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ScienceDirect
Journal of Power Sources 162 (2006) 486–491
JOURNAL OF POWER SOURCES
www.elsevier.com/locate/jpowsour

Short communication

Performance of the gold-plated titanium bipolar plates for the light weight PEM fuel cells

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Received 7 May 2006; received in revised form 28 June 2006; accepted 29 June 2006
Available online 14 August 2006

Abstract

In this present work, we are attempting to develop a light weight and corrosion resistant bipolar plate for the proton exchange membrane fuel cell. A titanium bipolar plate substrate has been chosen as the base metal due to its low cost, ease of manufacture into stampable bipolar plates, and its light weight. Our approach to obtain a smaller and lighter weight single fuel cell is to coat titanium with a corrosion resistant coating. Gold (Au) was investigated. The cell performance of the gold-plated bipolar plates is close to and even better than the PEM fuel cells with graphite and pure titanium bipolar plates. Gold-plated titanium bipolar plates can be employed to produce fuel cells with light weight, low coating cost and low contact resistance, ideal for portable applications.

Keywords: Performance; Gold-plated; Titanium; Fuel cells; Bipolar plates; PEM

1. Introduction

The use of metal-based bipolar plates in PEMFC stacks potentially offers a number of advantages, particularly for transportation applications, including low-cost mass-production via stamping or embossing of sheet product; fabrication in very thin form (<200 μm) to reduce weight and volume in the overall stack; impermeability to fuel, oxidant and water vapor; and in general, excellent thermal conduction properties and good mechanical robustness, even as a thin stamped foil. The primary challenge with metal interconnects is surface corrosion, and the current drive to increase the operating temperature of the stack will only exacerbate this problem. Corrosion of the bipolar plate leads to a release of metal ions that can contaminate the electrolyte membrane and poison the electrode catalysts [1,3–5].

In addition, the formation of a passivating oxide or oxhydroxide layer on the surface of the metal will increase the contact resistance between the bipolar plate and the adjacent graphite electrode backing layer by many orders of magnitude. Both conditions can significantly degrade stack performance. A number of researchers have investigated various schemes for protecting metallic bipolar plates, most of which rely on a thin, inert yet electrically conductive coating [1,3,5,7–11,14–16]. The greatest level of success that has been openly reported has been achieved with noble metal coatings such as gold and palladium. Unfortunately, commercial use of these materials, even as thin coatings, is cost-prohibitive.

The bipolar plate is the most bulky component in the PEMFC stack (in both weight and volume) and one of the most expensive to manufacture. It not only serves as the electrical junction between serially connected cells, but also performs several other key functions in the device, for example: distributes the fuel and oxidant uniformly over the active areas of the cells; facilitates water management of the membrane to keep it humidified, yet mitigate flooding; acts as an impermeable barrier between the fuel and oxidant streams (particularly H_2) to maintain the hydrogen gradient across the membrane necessary for high power output; provides some measure of structural support for the stack and removes heat from the active areas of the cells.

Thus, in this present work, we have focused mainly on the gold-plated titanium bipolar plates technology, which enables

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doi:10.1016/j.jpowsour.2006.06.084

thin bipolar plates to be used and, in the case of titanium, plates with low weight materials. Unfortunately, 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 performance drops, 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. [2,6]), but still few data has 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 [2,9,13].

