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Enhancement of the electrochemical membrane electrode assembly in proton exchange membrane fuel cells through direct microwave treatment

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HIGHLIGHTS

- We developed a new method of direct microwave irradiation treatment to the MEA.
- Improved micropore structure was achieved using microwave treatment.
- High active site at the catalyst layer was achieved using microwave treatment.
- High Pt utilization at the catalyst layers was achieved using microwave treatment.
- The microwave-irradiated MEA show superior cell performance over non-treated MEA.

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ABSTRACT

Demonstrated herein is a novel and easily controllable method using direct microwave irradiation treatment to enhance the electrochemical structure in the membrane electrode assembly (MEA) of the fuel cell. Through direct microwave irradiation, it is found that the pore dimension changed to an improved micropore structure with a 1.5-fold larger surface area (from 9.68 to 15.21 $m^2\ g^{-1}$) at the microwave power of 500 W than the rare statement, which is proportional to the mass/heat transfer properties, along with the higher interfacial site area in the electrode, for better electrochemical properties. This upgraded structure also increases the Pt catalyst utilization and reduces the electrical loss by increasing the ionic conductivity between the catalyst layer and membrane when combined with polymer electrolyte, a catalyst, and the Nafion membrane in MEA. Due to the enhancement of the MEA properties, the fuel cell performances of the microwave-irradiated MEAs show a significant improvement to 1.87 A cm^{-2} at 0.6 V over the conventional MEA performance of 1.47 A cm^{-2}. Especially achieved is a 110% enhancement in the limiting current density resulting from the developed electrochemical micropore structure.

1. Introduction

Proton exchange membrane fuel cells (PEMFCs) can convert chemical energy to electrical energy through electrochemical reaction [1–6]. For the central component of PEMFC, a membrane electrode assembly (MEA) is placed, which consists of a proton exchange membrane, two electrodes (catalyst layers), and gas diffusion layers (GDLs). These components are commonly fabricated individually and then pressed together at a high temperature and pressure [7–10]. Recently, several research groups reported methods of designing an effective MEA by enhancing the membrane/electrode interface, considering better smooth mass transfer and a higher interfacial site area [11–13]. There have been no studies, however, on the direct treatment of the fabricated MEA.

The electrochemical reaction in the fabricated MEA can occur only at the "triple boundary phase (TBP)," where the electrolyte, reaction material, and electrically connected catalyst particles come in contact with one another. The TBP in the MEA must be required because this phase can easily transport the protons and reactants generated through the MEAs reactant to minimize the electrical losses and to enhance the electrochemical reaction for improved performance and durability. One of the most important factors to consider in the improvement of the TBP structure for better reactant transfer is the catalyst layer design. The catalyst layers at both

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the cathode and anode in the MEA typically include catalysts, catalyst supports, proton conductors, and adhesives. These catalyst layers should be highly porous to make mass transfer easier and to increase the site area for better electrochemical reaction properties [14]. Many research groups have attempted to fabricate a highly porous cathode catalyst layer with an effective structure for a high surface area and a good transfer property. Most of the studies included a pore formation step during the synthesis of the catalysts before applying them to the MEA fabrication process [15–20]. Another matter that must be taken into account for the fabrication of an effective catalyst layer is that it is also necessary to maximize the Pt utilization, which usually indicates the metal dispersion and the amount of exposed metal atoms at the TBP. Usually, the Pt utilization of the commercial Pt/C in the PEMFC appears within the range of 20–50% at the Pt particle size of 2–4 nm [21–23]. The few studies under way at research institutions focus only on the synthesis of effective catalysts that improves the metal utilization [11–13].

Along the above lines, the components of MEA have been individually synthesized to improve their electrochemical properties, and have then been fabricated together. Such kinds of catalyst or membrane preparation/treatment methods are complicated, however, as they involve many processes and thus require a long preparation time.

In this report, a new, simple approach to effective treatment is presented using direct microwave irradiation of the fabricated MEA. Microwave treatment has been used for synthesizing organic/inorganic materials, for chemical analysis, and for electrocatalysis due to its distinctive characteristics of swiftness, uniformity, simplicity, and energy saving compared with the traditional heating treatment [24,25]. To date, however, there has been no research on the electrochemical device's MEA system. Compared to a non-treated MEA, the simple direct microwave treatment of an MEA significantly increases the PEMFC cell performance by enhancing the porosity of the catalyst layers and the interface bonding between the membrane and catalyst layer, even with a short reaction time (~5 s).

