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An experimental study on the enhancement of the water balance, electrochemical reaction and power density of the polymer electrolyte fuel cell by under-rib convection

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ABSTRACT

The flow field design of the uniform distribution of reacting gas generates broad scientific interest, especially among those who study the performances of polymer electrolyte fuel cells (PEFCs). In this study, we find a new serpentine flow field equipped with sub-channels and by-passes to promote under-rib convection. This flow field enables a more effective utilization of the electrocatalysts by increasing the mass transport rates of the reactants from the flow channel to the inner catalyst layer (CL) and by significantly reducing the water flooding at the cathode. This study experimentally evaluates the effect of the new serpentine flow field with sub-channel and by-pass (SFFSB) on the single cell performance and compares it with a conventional advanced serpentine flow field (CASFF). The maximum current and the power densities of the SFFSB are increased by 18.85% and 23.74%, respectively, due to the promotion of under-rib convection.

1. Introduction

The polymer electrolyte fuel cells (PEFCs) offer the possibility of cleaner electricity with less impact on the environment than the traditional energy conversion technologies, such as the automotive propulsion and the smart grid system [1]. One of the main obstacles to the commercialization of PEFCs is the flow fields in the bipolar plate (BP) that cause severe water flooding and mass transport loss of the cathode. Nonetheless, the BP design as a whole and the flow channel layout configuration in particular have the potential to make an alternative clean power source compatible with its counterparts [2].

The presence of a convective flow in the under-rib regions enables an effective utilization of the electrocatalysts. This under-rib convection has recently been recognized as a non-negligible transport process that influences the performance of PEFCs with serpentine flow fields [3–14]. Under-rib convection should not be ignored when the GDL permeability exceeds 10^{-13} m^2, which is consistent with the numerical prediction of the relative influence of under-rib convection [4,5]. Experimental studies have shown that higher gas diffusion layer (GDL) permeability improves the performance of PEFCs with serpentine flow fields [6–12]. Recently, the convection-enhanced serpentine flow field has been confirmed to have a better water handling ability than the conventional design [13], and the cathode flow field design for a single serpentine PEFC has promoted strong convection flows to enhance oxygen transport and water removal [14].

These results largely show that under-rib convection plays a role in improving PEFC power density. To provide a better understanding of the flow features, we designed a new serpentine flow field with sub-channels and by-passes (SFFSB) [15]. In this study, we present the under-rib convection mechanism and evaluate the effects on the enhancement of the water balance, electrochemical reaction and the power density by comparing SFFSB with conventional advanced serpentine flow field (CASFF) by under-rib convection.

2. The under-rib convection mechanism

For a better understanding of under-rib convection, Fig. 1 shows the schematics of CASFF and SFFSB with 5 passes and 4 turns on a 25 cm^2 active area and the cross-sectional views that illustrate the representative liquid water transport and the distribution caused by the under-rib convection. Under-rib convection is an additional convective flow through the GDLs designed to increase the mass transport rates of the reactants from the flow channel to the inner catalyst layer, to facilitate the liquid water removal from those regions and to enable a more uniform reactant concentration distribution from the inlet to the outlet.

In the case of CASFF, at the anode, a generally uniform velocity can be observed in the main channel and the rib area, both of which show

