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EIS and local resolved current density distribution analysis on effects of MPL on PEMFC performance at varied humidification

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ABSTRACT

The performance of two MEA samples with different kinds of gas diffusion layer (with and without micro-porous layer) were investigated at different humidification conditions. Throughout the experiment, segmented cell technique was applied to record the current density distribution. EIS results were recorded combined with the equivalent circuit method to study the internal electrochemical mechanism on performance evolution. The performance of the MEA sample with the micro-porous layer furnished gas diffusion layer improved significantly at both low and high humidification condition. At low load and low humidification condition, the micro-porous layer could retain the product water increasing the hydration level of the membrane and the ionomer in catalyst layers, which greatly reduce the ohmic and activation resistance. Apart from that, the reactant transport resistance is also reduced when product water is retained to hydrate the ionomer, which could be confirmed by the EIS results. At high load and high humidification condition, the micro-porous layer could help curb the flooding in catalyst layer and gas diffusion layer with its excellent water removal capability thus improve the cell performance.

1. Introduction

Fuel cell represent a promising alternative energy technology that efficiently converts chemical energy present in a fuel directly into electricity. Amongst the various fuel cell technologies available, the proton exchange membrane fuel cell (PEMFC) is the primary candidate for transport and portable applications. Its high power density and ability to vary output quickly to meet shifts in power demand has resulted in its use in light duty vehicles, auxiliary power units, consumer electronics and backup power systems for the telecommunications industry. However, further improvement in performance and reliability is required to ensure that PEMFC constitute a large proportion of future power generation devices. The critical component of a PEMFC is the membrane-electrode assembly (MEA), which typically consists of a catalyst-coated membrane (CCM) and a gas diffusion layer (GDL) on both sides. The GDL acts as a pathway of reactant gases and liquid water, electric conductor, thermal conductor, and mechanical support. In particular, it acts as a path of two-phase mass transport so it is no exaggeration to state that the GDL is a key component in solving the water management problem [1–5].

A GDL is generally composed of gas diffusion backing (GDB) coated with a hydrophobic microporous layer (MPL), which is usually a mixture of fine carbon particles and a hydrophobic agent [6,7]. To improve their gas and water transport, GDBs are commonly treated with a hydrophobic agent such as polytetrafluoroethylene (PTFE) to increase the hydrophobicity [8]. A systematic experimental study by Ramasamy et al. [9] has clearly demonstrated improved mass transfer when these treatments are applied, both in terms of increased limiting current as well as reduced mass transfer resistance measured via AC impedance. The MPL treatment has been shown to be particularly beneficial although the actual function of this layer is still under debate. The MPL presumably creates better electrical and thermal contact between the catalyst layer and the GDL by providing a smoother, more continuous interface. Since the MPL actually adds a diffusive resistance to mass transfer, it is generally thought that the MPL somehow alters the liquid water distribution in the cell to a more favorable arrangement for gas phase transport [10,11]. The MPL question has been recently addressed with full-cell models, which predict that the MPL acts as a capillary barrier to water entering the cathode GDL and forces water to permeate from the cathode to the anode [12]. However few researches have explained the function of MPL from the perspective of internal impedance and local current density distribution. Electrochemical impedance spectroscopy (EIS) is a non-invasive diagnostic tool capable of

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measuring the fuel cell impedance over a wide range of frequencies. This powerful technique can determine various sources of polarization loss in a short time, being very useful to the optimization of the MEA design [13,14]. And the in-situ segmented cell technique can provide real-time, accurate current density distributions and reflect the uniformity of the internal electrochemical reaction in the fuel cell [15,16]. So in this study we combined the EIS and segmented cell technique to investigate the effects of MPL on fuel cell performance at high and low cathode relative humidity.

