas channel, which was composed of the GDL surface and separator walls. Fig. 1 (a) and (b) shows a schematic view of the liquid water distribution in the case of relatively hydrophilic walls. As shown in Fig. 1 (a), a liquid–gas two phase flow is formed in a conventional gas channel, and it is probable that liquid water accumulates on the GDL surface when a large quantity of water is produced. The objective of this study was to enhance the removal performance from the MEA to gas channel through the GDL. As shown in Fig. 1 (b), microgrooves with axes at a tilt angle are arranged at both the side and top walls inside a square cross section of the gas channel. The water flowing through and from upstream moves to the opposite top wall from the GDL through the microgrooves without accumulating on the GDL surface, by means of the air flow shearing and capillary force produced by the surface tension within the microgrooves. The effects of the air velocity in the gas channel, flow rate of the liquid water through the GDL, and tilt angle of the microgrooves were examined in this study.

2. Experimental apparatus and procedure

2.1. Configuration of microgrooves and experimental system

Fig. 2 shows the structures of the microgrooves on the imitated separator wall made of acrylic plate, whose surface was good in water wettability. Their axes have a tilt angle to the air flow, and they are arranged at both the side and upper walls inside the gas channel. Table 1 lists the specifications of the microgrooves, where the symbols correspond to those denoted in Fig. 2. Two kinds of gas channels with square cross sections were used, with a width and height of $d_g = 1.0$ mm and 2 mm, respectively. In addition, microgrooves with axes at a tilt angle to the air flow were arranged at the walls inside the gas channel. Moreover, a larger groove, which allowed liquid water to move in the direction of the gas flow, was arranged in the center of the upper wall. The widths and depths of the two microgrooves at both the side and upper walls were

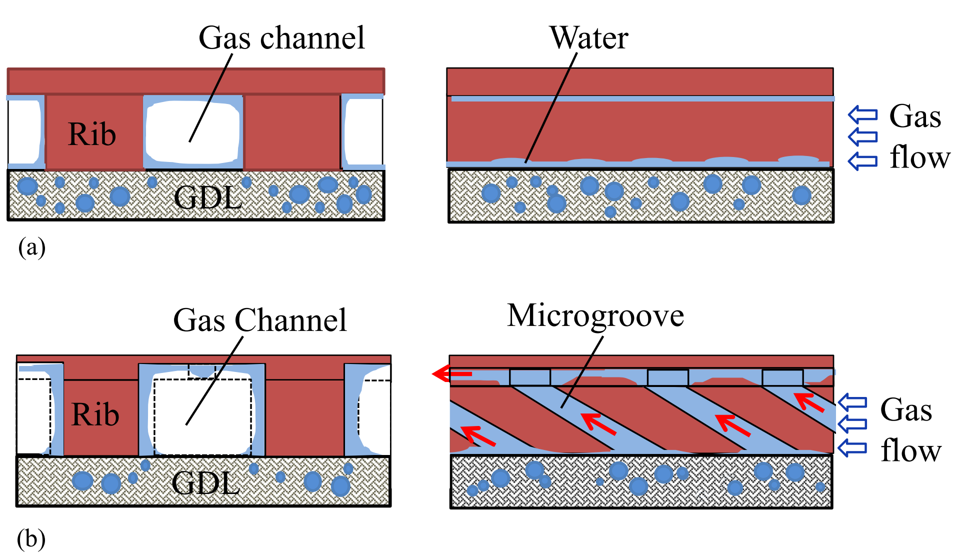

Fig. 1. Schematic of water behavior through microgrooves from GDL. (a) Conventional separator without microgrooves. (b) Separator with microgrooves.

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