2. Experimental

In our previous investigation, two materials such as titanium bipolar plate coated with Pt and titanium bipolar plate sintering with IrO_2 were investigated, which could be possible alternatives to commercial graphite as a bipolar/end plate material [16]. Concentrating on different factors like weight, cost, density, mechanical strength and availability, gold-plated titanium was chosen as the alternative. The cell tests were conducted in single cells of 25 cm^2 active area. The membrane electrode assembly consisted of Nafion 112 membranes and Torray paper with a catalyst loading of 0.2 mg cm^{-2} on anode and 0.4 mg cm^{-2} on cathode electrode. The flow channel chosen for comparison was a serpentine flow field with two parallel channels. Operation temperature of the fuel cell (T_{cell}) were 40, 50 and 60 °C, respectively. 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 achieve the performance of the cell in the complete operation range from 0 to 3.0 A cm^{-2}. Surface contact resistance (SCR) Davies' method [17] for measurement of the surface contact resistance (SCR) between stainless steel and carbon paper was modified. In this study, two pieces of treated Toray conductive carbon paper were sandwiched between the samples and two copper plates. Such carbon paper has been used as the electrode backing [15]. By measuring the total voltage drop through this setup, while the compaction force was gradually increased from 20 to 60 kgf cm. The compaction force was applied by means of a PARSTAT 2263 (Advanced Electrochemical System) and the force was monitored with a digital force gauge (Advanced Electrochemical System).

The titanium metallic bipolar plates coated with gold (Au) were studied. This material was chosen merely as they were light weight, electrically conductive, had good mechanical properties and was easily available. The coating of gold (Au) onto titanium (2.5 μm) was performed using proprietary method. The coating method which is classified due to commercial reason can be used for any structure of bipolar plate and does not significantly affect the dimensions of the flow channels. The cost of gold plating was about US$ 20 per bipolar plate. 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 [5–8,11,12,17] 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.

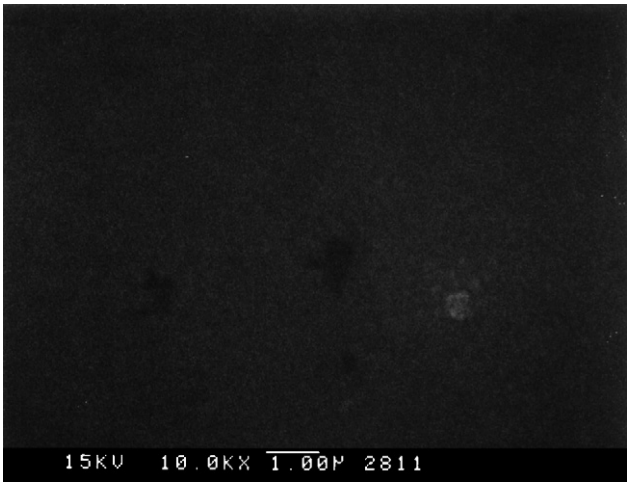

Fig. 1. SEM image of pure titanium bipolar plates without surface modification.

Figs. 1 and 2 show the SEM pictures of surface structure of pure titanium bipolar plate and titanium bipolar plate coated with Au, respectively. Fig. 3 shows the comparison pictures of prototype one-cell PEM fuel cell stack with graphite bipolar/end plates (left hand side), titanium based metallic bipolar/end plates coated with Au (middle side) and pure titanium metallic bipolar/end plates (right hand side) as used in experiments. Fig. 4 shows the cell schematic diagram showing cell configuration of titanium bipolar/end plate. The pure titanium bipolar plates and gold-plated titanium bipolar plates with machined multi-parallel channel gas flow-field design designed and developed at the Kejin Water Treatment Co., Ltd. Taiwan, ROC are shown in Figs. 5 and 6, respectively. A one-cell prototype PEM fuel cell stack with gold-plated titanium bipolar plates and aluminum support plates was assembled using the facilities at the Kejin Water Treatment 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

