Applied Energy 212 (2018) 333–339

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Metallic bipolar plate with a multi-hole structure in the rib regions for polymer electrolyte membrane fuel cells

Kyung Don Baik*, Il Sung Seo

Agency for Defense Development, Daejeon 305-152, Republic of Korea

HIGHLIGHTS

- A novel MBP with a multi-hole structure in the rib regions is suggested.
- The fuel cell with multi-hole structure shows a 37.75% performance increase at 0.4 V.
- The cell of the multi-hole structure can reduce the mass transfer resistance.
- The pressure drop at the cathode is much lower compared to a conventional MBP.

ARTICLE INFO

Keywords:
Multi-hole structure
Number of holes
Metallic bipolar plate
Polymer electrolyte membrane fuel cell

ABSTRACT

A metallic bipolar plate (MBP) with a multi-hole structure (MHS) in the rib regions is developed to improve the cell performance at high current densities. The polarization curve, high-frequency resistance (HFR), low-frequency resistance (LFR), and pressure drop at the cathode of five different fuel cells with different MHSs are compared. The MHS design with three holes produces the highest cell performance and a 37.75% increase in the current density at 0.4 V. The HFR values of the fuel cells with MHSs are higher than that with a conventional flow field; this is mainly due to the large contact resistance between the MHS of the MBP and the gas diffusion layer. The LFR values of the fuel cell with the conventional flow field are much higher than those with MHS MBPs at high current densities; this is the result from a shortage of oxygen due to water flooding of the cathode. The pressure drop at the cathode for the cells with MHS MBPs is much lower than that for the cell with a conventional MBP.

1. Introduction

The polymer electrolyte membrane fuel cell (PEMFC) system is highly efficient and environmentally friendly and has been suggested as a promising alternative for future power generation systems. Utilizing fuel cells to power various applications such as automotive and military equipment requires a reduction in size and increase in power because current fuel cell systems are not profitable and are still too large. Solving these issues for fuel cells will require a novel fuel cell structure for operation at high current densities.

The metallic bipolar plate (MBP) feeds hydrogen to the anode and air to the cathode through channel regions while also serving as an electron flow path across the face of the electrode to the current collector through the rib regions. To increase the current density and improve the fuel cell performance, it is important to promote the diffusion of air and exclude the produced water. Toyota Motor Corp. [1] adopted innovative flow channel structures (*i.e.*, a 3D fine-mesh flow field) to develop a new fuel cell stack that can achieve a high power density of 3.1 $kW\,L^{-1}$. The new flow channel at the cathode makes it possible for the generated water to be quickly drawn out through the 3D fine-mesh flow field and prevent the accumulated water from obstructing the flow of air (oxygen). Toyota Motor Corp. [2] also developed a novel cathode electrode to enable operation at high current densities by incorporating vertically aligned carbon nanotubes as the catalyst support. This improved the mass transport of reactants (*i.e.*, oxygen, protons, electrons, and water) in systems operating at a current density of 2.6 $A\,cm^{-2}$ and voltage of 0.6 V. Honda Motor Corp. [3] announced an innovative fuel cell stack (3.0 $kW\,L^{-1}$) that uses a proprietary V-flow cell structure and wave flow channel separators.

Other efforts to improve the power density have involved adopting a metal foam as flow channels or gas diffusion layers (GDLs) [4–12]. Mench et al. [4,5] investigated a fuel cell with an open metallic element (OEM) that was conceived and designed by Nuvera Fuel Cells. This fuel cell dramatically increases the limiting current density compared to

* Corresponding author.
E-mail address: nase100@gmail.com (K.D. Baik).

https://doi.org/10.1016/j.apenergy.2017.12.057
Received 14 July 2017; Received in revised form 8 December 2017; Accepted 9 December 2017

