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Analysis of operational characteristics of polymer electrolyte fuel cell with expanded graphite flow-field plates via electrochemical impedance investigation

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ABSTRACT

Expanded graphite was investigated as a material for flow-field plates in PEFCs (polymer electrolyte fuel cells). Because expanded graphite is flexible but has similar material properties with normal graphite, channels on flow-field plates were designed to have single channel in order to compare operational characteristics including diffusion of reactants through ribs by comparing polarization curves and electrochemical impedance spectra between PEFCs with expanded graphite and graphite flow-field plates. As a result, PEFC with the expanded graphite flow-field plates has comparable open-circuit voltage to that with the graphite flow-field plates. However, PEFC with the expanded graphite plates had higher ohmic resistance than that with the graphite plates due to higher electrical resistance of the expanded graphite than that of the graphite. It was also found from faradaic resistances that the diffusion of the reactants through GDLs (gas diffusion layers) is disturbed in the case of the expanded graphite flow-field plates because the GDL is compressed excessively due to its flexibility.

1. Introduction

PEFC (Polymer electrolyte fuel cell) has been considered as one of the promising energy-generating device due to its high energy/power density and eco-friendliness [1–5]. It shows the potential to play a role for an alternative for internal combustion engines and portable electronic power devices [6]. Because of this potentials, there have been a great diversity of research areas related to PEFCs such as catalyst on membrane-electrode assembly (MEA), analysis of flow channels design, prevention of flooding effect, building of mathematical model, and so on [7–11]. However, the total price of PEFCs is preventing their commercialization. The flow-field plates (or monopolar/bipolar plates or separators), one of the main components in PEFCs, account for about 45% of the total price [12,13]. The role of flow-field plates is to support the MEA, supply hydrogen and air properly, conduct electrochemically generated heat outside, and carry electrons to the external electric circuit. Accordingly, many requirements should be satisfied if PEFCs are to operate well. Such requirements include high electrical conductivity, high thermal conductivity, a high mechanical strength, low gas permeability, high corrosion resistance, a high compressive strength, low density, and good machinability [14,15]. Thus far, graphite has been commonly used as a material for flow-field plates in PEFCs, but it is postulated that the price will not decrease as long as graphite is used due to its bad machinability [14]. To overcome this obstacle, there have been numerous studies about reducing the cost of flow-field plates by changing the material to metal, metal-coated plastic, and carbon composite in these devices [16–24].

This study utilizes expanded graphite (EG), which is also known as exfoliated graphite, graphite sheet, or Grafoil™ as a material for the flow-field plates in PEFCs. The chemical properties of EG are nearly identical to those of graphite because it is mostly composed of carbon. The difference between EG and graphite is that mechanical properties of the two materials are quite different in that EG is flexible, and compressible. Due to this feature, it is currently used as sealing gaskets in high-temperature and chemically harsh conditions. It means that EG can also be used in flow-field plates for PEFCs. Furthermore, the machinability of EG is so easy that it can significantly lower the price of PEFC stack.

There have been several studies where EG is used as flow-field plates or current-collecting layers in PEFCs [25–29]. Hentall et al. suggested that an EG be a useful material in PEFCs, and Hwang et al.

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fabricated flow-field plates using the EG [28,29]. Yan et al. successfully fabricated a PEFC stack with flow-field plates of EG [25]. Previous researches showed the advantages and performance levels of flow-field plates composed of EG, while the differences in the electrochemical characteristics between graphite and EG were not investigated in detail. This study, thus, investigated the characteristics of PEFCs with flow-field plates of graphite and EG. Specifically, electrochemical impedance spectroscopy (EIS) was utilized to characterize the differences between graphite and the EG. In addition, the flow channel was designed to have one single channel in order to investigate the diffusional characteristics through ribs. The assembled fuel cells were assessed at various clamping pressures to observe variation of diffusional characteristics through ribs.

2. Experimental setup

2.1. Setup of fuel cells

Fig. 1(a) shows a unit PEFC with dimensions. The 0.5 mm thick EG (SGL Inc., Germany) was used for flow-field plate. Here, six EGs were overlapped and compressed to 2 mm at 20 MPa in order to avoid compression after the full assembly of fuel cell. The thickness of 2 mm is identical to that of the GFP (graphite flow-field plate). Next, the single flow channel with a cross-sectional area of 1×1 mm^2 was fabricated by cutting. GFPs with the dimensions same as the EGFPs (expanded graphite flow-field plates) were also fabricated to compare each other. Buffer layers between the flow-field plates and end-plates at both the anode and the cathode sides were made of polycarbonate. These were used to distribute clamping pressure homogeneously and supply hydrogen and air to the anode and cathode, respectively. The end plates were made of stainless steel where six holes were machined to clamp bolts and nuts. When fastening the bolts and nuts, wood sleeves were inserted in order to distribute the pressure from the bolts and nuts uniformly.

