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Basic examination of membrane electrode assembly of proton exchange membrane fuel cell considering heat deterioration

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ABSTRACT

The purpose of this research is to develop a standard preparation method for membrane electrode assemblies (MEAs). Therefore, the preparation method for multilayered MEAs with gas diffusion layers (GDLs) and the degree to which polymer membranes deteriorate by heating were studied. As a result, improvement of power density by making multi catalyst layers provides a solution to some problems found in thin polymer membranes. In addition, it was found that improving the diffusion of gas through two-layer GDLs in cathode (duct side: carbon paper, catalyst layer side: carbon cross) results in a cross leak reduction. Moreover, a making condition of MEAs was optimized by varying the temperatures used for the multi catalyst layers and two-layer GDLs. The analysis of heat deterioration of the Nafion membrane using X-ray photoelectron spectroscopy (XPS) indicates that the optimal hot press temperature is 130 °C.

Keywords: Proton exchange membrane fuel cell; Membrane electrode assemblies; Catalyst; Multilayered

1. Introduction

Fuel cells have attracted much attention due to their potential for preventing global warming and energy problems; this is because fuel cells do not emit NO_x or SO_x, and they produce little CO_2. In addition, the electrical energy is generated directly from chemical energy and not through thermal energy. Therefore fuel cells are researched all over the world. The proton exchange membrane fuel cell (PEMFC) has great potential for applications in both movable and stationary power supply systems. For such uses, the fuel cell must be capable of operating at a high power density with low catalyst content in order to reduce its weight, volume, and cost (Susai et al., 2001; Escudero et al., 2002). Improving the MEAs performance has become a key issue in reducing the PEMFC cost, weight, and volume, and considerable research on MEAs development has been devoted to improving the catalyst utilization efficiency by reducing the amount of catalyst (Frey and Linardi, 2004; Wang et al., 2008). Many MEA fabrication methods have been developed recently to enhance the catalyst utilization efficiency, to reduce the cost, and to optimize the mass production of MEAs; these include spraying (Hsu and Wan, 2003), the dry spraying preparation technique (Gülzow et al., 2000), screen-printing (Kim et al., 1998), and the sputtering technique (Wan et al., 2006). Screen-printing is also a relatively easy and useable technique for preparing MEAs with multiple catalyst layers. While there are frequent reports concerning the study and development of materials used for PEMFC, there are no reports about the mechanical design of the MEAs. Therefore, we examined the preparation methods for multilayered MEAs with GDLs, and the degree to which the polymer membranes deteriorate by heating, and we report our findings here.

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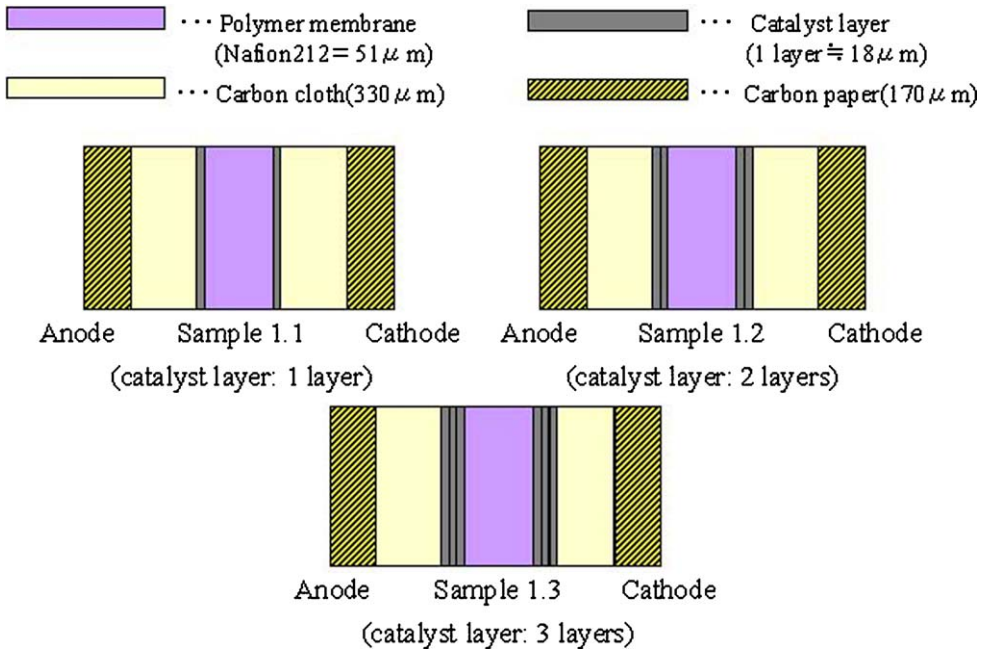

Fig. 1 – Schematic drawing of one single-layered MEA and two kinds of multilayered MEAs.