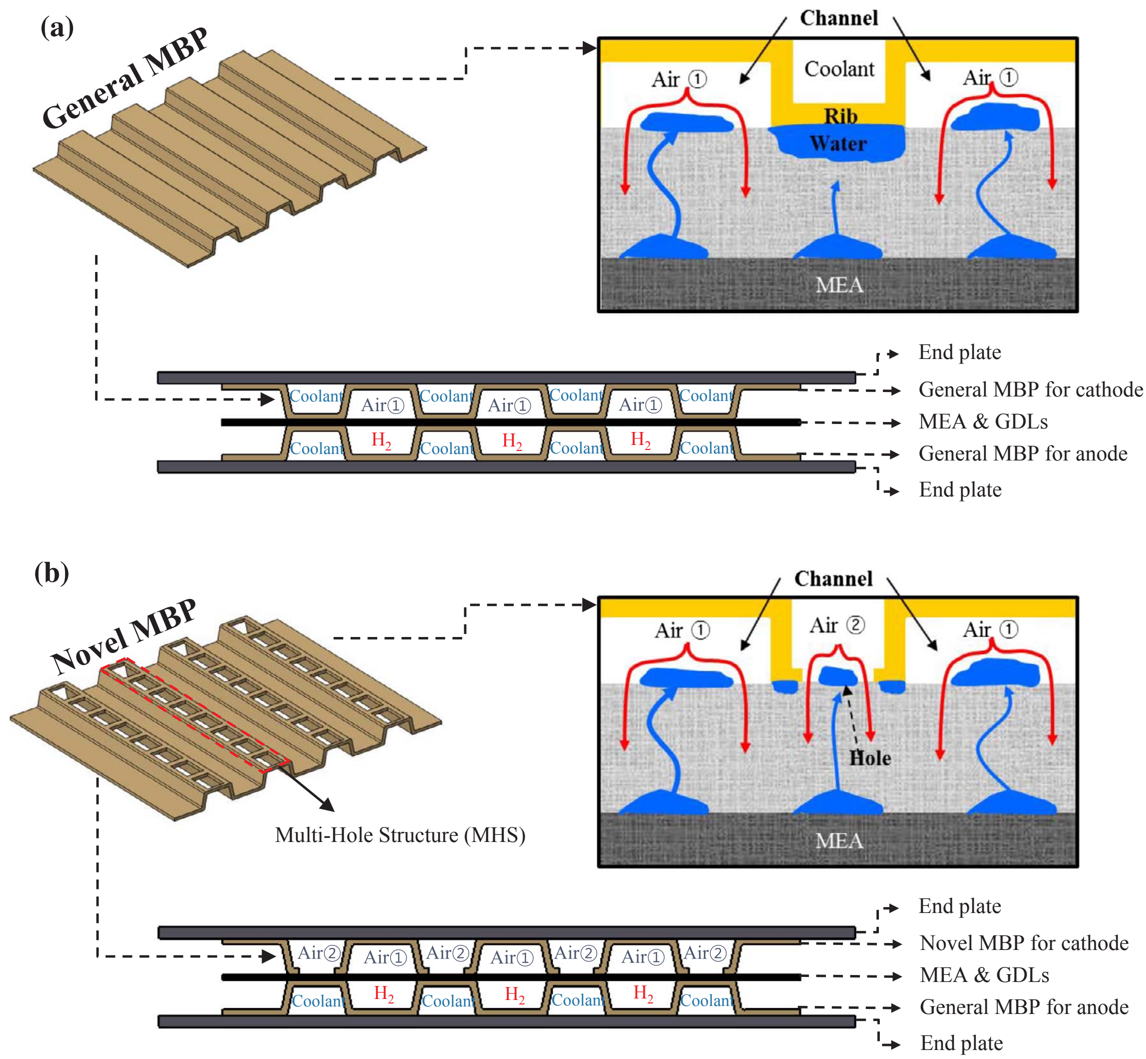

Fig. 1. Schematic diagrams of the (a) general and (b) novel MBPs and their cross-sectional views.

Table 1
Characteristics of the cathode MBPs used in this study.

MBP code	Number of holes	Hole width (cm)	Hole length (mm)	Hole area (cm^2)	Rib/hole area ratio (%)
HN-0	0	0.8	0	0	0
HN-1	1	0.8	5.85	4.68	46.80
HN-2	2	0.8	2.73	4.37	43.68
HN-3	3	0.8	1.68	4.03	40.32
HN-4	4	0.8	1.16	3.71	37.12

conventional designs. A stable peak power of 1.2 W cm^{-2} at a current density of 3.0 A cm^{-2} was generated by using OEM architecture with low-humidity hydrogen at the anode and dry air at the cathode. Tsai et al. [6] proposed several flow field designs for a PEMFC with metal foam as the flow distributor to improve the cell performance. They showed a power density of 1.46 W cm^{-2} at a voltage of 0.6 V with an operating pressure of 3 atm. Tanaka et al. [7,8] reported a novel fuel-cell structure that reduces electrode flooding by utilizing corrugated mesh as gas-flow channels and gas diffusers placed directly onto the micro-porous layer (MPL) without a conventional GDL. They achieved a cell voltage of 0.45 V at 3.0 A cm^{-2} by utilizing a corrugated mesh in the flow channel located directly on the MPL without using a GDL. Utaka et al. [11] proposed a method where thin microgrooves with axes tilted at an angle to the air flow are arranged on both the side and upper walls inside the gas channel to reduce the accumulation of liquid water on the GDL surface. They realized operation at a current density of 2.0 A cm^{-2}. Park et al. [12] investigated the effect of inducing a cross-flow on the flow pattern and performance of a PEMFC. They reported that the cross-flow plays an important role in changing the transport pattern and performance.

The above studies focused on operation at high current densities in relation to the flow field geometry [13–15]. In order to increase the fuel cell performance at high current densities, this work suggests a new MBP with a multi-hole structure (MHS) in the rib regions. The MHS can easily remove the accumulated water and supply reactant gas in the rib regions to improve the cell performance and operating stability. Here, we report the preparation of the MBPs and the evaluation results with regard to the polarization performance, high-frequency resistance, low-frequency resistance, and pressure drop between the inlet and outlet at the cathode. Our main purpose is to improve the performance of PEMFC, which is one of the energy conversion components, by changing the structure without changing the materials. The novelty of the MHS MBP lies in the fact that its effect has been accomplished within a conventional fuel cell MBP. The results of the improvement of the fuel cell performance by changing the structure of MBP can be employed in the development and demonstration of a fuel cell stack having a high volume or weight density.