MEAs (CNL Inc., Korea) were purchased commercially and used in all fuel cells without modification. It was composed of Nafion® 112 with a platinum/carbon loading of 0.4 mg/cm^2. The gas diffusion layer (GDL) attached onto the MEA was carbon paper. Its thickness was 425 μm. The electrochemical reaction area on the MEA was 40×4 mm^2. The thicknesses of the gaskets were 0.3 mm and hole of 40×4 mm^2 in the center was cut. These were placed between the MEA and a flow-field plate to appropriately press the GDL [30]. The fastening torques of the bolts and nuts were set to 25, 50, and 75 kgf cm. Fig. 1(b) indicates a picture of assembled fuel cell.

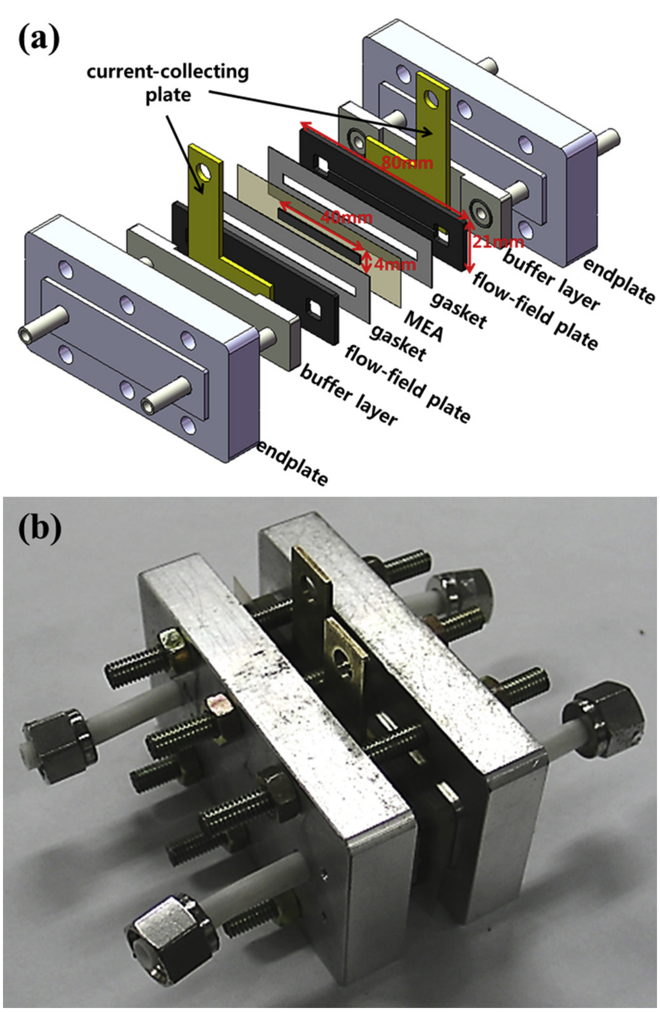

Fig. 1. (a) Exploded view and (b) real picture of single-channel PEFC. The flow-field plates were made of graphite and expanded graphite.

2.2. Operational conditions and characterization method of fuel cells

Before hydrogen was supplied to the anode, the cell was purged by nitrogen gas to avoid a direct reaction between the hydrogen and remaining oxygen. Then, pure hydrogen and air were supplied to the anode and cathode, respectively. The two gases were fully humidified at 50 °C using a bubble-type humidifier. The volumetric flow rate of hydrogen was 20 mL/min and that of air was 200 mL/min at atmospheric pressure and room temperature.

All resulting data were measured by a Solartron 1287 potentiostat and a 1260 impedance/gain-phase analyzer. Before measuring the current–voltage (I–V) curve, 0.5 V of voltage was applied to a cell for 30 min to activate and obtain stable data. After the activation process, a potentiodynamic method was used to measure the I–V curve. The scan rate of I–V curve was 10 mV/s, and scanning was initiated from the open-circuit voltage (OCV). Subsequently, a potentiostatic load of 0.5 V was applied repeatedly to the cell until the resulting current reached a stable state again. This potentiostatic mode for stabilizing the fuel cell performance was applied to all transitions during the measurements. The electrochemical impedance was then measured at a constant voltage. A sinusoidal signal with an amplitude value of 30 mV and a frequency range from 100 kHz to 0.1 Hz was applied to a cell. The impedance responses were measured at 0.5 V. After obtaining the impedance spectra, low frequency data were fitted to semicircles in order to find the intercept of impedance spectrum at low frequency region. From the obtained spectra, ohmic resistances were measured from the first Z′-intercept of the spectra and faradaic resistances were measured from the distance between the first and the second intercepts of the spectra. These experimental procedures were identical in the test of both the GFPs and the EGFPs.

3. Results and discussion

The variations in the I–V curves in the case of graphite and expanded graphite versus the various fastening torques are indicated in Fig. 2(a) and (b), respectively. In both cases, the OCV shows increasing tendency as the fastening torques increase. It is clearly shown in Fig. 3 where the variations of the OCVs are plotted with respect to the fastening torques. These results stem from the effect that the sealing of hydrogen and air was improved after increasing the pressurization of the boundary part of a cell [31]. If these gases