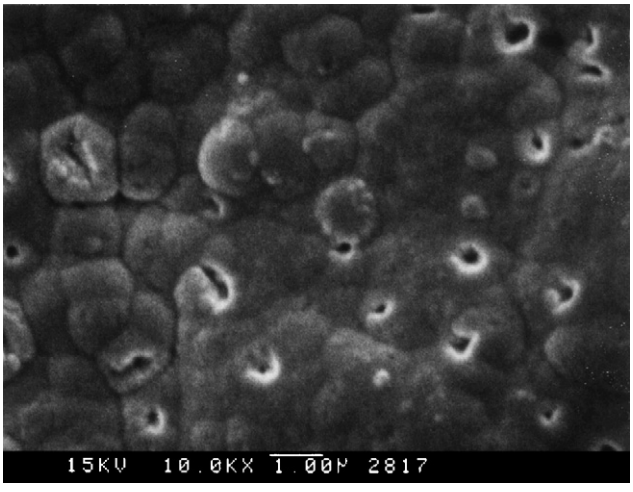

Fig. 2. SEM image of titanium bipolar plates coated with gold (Au).

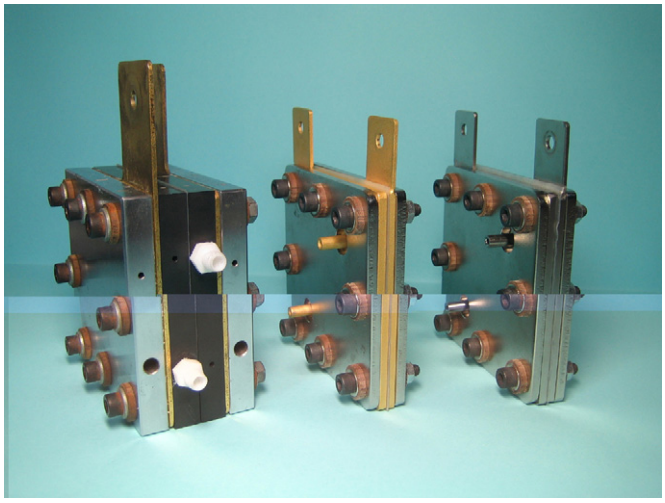

Fig. 3. Comparison pictures of prototype one-cell PEM fuel cell stack with graphite bipolar/end plates (left hand side), titanium bipolar/end plates coated with gold (Au) (middle side) and pure titanium bipolar/end plates (right hand side).

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 3311 C 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 300 M 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

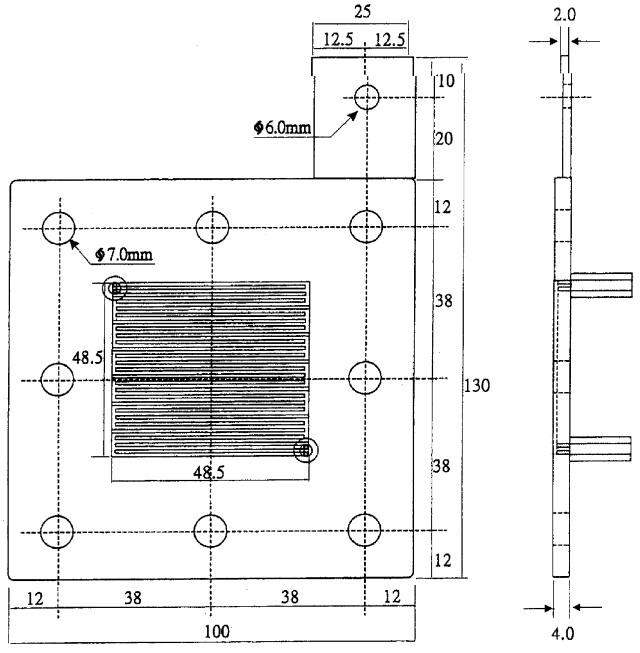

Fig. 4. Schematic diagram showing cell configuration of titanium bipolar/end plate.