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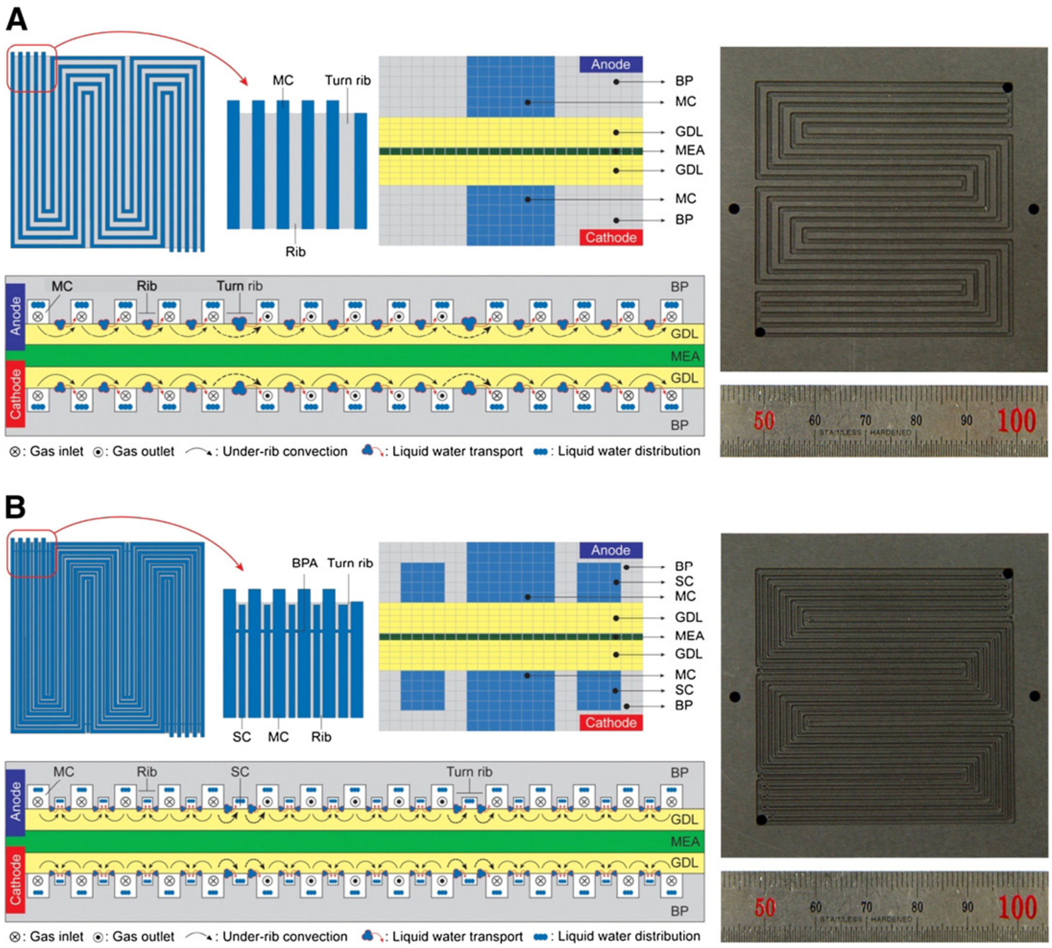

Fig. 1. Schematics of (A) CASFF and (B) SFFSB of 5 passes and 4 turns on a 25 cm^2 active area and the cross-sectional views illustrating the representative liquid water transport and the distribution caused by under-rib convection.

the same gas flow direction, but there is a minor change with the inlet-to-outlet direction. In the turn rib area where there is a change in the flow direction, the velocity vectors are significantly increased due to the large pressure difference between the adjacent main channels. At the cathode, under-rib convection is generated from the inlet to the outlet due to the high stoichiometry ratio, and the high velocity vectors are observed in the adjacent rib and the turn rib area.

In the case of SFFSB, the decreased rib width improves the gas permeability and the overall gas diffusion force as we add the sub-channel to change the flow direction of under-rib convection. Therefore, at the anode, the velocity vectors are large at the main channel inlet, and the under-rib convection flow direction converges to the sub-channel through convection because the main channel has a higher pressure than the sub-channel. The velocity is uniform in the main channel outlet because of the pressure decrease. At the cathode, under-rib convection with a different size but a similar tendency with the one at the anode is generated, and the under-rib convection flows from the sub-channel to the main channel at the channel outlet due to the high stoichiometry ratio. As the reactant that travelled through the sub-channel now migrates to the outlet, the internal pressure of the sub-channel is increased, and the flow direction is changed toward the main channel for a smooth discharge.

Fig. 1 illustrates the under-rib convection mechanisms of the flow direction and the liquid water transport of CASFF and SFFSB. The enhancement of under-rib convection can reduce water flooding at the cathode and increase the electrochemical reaction, thus improving both the cell performance and the operating stability.

3. Experimental procedure

The PEFC performance was evaluated by measuring the polarization curve while adjusting the operating conditions, such as pressure, temperature, humidity, flow rate and reacting gas (Table 1). To measure the experimental evidence of the enhanced PEFC performance caused by the under-rib convection, we fabricated the CASFF and the SFFSB shown in Fig. 1. For single cells, the bipolar plates of the anode and the cathode were produced with the semi-counter flow of the reacting gas. The W.L. Gore & Associates PRIMEA® Series 57 MEA is sandwiched between the anode and the cathode (SIGRACET® GDLs), which has a porous structure, and a membrane and two electrodes are composed of highly dispersed carbon-supported platinum catalysts.

A performance test was performed as the preliminary step to quantify the PEFC performance evaluation, to minimize the physical damages to the MEA and to keep a stable state of the electrical load. Prior to the performance procedure, a sufficient humidification process was conducted for 30 min to hydrate the dried MEA. Based on the FCTESTNET performance test, we constructed a maximum performance test procedure with a cell voltage ranging from 1.0 V to 0.35 V in 0.01 V decrements; the test was performed for 66 min or 132 steps per cycle [16].

4. Results and discussion

The PEFC performances with 5 passes and 4 turns on an active area of 25 cm^2 were experimentally evaluated for a new flow field design,