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Performance improvement in direct methanol fuel cells using a highly porous corrosion-resisting stainless steel flow field

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ABSTRACT

Power generation with direct methanol fuel cell (DMFC) systems requires only simple equipment, and has the important advantage of using a liquid fuel with higher energy density and easier handling characteristics than hydrogen. However, the power output of DMFC is lower than hydrogen fuel cells. To improve the power output of DMFC it is very important to reduce diffusion polarization at higher current density conditions. This research used a corrosion-resisting type porous stainless steel developed based on the technology for metal–hydride battery electrodes in the separator flow fields for reactants and products in a single cell DMFC and analyzed its influence on performance characteristics.

1. Introduction

Fuel cell technology has advanced greatly in the last decade, and hydrogen fuel cells are expected to become a sustainable power source in the environmentally friendly society of the future. However, hydrogen has the disadvantage of very much lower energy density per unit volume than conventional liquid fuels, the handling of hydrogen is also more difficult than liquid fuels [1]. Because of this, direct methanol type fuel cells (DMFCs) fed with liquid methanol appear more advantageous than hydrogen fuel cells. A DMFC system is simpler than hydrogen fuel cell systems and is suited for many applications such as small portable power sources [2]. In spite of the advantages, DMFC also has the downside that the power output and efficiency are substantially lower than hydrogen fuel cells [2,3]. This makes it very important to improve the efficiency and output power of DMFC. The efficiency characteristics of the proton exchange membrane (PEM) type fuel cells are influenced by the activation polarization, the ohmic polarization, and the diffusion polarization [4]. Diffusion polarization limits the performance at higher current density conditions, and reducing the diffusion polarization is crucial to improve the performance of DMFC [5,6]. This research applied a corrosion-resisting type porous stainless steel (porosity around 90%) developed based on the technology for Ni–MH battery electrodes [7] to the separator flow fields for reactants and products in a single cell DMFC and used experiments to analyze its influence on efficiency and power output with different cell temperatures.

2. Experiments

The experiments used a single cell with different kinds of flow fields, 5 wt% methanol in water solution was fed to the

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anode at preset flow rates through a diaphragm type electromagnetic pump (ProMinet GVLA1000). The cathode was fed with oxygen from a high pressure cylinder through a pressure regulator. The cathode gas flow rate was controlled with a needle valve and measured with a mass flow meter (Yamatake CMS0005). Fuel cell output power was measured with a fuel cell load unit coupled with a frequency response analyzer unit for impedance measurement (Kikusui KFM2030). Cell temperature and anode feed temperature were controlled with a constant temperature vessel (Azone DOV-450P). Specifications of the tested membrane electrode assembly (MEA) are shown in Table 1. The catalyst loading on the anode was 1 mg/cm^2 (Pt–Ru), while that on cathode was 1 mg/cm^2 (Pt). The catalysts are with carbon support. Percentages of Pt–Ru and Pt to carbon powder were 50 wt%. A Nafion 117 polymer electrolysis membrane was sandwiched between the electrodes. Carbon paper with 0.28 mm thickness was used as gas diffusion layer (GDL) on both sides of the MEA. The setup of the tested fuel cell is schematically shown in Fig. 1.

Table 2 shows the specifications of the tested porous stainless steel. To achieve good corrosion-resisting properties, the composition has been adjusted to Fe with 30 wt% Cr, 2 wt% Ni, and 4 wt% Mo. The corrosion characteristics of an ordinary stainless steel (JIS SUS316L; Fe–19Cr–12Ni–2Mo) and the tested corrosion-resisting type stainless steel (Fe–30Cr–2-Ni–4Mo) are shown in Fig. 2 [7]. The figures show the elution characteristics of Fe and Cr from the two kinds of steel into sulfuric acid. Test pieces of 10 × 10 × 0.2 mm made of the two kinds of steels (non-porous, machined samples) were soaked in 1 N sulfuric acid at 353 K. The elusion of Fe and Cr from the corrosion-resisting stainless steel is of substantially lower order of magnitude than that from the ordinary stainless steel especially at longer soak times, over 90 h. This good corrosion-resisting performance would enable the compound to be used in polymer electrolysis fuel cells. The current research tested a separator flow field made of the corrosion-resisting stainless steel in a highly porous structure as shown in Fig. 3. It has a porosity of around 90% and a pore size of 0.3–0.4 mm. The images in Fig. 3 were obtained with a laser scanning microscope (Keyence VK-9700).