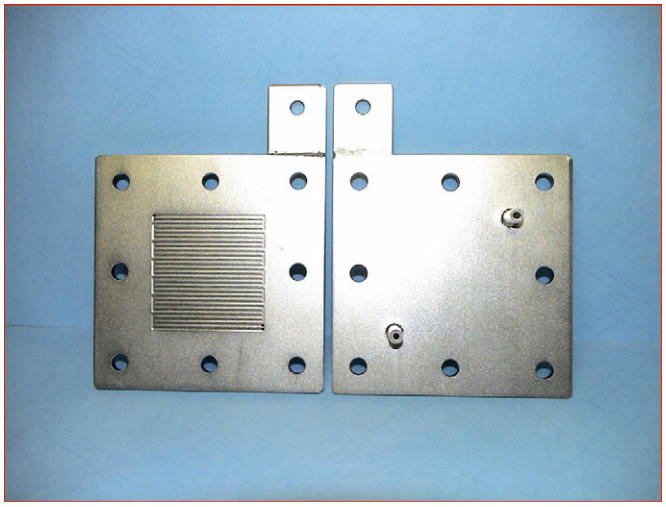

Fig. 5. Pure titanium bipolar/end plate with machined multi-parallel channel gas flow-field design designed and developed at the Kejin Water Treatment Co., Ltd. Taiwan, ROC.

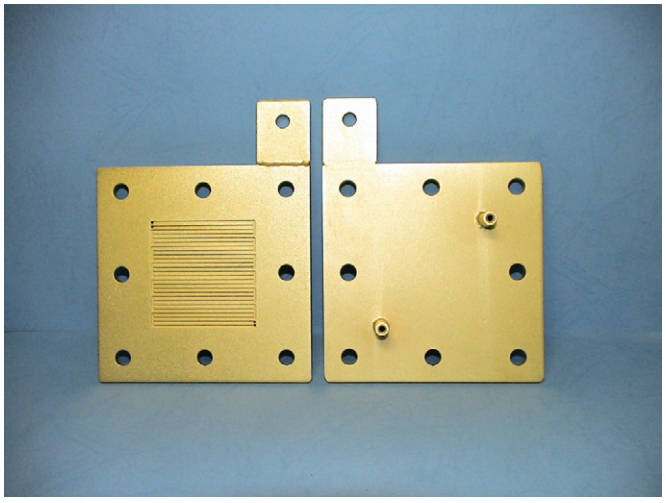

Fig. 6. Gold-plated titanium bipolar/end plate with machined multi-parallel channel gas flow-field design designed and developed at the Kejin Water Treatment Co., Ltd. Taiwan, ROC.

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

the gas controller unit. The operating conditions for anode side were $T_a = 80$ and 90 °C, respectively. The cathode sides were $T_c = 70$ and 80 °C, respectively; $P = 5$ psi (back pressure); anode flow rate, $Q_a = 340\ cm^3\ min^{-1}$ + load based flow (LBF); cathode flow rate, $Q_c = 240\ cm^3\ min^{-1}$ + LBF.

3. Results and discussion

It is well known that the performance of a PEMFC is a function of operating temperature and pressure. However, the operating temperature increases will cause thermal management and membrane dry-out problems. Operating pressure increases will result in the system complications. Therefore, this study emphasis is on the evaluation of fuel cell operating temperature and membrane humidifier temperature for a PEMFC single cell that could be carried by one person [9,11,13,16].

The performance of PEM fuel cell was affected by the surface modification and materials of the bipolar plates. Moreover, The performance of bipolar plates was affected by the following factors: resistance over-potential, activation over-potential and concentration over-potential [2,9,13]. The best performance in single cell operating temperature of the graphite bipolar plates was at 60 °C with low membrane humidifier temperatures as shown in Fig. 8. However, Fig. 8 indicates that the gold-plated titanium bipolar plates obtained the lowest and unstable performance as the fuel cell operating temperature increasing from 40 to 60 °C due to the dehydration of the membrane. Fig. 9 shows that the best performance in single cell operating temperature of the gold-plated bipolar plates was at 40 °C with high membrane humidifier temperatures.