2. Experimental

2.1. Test sample and operating conditions

To investigate the effects of MPL on performance and current density distribution of PEMFC at varied humidification (RH 40%, RH 70%, RH 100%), commercial Nafion membrane with sprayed Pt/C catalyst layers on both sides (CCM) sandwiched between two commercial gas diffusion layers from SGL Corporation were tested on our fuel cell test bench (Greenlight Corporation). The Pt/C catalyst loading were 0.2 mg cm^{-2} and 0.1 mg cm^{-2} for cathode and anode respectively. The membrane thickness was 23 μm and the effective electrode area was 50 cm^2. In this study we used two different types of commercial gas diffusion layers which were hydrophobic 24BA (without MPL) and 24BC (24BA furnished with MPL). The 24BA type GDL is the 24AA type carbon substrate treated with 5 wt% PTFE loading. The 24BC type GDL is the 24AA type carbon substrate treated with a microporous layer based on 77% carbon black and 23% PTFE. Other typical properties of these two types of GDL are listed in Table 1. The gas diffusion layers were sealed on both sides of the CCM rather than hot pressing in order to avoid damage of the microstructure of the gas diffusion layer. To preclude the interference of other operating conditions all but cathode relative humidity were kept the same for each MEA. The cell temperature was maintained at 70 °C. Back pressures of anode and cathode were kept at 1.3 bars absolute pressure. Hydrogen was 100% humidified by external humidifiers before entering anode while air humidification was varied by adjusting bubbler temperature. Stoichiometry of hydrogen and air were kept constant at 1.2 and 2.5 respectively. Three channel serpentine flow fields were applied on both electrodes. In order to keep the MEA, the gaskets and the current density collecting board in good contact clamping pressure of 8 bars was supplied by cylinder compression. For simplicity, the MEA with 24BA gas diffusion layers was denoted as M1 and the MEA with 24BC gas diffusion layers was denoted as M2.

2.2. Segmented cell technology

To investigate the local current density distribution, the segmented printed circuit broad (PCB) technology [16–18] was adopted. The segmented flow field plate integrated with temperature sensors was installed between the MEA and the anode current collector plate. Our previous study [16] ascertained the assumption of identical current density distributions in anode and cathode by integrating segmented bipolar plates on both sides of the cell. The identical current density distributions obtained indicate negligible lateral currents due to high conductivity perpendicular to the membrane plane compared to the in-plane conductivity and the anode and cathode current density distributions are equivalent. The current density distribution data was collected using a data acquisition unit consisting of a multiplexer and a digital multimeter. In our study we mainly focused on five area of the whole cell which are inlets and outlets of air and hydrogen plus the middle area.

2.3. Electro-chemical impedance spectroscopy

Electro-chemical impedance spectroscopy (EIS) technology [19] was applied to investigate the internal characteristic of the PEMFC. For the internal impedance is significantly influenced by the hydration state of the cell [20] the EIS results were recorded at low load and high load respectively for every cathode humidification level. Equivalent circuits were also constructed to quantify the contribution of specific components to the total impedance of the cell [21]. In our study the EIS measurements were conducted using Zahner pp241 electrochemical workstation.

3. Results and discussion

3.1. Performance analysis of MEA M1

Fig. 1 shows the performance of MEA M1 at different cathode humidification conditions. It's clear that the cathode humidification has significant influence on cell performance. In low load range (less than 300 mA cm^{-2}) the cell performance were almost the same at RH 70% and RH 100% both of which were better than at RH 40%. However at high load range (higher than 300 mA cm^{-2}) the cell performance was best at RH 40% with performance decreasing fast at RH 70% and 100%. Similarly, the I-P curves showed little difference at low load range (less than 300 mA cm^{-2}) for three different humidification level but scattered significantly at high load range. So we made detailed study for low load range (less than 300 mA cm^{-2}) and relative high load range (higher than 300 mA cm^{-2}) separately.

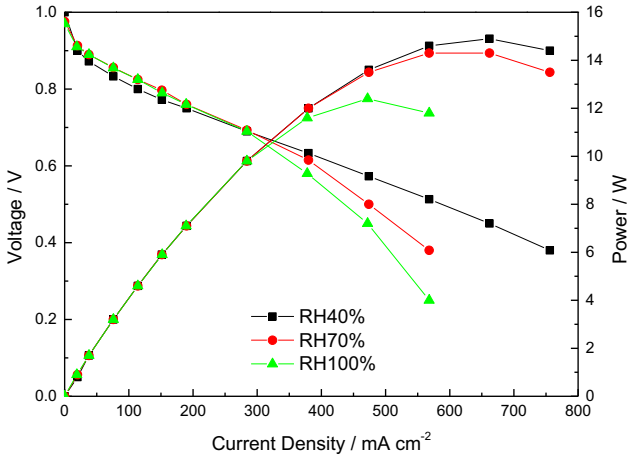

Fig. 1. The I-V and I-P curve of MEA M1 at varied cathode humidification. T_{cell} = 70 °C, anode RH: 100%, back pressure for both electrodes: 0.3 bar, stoichiometry: 1.2/2.5 (H_2/Air).

Table 1
Typical properties of two commercial GDL samples.

Type	Thickness (um)	Pore diameter (um)	Porosity	PTFE content	Contact angle	Air permeability $cm^3/(cm^2 \cdot s)$
24BA	190	30–35	84%	5% wt (total)	>150°	60
24BC	235	0.1–0.3 (MPL)	76%	23% wt (MPL)	>150°	0.6