2. Experimental

2.1. *Preparation of catalyst layer*

Nafion–carbon ink was prepared by mixing 1.2 mL Nafion (EC-NS-05, 5%, Electro Chem) with 100 mg Vulcan XC-72 carbon powder using a supersonic wave mixing machine for 30 min. An appropriate amount of solvent was removed to obtain the Nafion–carbon ink, which was dried in an incubator at 30 °C for 3 h.

2.2. *Preparation of multilayered MEAs by screen-printing method*

The prepared Nafion–carbon ink was applied to a carbon cloth by a screen printer (MEC-2400, Kyushu Mitani Co.), and a catalyst layer was formed. To increase the number of catalyst layers, subsequent layers were applied by screen printing after drying the previous catalyst layer at a constant temperature of 60 °C for 30 min. MEAs with a reactive surface area of 5 cm^2 were prepared by using a hot pressing machine centred on an ion exchange membrane using the following procedure: adequate hydrogen peroxide, water and sulfuric acid were passed through the carbon cloths. Carbon cloth with a thickness of 0.33 mm and density of 1.75 g/cm^3 (Electrochem, 3% wet) and carbon paper with a thickness of 0.17 mm and density of 0.49 g/cm^3 (Toray, 35% wet) were set on the side of the ion exchange membrane, and a force of 7.5 MPa was then applied for 3 min.

2.3. *Evaluation method of multilayered MEAs*

The MEAs were placed between two silicone gaskets of 0.24 mm thickness and inserted between two graphite plates having serpentine grooves, and then placed in a single cell test fixture (FC25-01SP, 5 cm^2, produced by Electrochem, Inc., USA). The fuel cell was connected to a fuel cell evaluation system (FC-5100 produced by CHINO Co.) and equipped with a gas humidifier, a mass flow controller, and a temperature indicator controller. Performance of the multilayered MEAs was evaluated by determining the maximum power density (obtained from current–voltage (I–V) characteristics) and the hydrogen permeation current density (obtained from linear sweep voltammetry (LSV) characteristics of single cells). The single cell was operated at 70 °C, with a humidifier temperature of 80 °C. I–V characteristics were measured by feeding humidified hydrogen and oxygen gases into the cell at a flow rate of 300 sccm and 300 sccm at 0.15 MPa respectively. Also, LSV characteristics were measured by feeding humidified hydrogen and nitrogen gases into the anode and cathode at a flow rate of 300 sccm and 300 sccm respectively at 0.15 MPa, while applying a DC voltage from 100 mV to 500 mV using potentiostat HZ-5000 (produced by Hokuto Denko Co.). Hydrogen permeation current density was measured at 180 mV because this current density saturated over 180 mV.

3. Results and discussion

3.1. *Evaluation of multilayered MEAs*

In our previous research, improvement of power density for the number of multi catalyst layers was confirmed (Tashima et al., 2010). Therefore, reduction of cross leakage by multilayered MEAs was examined. Fig. 1 shows schematic drawing of one single-layered MEA and two kinds of multilayered MEAs. Sample 1.1 has single catalyst layer and sample 1.2 has two catalyst layers and sample 1.3 has three catalyst layers. The thicknesses of produced electrodes were 1087 μm in sample 1.1, 1123 μm in sample 1.2 and 1159 μm in sample 1.3. Fig. 2 shows maximum power density of three kinds of sample and hydrogen permeation current density at output voltage of 180 mV. Therefore, low hydrogen permeation current density shows low cross leakage. Maximum power densities of sample 1.2 and sample 1.3, which were two catalyst layers and 3 catalyst layers type MEAs, were 572 mW/cm^2 and 538 mW/cm^2 respectively. Power density of sample 1.2 was about 1.6 times in comparison with sample 1.1. In addition, multi catalyst