Thus, the main effort of this study was to evaluate the performance of a light weight alternative material for the bipolar plates by using gold (Au)-plated titanium (Ti) bipolar plates in the PEM fuel cell stack. Polarization studies are typical for any electrochemical system to evaluate fuel cell performance. Figs. 8 and 9 show the *I–V* and *I–P* curves for the one-cell PEM fuel cell stack with different bipolar plates design, different fuel cell operating temperature and different membrane humidifier temperature, respectively. 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 coated with Au and pure titanium bipolar plate. However, Fig. 9 shows that the performance of titanium bipolar plate coated with Au was highest followed by

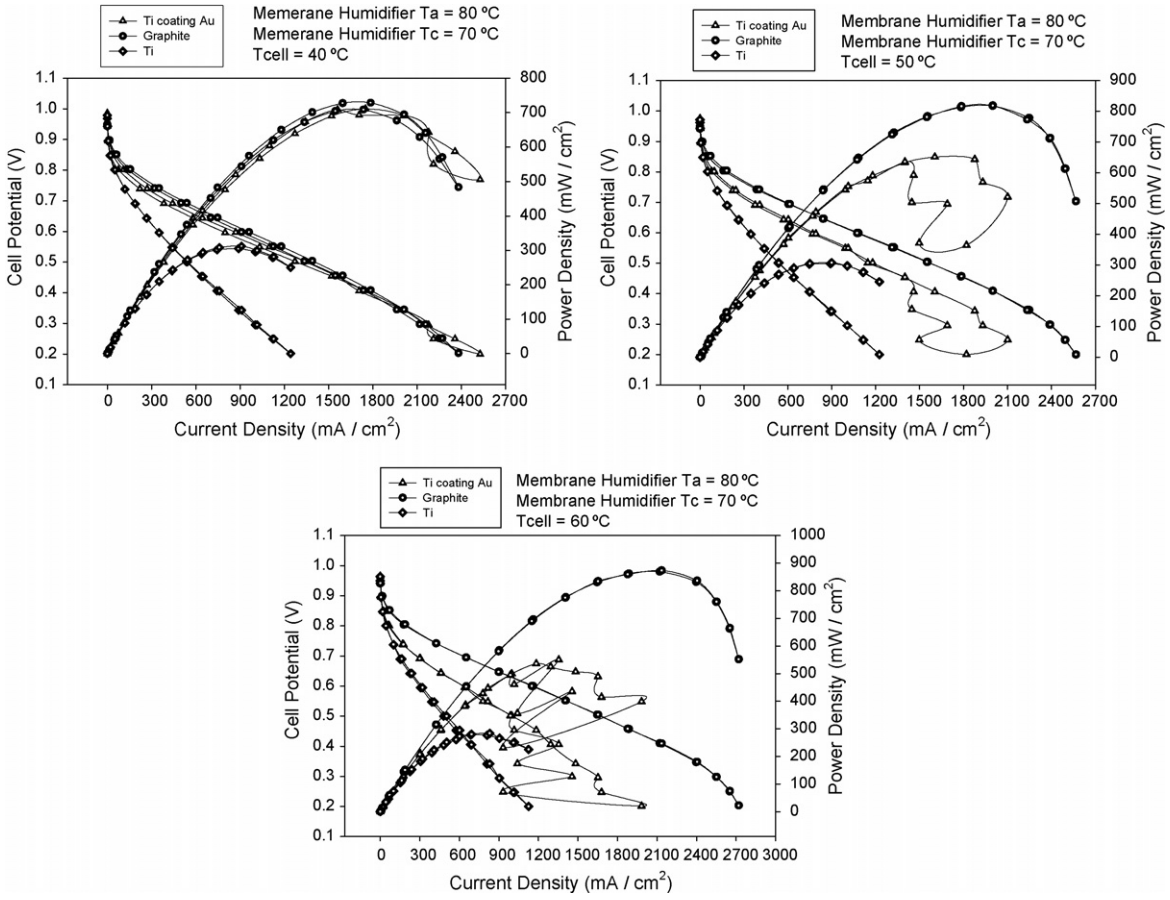

Fig. 8. *I–V* and *I–P* curves for the single cells using graphite, pure titanium, and titanium coated with Au ($T_{cell} = 40$, 50 and 60 °C; $T_a = 80$ °C; $T_c = 70$ °C).

