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Investigation of bipolar plate materials for proton exchange membrane fuel cells

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ABSTRACT

Low-cost parts, materials, and production methods are important for effective establishment of polymer electrolyte membrane fuel cells (PEMFCs) into the commercial marketplace. The bipolar plate is one part that substantially impacts the PEMFC manufacturing cost. Metallic bipolar plates are an attractive alternative to graphite because they provide the necessary electrical and thermal conductivity and they offer good mechanical strength which supports the forces within the stack. Stainless steel, which is reasonably cheap, a good conductor, and corrosion resistant with high strength, has exhibited acceptable performance as a bipolar plate for several thousand hours of experiments. In this work, a through-mask electro-etching process was selected for fabrication of 304L and 430 stainless steel alloy bipolar plates for 25-cm^2 PEMFC and they were compared against the graphite material. The key results revealed that stainless steel bipolar plates give comparable performance to graphite plates especially under well humidified conditions. At drier conditions, the resistance is the largest factor on the overall performance for all bipolar plate materials. Toray paper and Carbel CL GDLs give different performances under various bipolar plate materials and operating conditions. It is also shown that significant differences in channel depth profiles affect the overall performance.

Introduction

With the demand of energy consumption continuously increasing every year along with the depletion of resources, the development and research on alternative energy is necessary to mitigate this energy issue. Polymer Electrolyte Membrane Fuel Cells (PEMFCs) are that alternative energy technology, producing electricity from electrochemical reactions without combustion. Moreover, PEMFCs operate at

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low temperature and pressure while having fast startup and shutdown times with low noise and high efficiency. PEMFCs can meet high power demands for residences and electrical vehicles while also being applicable for low power devices such as electronics.

Low-cost materials and production methods are necessary for fruitful incorporation of PEM fuel cells into the commercial energy sector. The bipolar plate is one part that impacts the manufacturing cost of the PEMFC substantially [1]. Graphite has been broadly used for bipolar plates in laboratory scale research due to its sufficient electrical conductivity, good corrosion resistance, and light weight, but manufacturing precise flow-field channels in the graphite is hard and costly. Moreover, there are mechanical concerns, such as the fragility of thin graphite plates within the stack that have led to the exploration of different bipolar plate materials. Metallic bipolar plates are strong candidates for replacing graphite, offering great electrical and thermal conductivity while offering effective mechanical strength to support the forces within the stack even at a thinner plate thickness [2–7]. Stainless steel (SS) has shown satisfactory performance as a bipolar plate for thousands of hours of testing [8,9]. Moreover, in the development of manufacturing for metal bipolar plates, the variations in channel depth and undercut for any mask or pattern might be expected [10–18]. Further, machining tolerances and tool deterioration could cause a variance in laboratory plates obtained from various vendors. So that modeling work performed looked at effects of the typical variation in channel undercut, bending angle, and channel depth. The predictions suggested that the small tolerances should not impact the overall performance and durability of fuel cells [19]. Nevertheless, the effect of austenitic and ferritic grades in stainless steel was missing in that study and it was furthermore complicated to evaluate its impact on the fuel cell performance using a numerical technique.

For this work, two different types of SS bipolar plates were selected together with standard graphite material for evaluation and justification. The effect on the performance from the carbon paper, gas diffusion layer (GDL), and carbon clothe GDL combined with SS bipolar plates were accounted for. Finally, the different channel depth profiles for the flow-fields in the bipolar plates were considered so as to take into account the malfunctions in the manufacturing process. The outcomes of this study will provide insight into understanding how different materials used for bipolar plates impact the fuel cell performance with various GDLs, operating conditions, and manufacturing errors.

Experimental procedure

Fuel cell setup and polarization measurements

Two types of Stainless Steel (SS) fuel cell flow-field plates from Faraday Technology, Inc. (Clayton, OH, USA.) with an active area of 25 cm^2 were employed in the tests along with a standard 25 cm^2 graphite fuel cell. Through-mask electro-etching was used for constructing the flow-field plates [10,11]. This specific technique uses standard photolithography to pattern the surface of the bare, flat metallic substrate to protect specific areas during the etching process. An electric field is applied between the patterned bipolar plate substrate and a counter electrode submerged in an electrolyte solution to electrochemically remove the exposed metal not protected by the photoresist mask. Once the etching process is complete, the photoresist is removed from the substrate to reveal the surface features, e.g. gas flow field channels. The cell consisted of triple serpentine flow-field plates with anode and cathode co-current flows and in the experiments, PRIMEA®S-eries 57 MEAs from W. L. Gore & Associates, Inc. (Elkton, MD, USA.) were used. The MEAs contained 0.1 mg Pt/cm^2 in the anode, 0.4 mg Pt/cm^2 in the cathode, and a membrane with a 35 μm nominal thickness. Toray™, TGP-H-060, was employed as gas diffusion layer (GDL) as described above. Silicone coated glass fiber with a thickness of 178 μm (7 mil) from Saint-Gobain (Hoosick Falls, NY, USA) was used as a gasket during the assembly of the cell.

The experiments were conducted using a fuel cell test station model 890B from Scribner and Associates Inc. (Southern Pines, NC, USA). High purity hydrogen (99.997%) and compressed air were supplied to the anode and cathode, respectively. Three operating conditions were performed as shown in Table 2. Each test cell was broken-in by repeatedly running this procedure, OCV-0.6V-OCV-0.4V-OCV, and each potential was held for 30 s. A total of 2 × 40 cycles of this procedure was applied for conditioning procedure of PRIMEA® 57 series. The polarization curve was obtained by varying the cell voltage from open circuit potential to 0.2 V. At each point, the voltage was maintained for 15 min then the average current was recorded. Tables 1 and 2 presents the detail flow-field geometry and the experimental conditions.

Results and discussion

The effect of bipolar plate materials on PEMFC performance

Fig. 1 shows the channel depth profiles of the flow-field plates from the electro-etching process on the stainless steel (SS) 430 and the SS304L that gave an average channel depth of 0.4 mm. The flow-field pattern was triple serpentine on a 25-cm^2 reaction area fuel cell. The results from this study were compared to a baseline graphite plate on a 25-cm^2 reaction

Table 1 – Geometry details.

Description	Value
Active area	25 cm^2
Channel width	0.8 mm
Channel height	0.4 mm in average
Rib-spacing width	0.8 mm
GDL material	Toray™ TGP-H-060 Carbel CL™
GDL thickness	Toray 190 μm Carbel CL 400 μm
GDL porosity	Toray 78% Carbel CL 82%
GDL electrical resistivity	Toray 80 mΩcm Carbel CL 79 mΩcm
MEA thickness	35 μm
Gasket	178 μm