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Short communication

Surface modification and development of titanium bipolar plates for PEM fuel cells

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Abstract

The use of titanium (Ti) bipolar plates in polymer electrolyte membrane (PEM) fuel cells, with a surface modification on the titanium to reduce voltage losses due to the formation of passive layers, has been demonstrated. An alternative material of titanium bipolar plates for polymer electrolyte membrane fuel cells with and without surface modification was assembled and evaluated. Two different surface modification materials: iridium oxide (IrO_2) and platinum (Pt) were investigated respectively. The cell performance was close to the PEM fuel cells using graphite bipolar plates. Titanium bipolar plates can be employed to produce fuel cells with very high volumetric and gravimetric power densities, ideal for portable applications.

Keywords: Surface modification; Titanium; Fuel cells; Bipolar plates; PEM

1. Introduction

The bipolar plate is the most bulky and heavy component in the PEMFC and one of the most expensive to manufacture. With bipolar plates accounting for the bulk of the stack, it is more attractive to create plates with the smallest possible dimensions permissible. Conventionally, carbon based materials have been selected, as these are chemically steady in a fuel cell environment and produce the highest electrochemical power output. Nevertheless, the lack of mechanical strength natural with carbon limits the size as same as the volumetric power density. Other alternative materials are being evaluated by a number of academic and industrial research groups, with the aim of producing a low voltage drop and long lifetime materials. The alternative materials to graphite fall into three categories: carbon–carbon composites [7], carbon–polymer composites [8] and metals [9]. It is expected that only carbon–polymer composites and metal systems will suit for the long term cost requirements for fuel cell technology. For portable PEM systems, both the weight and volume of the stack are the main concerns and the present thickness of polymer composite bipolar plates [4] results in stacks with low volumetric power densities (as measured on kW dm^{-3} basis).

Thus, in this study, we have focused mainly on the titanium (Ti) bipolar plate technology, which enables thin bipolar plates to be used and, in the case of titanium, plates with a low weight. Unluckily, although the passive films on the surface of these metals protect them from corrosion, it also acts in part as an electrical insulator and thus reduces cell performance due to ohmic losses. In order to reduce this loss, the bipolar plate surfaces have to be modified. Sintering and coating systems for metallic bipolar plates have been investigated by many experts in the field (e.g., [9]), but few data have been presented on the long term performance of suitably coated metal bipolar plates. This study describes the short term performance of coated metal bipolar plates [17,19].

2. Experimental

Screening tests for the performance of the coating comprise: contact resistance, corrosion testing and short term polarization performance. The cell tests were conducted on single cells of 25 cm^2 active area. The membrane electrode assembly consisted

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of Nafion 112 membranes and Toray paper with a catalyst loading of 0.4 mg cm^{-2} on the anode and 0.2 mg cm^{-2} on the cathode electrode. The flow channel chosen for comparison was a serpentine flow field with two parallel channels. The operation temperature of the fuel cell was 50 °C. The operation backpressure was 5 psi on both sides. The gases were humidified with a dew point of 75 °C [6]. An *I–V* curve was measured to determine the performance of the cell in the complete operation range from −0.2 to 2.2 A cm^{-2}.

Three different types of metallic bipolar plates were studied, pure titanium, titanium sintering with IrO_2 and titanium coating with platinum (Pt) coating. These materials were chosen because they were electrically conductive, had good mechanical properties and were easily available. The sintering of iridium oxide (IrO_2) and coatings of Pt onto titanium was performed using proprietary methods. The coating method which is classified due to commercial reasons can be used for any structure of bipolar plate and does not significantly affect the dimensions of the flow channels. The cost price for sintering 20 g m^{-2} iridium oxide is about US$ 320, where coating 2.5 μm platinum is about US$ 400. Moreover, the cost price for processing flow channels at the pure titanium bipolar plates is about US$ 200; however, the cost price for pure titanium bipolar plates is about US$ 100. Several researchers [5–8,11] are studying numerous possible solutions including the use of protective surface modification to increase the corrosion resistance of metals/alloys systems in fuel cell environment.