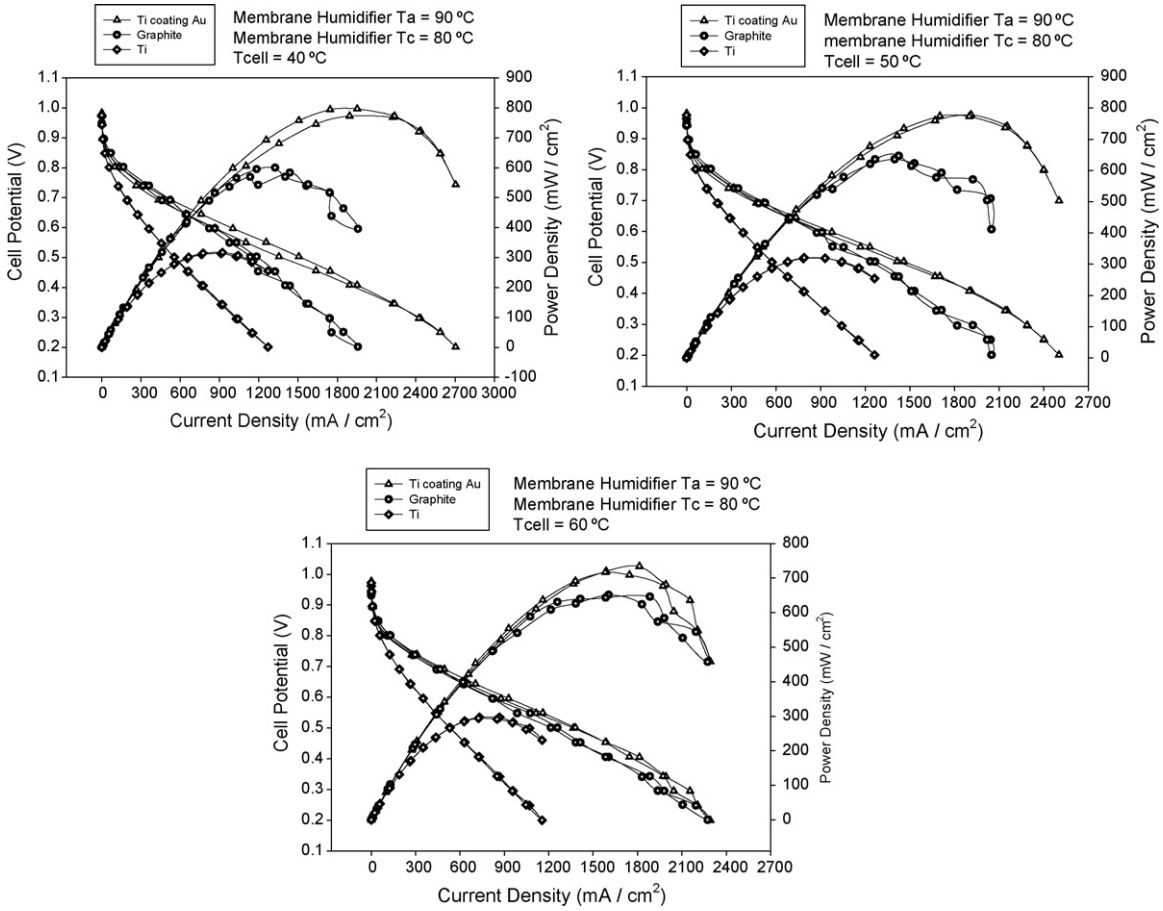

Fig. 9. *I–V* and *I–P* curves for the single cells using graphite, pure titanium, and titanium coated with Au (T_{cell} = 40, 50 and 60 °C; T_a = 90 °C; T_c = 80 °C).

