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Performance characteristics and internal phenomena of polymer electrolyte membrane fuel cell with porous flow field

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HIGHLIGHTS

- Identifying performance characteristics of a PEFC with porous flow field.
- Stable operation at high current densities but unstable with low relative humidities.
- Better drainage of the gas diffusion layer surface with hydrophilic porous materials.
- Higher temperature at the polymer membrane due to lower heat removal capability.

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ABSTRACT

Polymer electrolyte membrane fuel cells (PEFCs) with a porous flow field have been proposed as an alternative to cells with gas flow channels. In this study, the basic characteristics of a PEFC with a porous flow field are identified experimentally. It is shown that stable operation is maintained under conditions at high current density and low stoichiometric ratios of the cathode air, but that operation with low relative humidity gases is difficult in the porous type cell. To clarify the detailed causes of these characteristics, internal phenomena are investigated using a cell specially made for cross-section observations of the cathode porous flow field and temperature distribution measurements on the anode gas diffusion layer (GDL) surface. The direct observations show that the porous type cell is superior in draining the condensed water from the GDL surface, and that hydrophilic properties of the porous material are important for better cell performance at high current densities. The temperature measurements indicate that increases in temperature near the reaction area tend to be larger in the porous type cell than in the channel type cell due to the lower heat removal capability of the porous material, resulting in the unstable operation at relatively low humidities.

1. Introduction

The polymer electrolyte membrane fuel cell (PEFC) is considered a potential candidate as a power source with high efficiency and clean emissions for automobiles and stationary distributed power supply systems. For the practical use of PEFC, it is important to realize uniform current densities across the reaction areas and to maintain high performance of the power generation, and also proper management of the water, the reactant gas flow, and the temperature in the cell is essential. This is because the membrane needs to be fully hydrated to maintain high proton conductivity while excess amounts of water condensed in the gas diffusion layers (GDLs) and gas flow channels impede the supply of reactants to the electrodes at high current density and low air flow rate conditions. Therefore, the gas flow field, which supplies the reaction gas and removes the produced water into and from the GDL, must be carefully designed with this in mind.

Gas channel and land configurations are commonly used to supply the reactant gases through the GDL to the reaction area, and the performance characteristics of cells with various types of gas flow channels have been investigated (for examples [1–3]). In addition to the conventional serpentine and straight channels [1], a conventional and interdigitated-switchable gas flow field was proposed to improve the cell performance under flooded conditions [2], and a self-draining stirred tank reactor cell was proposed for operations with low relative humidity gases [3]. To develop a detailed understanding of PEFC dynamics, a number of studies on the diagnostics of PEFC, such as on the measurement of the current density distribution and visualization of the water production behavior, have been conducted [3–9], and an overview was

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provided on the distributions of current density, high-frequency resistance, gas species and temperature, and including a two-phase visualization [1]. The effects of the distribution of the produced water and the gas composition on the cell performance were discussed using the measured results of the current density distribution [4,5], and the relationships between the local cell impedance and current density have also been investigated [3]. The water production behavior in the cathode gas flow channels has been investigated using a transparent fuel cell, and the relation between liquid water behavior and cell performance was demonstrated [6]. Liquid water removal from gas channels has also been characterized in detail [7]. The authors have observed phenomena related to water production behavior inside a cell, analyzed the effects on the current and temperature distributions across the reaction area [8], and reported the specific phenomena in the flow of condensed water and gas using cells with serpentine and straight channels [9]. Different from the channel and land configurations, porous flow fields have been proposed as an alternative to conventional flow channels, and a structure without channels is expected to enable realization of uniform reaction over the active area of the membrane electrode assembly [10]. Recently, performance and mass transport of a single cell with open metallic element flow field architecture have been investigated at ultra-high current densities under low humidity conditions [11]. To further develop cells with porous flow fields, a more detailed understanding of the cell characteristics under a broader range of conditions and an elucidation of factors influencing the cell performance are necessary.

The objective of this paper is to identify the basic characteristics of a cell with a porous flow field under high and low humidity conditions, and to clarify the internal phenomena in the cell and its effects on the cell performance. The cell characteristics with the porous flow field were investigated by comparing with serpentine and straight flow channels. Further, to measure the internal phenomena determining the identified characteristics, which are stable operation under flooded conditions and unstable operation under low relative humidity conditions, two types of single cells were specially modified and developed: one is for cross-sectional observations of the condensed water behavior in the porous flow field and the other is for temperature distribution measurements on the anode GDL surface. From these measurements, the detailed mechanisms determining the cell characteristics with porous flow fields are discussed.