Figs. 1–3 show the SEM pictures of surface structure of pure titanium bipolar plate, titanium bipolar plate sintering with IrO_2 and titanium bipolar plate coating with Pt, respectively. Fig. 4 shows the comparison pictures of prototype one-cell PEM fuel cell stack with graphite bipolar/end plates (left hand side) and titanium based metallic bipolar/end plates (right hand side) as used in experiments. Fig. 5 shows the cell schematic diagram showing cell configuration of titanium bipolar/end plate. The pure titanium bipolar plates with machined multi-parallel channel gas flow-field design designed and developed at the Beam Associate Co., Ltd., Taiwan, ROC was shown in Fig. 6. A one-cell prototype PEM fuel cell stack with tita-

Fig. 1. SEM image of pure titanium bipolar plates without surface modification.

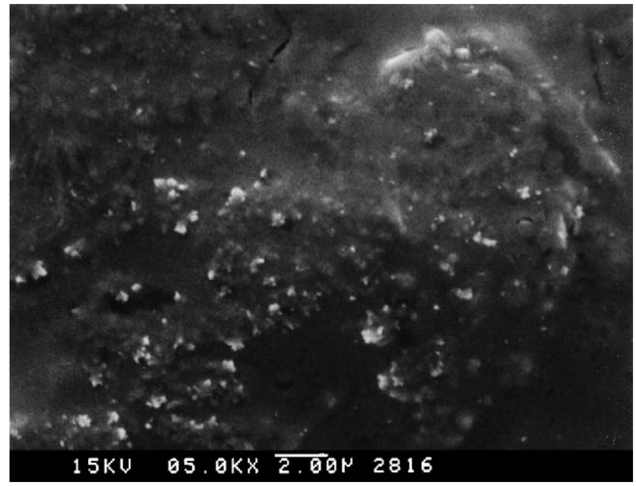

Fig. 2. SEM image of titanium bipolar plates sintering with iridium oxide (IrO_2).

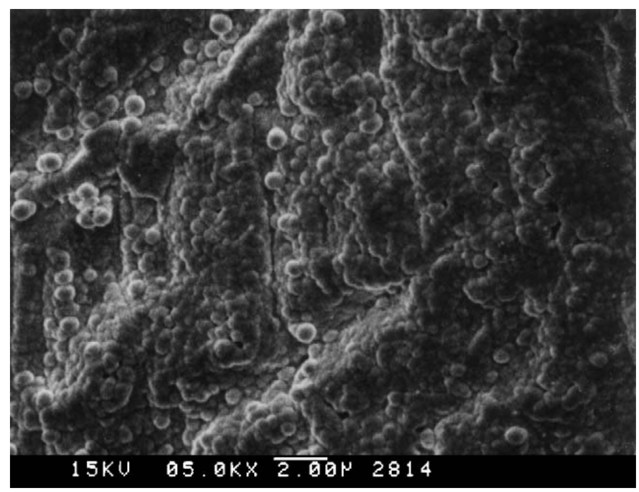

Fig. 3. SEM image of titanium bipolar plates coating with platinum (Pt).

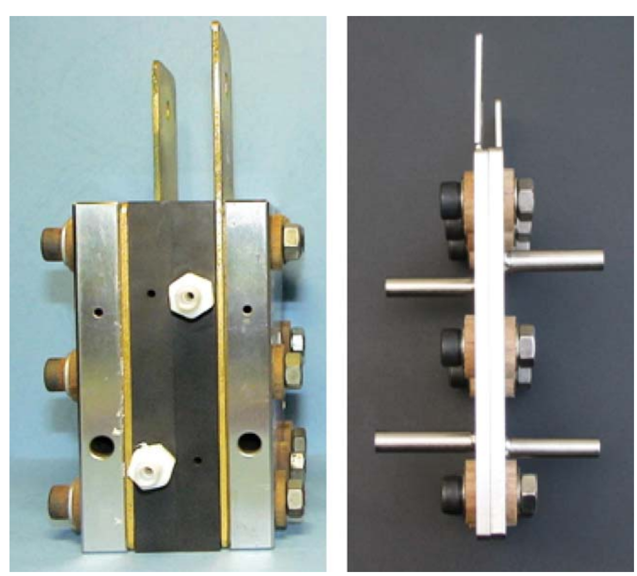

Fig. 4. Comparison pictures of prototype one-cell PEM fuel cell stack with graphite bipolar/end plates (left hand side) and titanium bipolar/end plates (right hand side).