graphite bipolar plate and pure titanium bipolar plate. To investigate ohmic and charge transfer resistance of the single cells, ac impedance was measured at a cell voltage of 0.85 V after the measurement of *I–V* curves presented in Figs. 8 and 9. The *I–V* performance of metallic bipolar plate is very similar to that of the graphite bipolar plate, and so is the *I–P* performance. Surface contact resistance (SCR) data as a function of compaction pressure are shown in Fig. 10. The graphite bipolar plate had a lower contact resistance than titanium bipolar plate coated with Au and pure titanium bipolar plate. By coating of gold on the surface of the titanium bipolar plate significantly lowered contact resistance (Fig. 10). The surface contact resistance between samples of the different materials was investigated at different compaction forces. The results indicated that the surface contact resistance decreases significantly with the Ti coated with Au compared with the pure Ti, with graphite showing the lowest surface contact resistance and pure Ti the highest. The surface contact resistance for different materials is of the order of graphite < Ti coated with Au < pure Ti. In this study, the *I–V* and *I–P* performances improved with the surface contact resistance decreased.

Fig. 9 indicates that gold-plated titanium bipolar plates provide a suitable replacement for the graphite composite plates at a low fuel cell operating temperature but high membrane humidifier temperature. 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. The weight of the bipolar/end plate can be reduced by around 30–50% of the weight of currently used graphite plates [1,3,5,8]. As a matter of fact, the weight of the gold-plated titanium single cell is only 875 g compared with the weight of the graphite single cell (2850 g). Moreover, the gold-plated titanium bipolar plates will act as gas

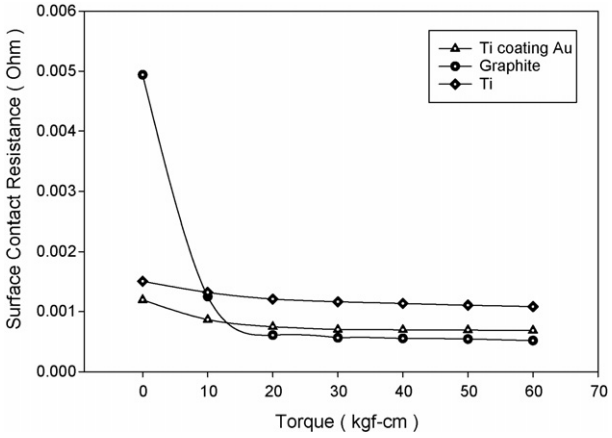

Fig. 10. Surface contact resistances for titanium bipolar plate coated with Au, graphite bipolar plate and pure titanium bipolar plate at different compaction forces.

flow-field distributor, electrodes and catalyst support, thereby reducing the number of components in the fuel cell stack [7,8,11,16].

4. Conclusions

In the present work, the results indicated that the alternative material of titanium bipolar plates coated with gold (Au) could be used in PEM fuel cells, which prevent the formation of oxide layers with high resistively. Both oxide formation and poisoning of the MEA are prevented and reduced. Moreover, the materials used have the potential to be low-cost coatings (only US$ 20) and thus lead to low cost and light weight (only 175 g) bipolar plates. Gold (Au) was considered as the surface modification material. Gold-plated titanium bipolar plates can be employed to produce fuel cells with light weight, low coating cost and low contact resistance, ideal for portable applications. These studies are in progress at the Kejin Water Treatment Co., Ltd. and Beam Associate Co., Ltd. Taiwan, ROC.

Acknowledgements

The authors would like to thank the Beam Associate Co., Ltd. Taiwan, ROC for their excellent support with the fuel cell development and test stations. Special thanks to Mr. Jin-Sheng Zhang (Kejin Water Treatment Co., Ltd.) for his greatest support with the fuel cell development.

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