2. Experimental apparatus and methods

Experiments were conducted with two single cells: Cell A was used for measurements of performance characteristics, and Cell B was used for the cross-sectional observations of the porous flow field and the temperature distribution measurements on the anode gas diffusion layer (GDL) surface. An outline of Cell A with an active area of 100 cm^2 (10 cm × 10 cm) is shown in Fig. 1. A catalyst-coated membrane (CCM) with a 30 μm thick polymer electrolyte membrane and two 10 μm thick catalyst layers is sandwiched between the GDLs, flow plates and current collectors, and the end-plates of the cathode and anode sides. Here, 0.3 mm thick carbon paper with a micro porous layer on the CCM side was used for the GDLs, and flow plates with the porous flow field, serpentine channels (which will be shown in Fig. 5(b) below), and straight channels were used on the cathode side. A porous material (SUMITOMO ELECTRIC, Celmet) was inserted in the current collector for the porous flow field, as shown in the center of Fig. 1. The porous material (right in Fig. 1) was made of nickel, and the thickness and porosity were 1.4 mm and 97%. The condensed water behavior on the surface of the porous material can be observed through a window in the cathode end-plate. The flow plates with serpentine or straight channels were made of copper overlaid with gold, and the width of the channels and lands of both plates were 2.0 mm. The flow plates have open channels through which the GDL surfaces can be observed, and the thickness of the plates, which corresponds to the channel height, was 0.5 mm [9]. In the anode flow plate with straight channels, electrically insulated 5.5 mm diameter pins were placed at 25 points and the current density distribution was measured with the pins. Each pin was connected to a shunt resistance of 0.1 Ω for the current measurements, and calibration was made with a variable resistance connected to each shunt resistance to compensate for contact resistance variations among the pins and to ensure uniform resistance over the whole area. The details of the calibration and analysis methods are in Ref. [9].

An outline of Cell B with an active area of 25 cm^2 (5 cm × 5 cm) is shown in Fig. 2. Cell B has a similar cathode structure, as Cell A, and the outlet area of the cathode porous material is open, as shown in Fig. 2(a). The transport behavior of the liquid water inside the porous flow field was estimated by observing the edge face of the porous material from the red arrow (in the web version) in Fig. 2(a). An optical microscope (LEICA, Z16APO) was used for the direct observations, and the anode flow plate has no pins for the current density measurements. For temperature distribution measurements, the anode structure was changed to one similar to the cathode structure of Cell A with straight channels. An infrared-transparent sapphire glass was used as the anode window, and an infrared thermograph (NEC, TH5104R) was used for the temperature distribution measurements on the anode GDL (Fig. 2(b)). At the cathode side, current collectors without the open part and an end-plate without a window were used. The reasons why the

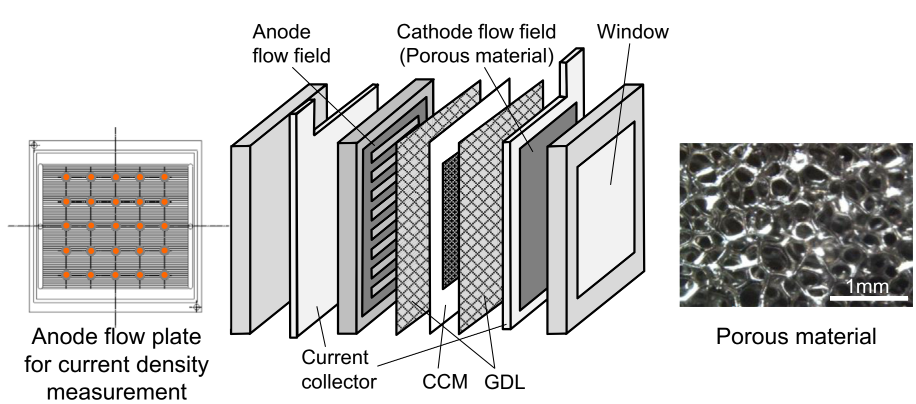

Fig. 1. Experimental arrangement for visual observations and current density measurements, Cell A.