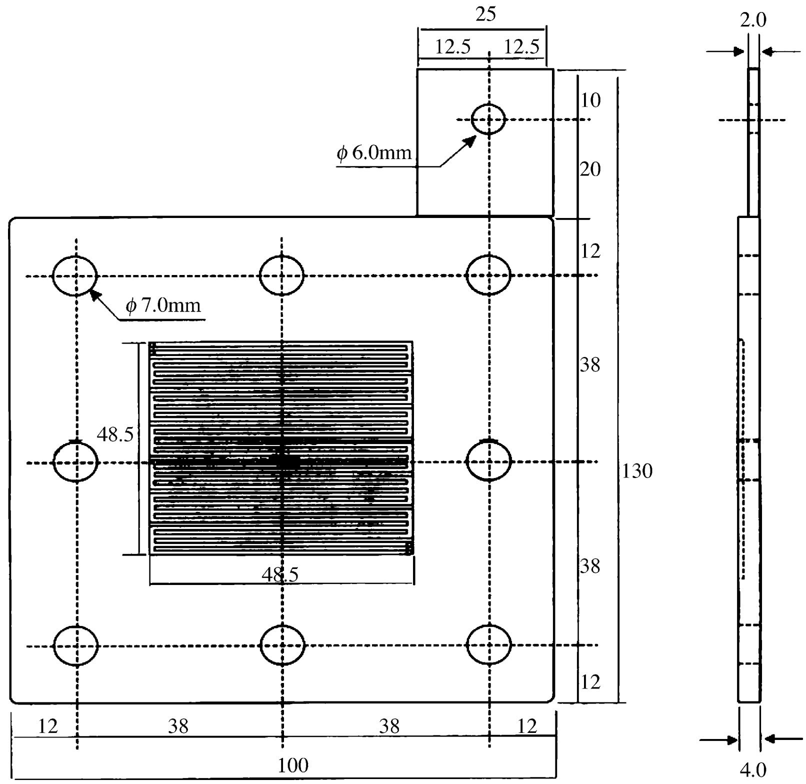

Fig. 5. Schematic diagram showing cell configuration of titanium bipolar/end plate.

nium bipolar plates and aluminum support plates was assembled using the facilities at the Beam Associate Co., Ltd., Taiwan, ROC (Fig. 7). The dimensions of the bipolar/end plates were: 10 cm × 10 cm × 0.4 cm and that of the gas flow-field were 4.85 cm × 4.85 cm × 0.1 cm. Titanium connectors were welded to these bipolar/end plates. Experiments were carried out using the fuel cell test station facilities at the Beam Associate Co., Ltd., Taiwan, ROC. The facilities include: (a) a mass-flow meter controller (Protec PC-540) for precise control of the mass flow of reactants as well as humidification, temperature and back pressure on both fuel and oxidant sides; (b) Prodigit 3311C 60 V/60 A/300 W dc electronic fuel cell test load for precisely drawing desired amount of current from the cell stack; (c) Beam Technology 300M Fuel Cell Test Station (Beam Associate Co., Ltd., Taiwan, ROC) software for precise computer control and monitoring of operating parameters. Pure hydrogen and oxygen were used as reactant gases on the anode and cathode sides, respectively. Nitrogen was used as a purging gas. The reactant gases were externally humidified by passing them through a humidification chamber in the gas controller unit. The operating conditions for anode side was T = 65 °C and cathode sides was T = 55 °C; *P* = 5 psi (back pressure); anode flow rate,

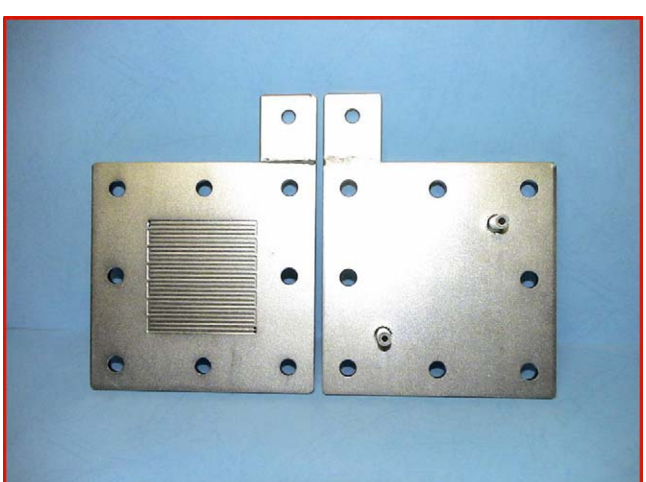

Fig. 6. Pure titanium bipolar/end plate with machined multi-parallel channel gas flow-field design designed and developed at the Beam Associate Co., Ltd., Taiwan, ROC.