2. Experimental

To prepare an MEA for PEMFC test, the catalyst slurry is prepared by mixing Pt/C (40 wt.%, Johnson Matthey Co.) with 5 wt.% Nafion solution in isopropyl alcohol. It is stirred for 5 min, sonicated for 3 min, and is repeated five times. The catalyst ink is sprayed onto a Nafion 212 membrane. The active electrode area for a single cell test is 1 cm^2 with Pt catalyst loading of 0.4 mg cm^{-2} for the cathode and anode. After then, the MEA is fabricated with a GDL (SGL 10BC) and catalyst sprayed membrane using hot pressing procedure at 125 °C, 0.7 ton for 90 s.

The microwave system consists of microwave generator, gas controller, teflon reactor, and MEA pressing system. The prepared MEAs are placed in a teflon reactor where N_2 gas is consistently flown to avoid the combustion of the catalyst during the microwave treatment. The reactor with the sample bed is, then, applied to a multimode resonant microwave cavity. The microwave irradiation system is set at different powers (500 W, 650 W and 800 W, respectively) with a treatment time of 5 s when the frequency is fixed at 2450 MHz.

To analyze the effect of the direct microwave treatment to the MEA, the morphological characteristics of the MEAs are observed using FE-SEM (JEOL-7001F, JEOL Ltd.). Nitrogen adsorption–desorption measurements are also conducted in BELSORP (Bel, mini II) to obtain information on the surface area and pore properties.

The single PEMFC performance is measured at an operation condition of 75 °C, 100% of a relative humidity. H_2/O_2 gases are supplied to the anode and cathode with a flow rate input of 100 and 150 ml min^{-1}, respectively. An activation step is operated with constant voltage at 0.6 V for 3 h. The polarization experiments are conducted using an electric load (EL500P, Daegil Electronics) and the AC impedance (0.7 V) results are analyzed using PGSTAT-30 (Autolab) to investigate the resistances in the MEAs.

3. Results and discussion

The SEM image in Fig. 1 illustrates the changes in the morphology of the catalyst layer in the MEAs resulting from the

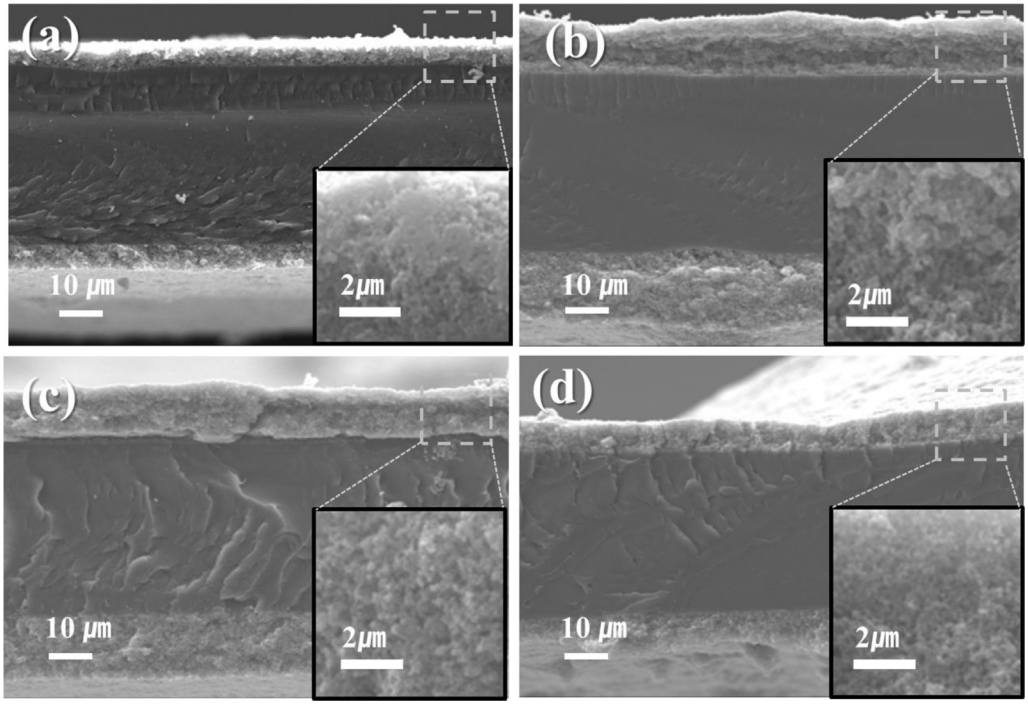

Fig. 1. FE-SEM micrographs of a cross section of the catalyst layer. (a) Non-treated MEA, and microwave-treated MEA at (b) 500 W (c) 650 W (d) 800 W for 5 s.