The porous stainless steel flow fields were placed in the cell separators shown in Fig. 4(a). For comparison, solid stainless steel separators with a straight-channel (groove) type flow field as shown in Fig. 4(b) were also used. The depth of the porous flow field was 2 mm which is the same as the depth of the groove type flow field. The flow field volume is 5 cc for the porous and 2.9 cc for the channel type. Experiments with four combinations: porous–porous, porous–channel,

Table 1 – MEA specification and feed conditions

Polymer membrane	Nafion117 (175 μm)
Reaction area	25 cm^2 (5 × 5 cm)
Anode catalyst	Pt–Ru 1.0 mg/cm^2
Cathode catalyst	Pt 1.0 mg/cm^2
Anode feed	5 w% MeOH solution
Cathode feed	dry O_2

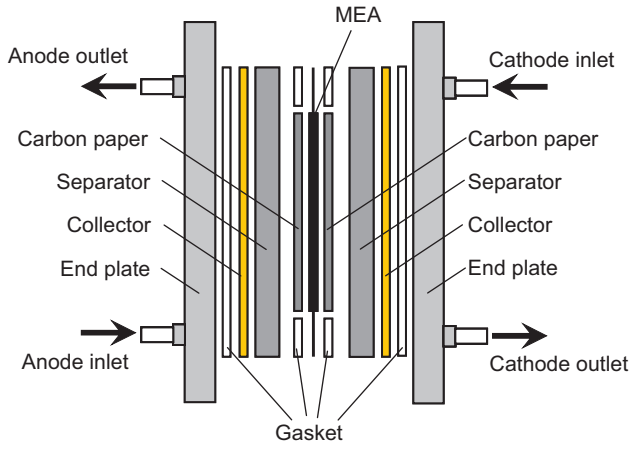

Fig. 1 – Setup of tested fuel cell.

Table 2 – Specification of the tested porous stainless steel

Composition	Fe–30Cr–2Ni–4Mo
Pore size	0.3–0.4 mm
Pore ratio	90 ± 2%

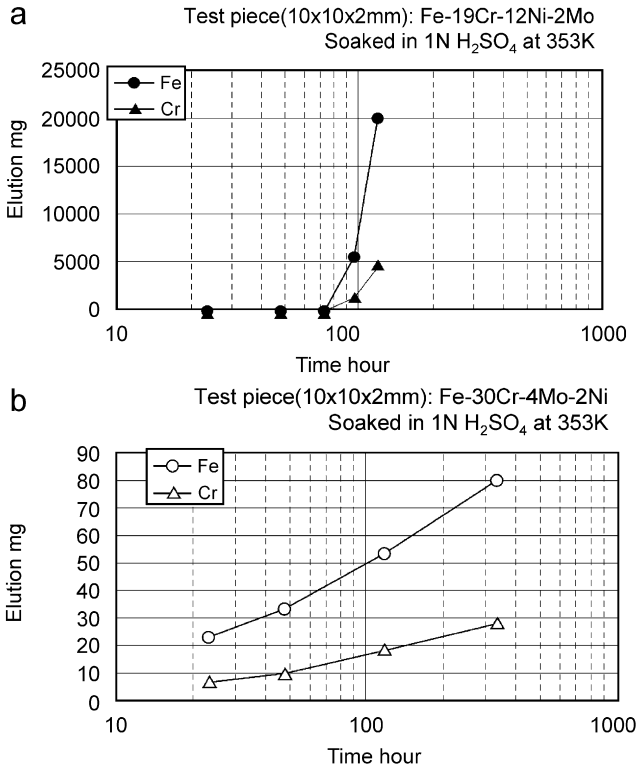

Fig. 2 – Corrosion characteristics of ordinary and corrosion-resisting stainless steels [7]. (a) JIS SUS316L stainless steel (Fe–19Cr–12Ni–2Mo). (b) Corrosion-resisting stainless steel (Fe–30Cr–4Mo–2Ni).