Fig. 7. Prototype one-cell PEM fuel cell stacks with titanium bipolar plates.

$Q_a = 340\,cm^3\,min^{-1}$ + load based flow(LBF); cathode flow rate, $Q_c = 240\,cm^3\,min^{-1}$ + LBF.

3. Results and discussion

The key of this study was to develop a low cost alternative material for the bipolar plates by using titanium bipolar plates in the PEM fuel cell stack. Polarization studies are typical for any electrochemical system to evaluate fuel cell performance. Fig. 8 shows the *I–V* and *I–P* curves for the one-cell PEM fuel cell stack with different bipolar plates design. These curves were obtained by increasing the load level (scan rate: $0.5\,A\,s^{-1}$) from the cell and monitoring the cell voltage. As same as typical of any electrochemical system, the curve shows a continuous decrease in voltage as the load level is increased. This is due to the polarization losses (activation, ohmic and concentration), the magnitude of which depends on the amount of current drawn from the cell. Activation polarization is predominant at low current densities, ohmic polarization at intermediate current densities while concentration polarization at high current densities. Furthermore, it can be shown from Fig. 8 that the performance of graphite bipolar plate was highest followed by titanium bipolar plate coating with Pt and titanium bipolar plate sintering with IrO_2. To investigate the Ohmic and charge transfer resistance of the single cells, ac impedance was used at a cell voltage of 0.85 V after the measurement of the *I–V* curves presented in Fig. 8. The *I–V* performance of composite bipolar plates is very similar to that of the graphite bipolar plate and so is the *I–V* performance. The data indicate that the optimum composition (75 wt.%) of the titanium bipolar plates provide a suitable replacement for the graphite composite plates. The result discussed here uses a thick (4 mm) bipolar/end plate where a slot of dimensions 4.85 cm × 4.85 cm × 0.1 cm was made. An improvement over this design can be made by brazing metal foams with a thin metal sheet (∼0.5 mm) to form bipolar/end plates. The weight of the bipolar/end plate with metal foams can be reduced by around 30–50% of the weight of currently used graphite plates [1–4,9,10–16].

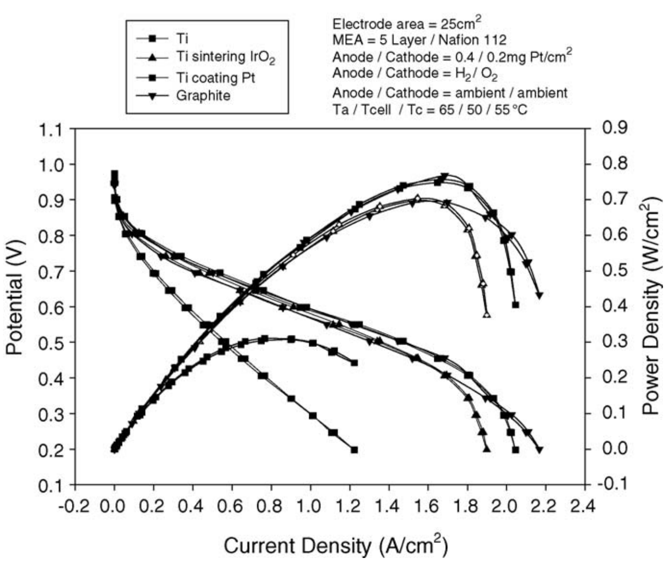

Fig. 8. *I–V* and *I–P* curves for the single cells using graphite, pure titanium, titanium sintering with IrO_2 and titanium coating with Pt bipolar plates.

In this study, the titanium bipolar plates will act as gas flow-field distributor, electrodes and catalyst support, thereby reducing the number of components in the fuel cell stack [18,20].

4. Conclusions

In the present work, the results indicated that the alternative material of titanium bipolar plates could be used in PEM fuel cells with surface modification, which prevents the formation of oxide layers with a high resistivity. Both oxide formation and poisoning of the MEA are prevented and reduced. Moreover, the materials used have the potential to be low cost coatings and thus lead to low cost bipolar plates. Two different types of surface modification material were considered: platinum and iridium oxide. Titanium bipolar plates can be employed to produce fuel cells with very high volumetric and gravimetric power densities, ideal for portable applications. These studies are in progress at Beam Associate Co., Ltd., Taiwan, ROC.

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