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Short Communication

Investigation of single-layer and multilayer coatings for aluminum bipolar plate in polymer electrolyte membrane fuel cell

Zhuguo Li [a,c], Kai Feng [a,c,*], Zhiyuan Wang [a], Xun Cai [a,c], Chengwu Yao [a], Yixiong Wu [a,b,c]

[a] Shanghai Key Laboratory of Materials Laser Processing and Modification, School of Materials Science and Engineering, Shanghai Jiao Tong University, Shanghai 200240, China
[b] State Key Laboratory of Metal Matrix Composites, Shanghai Jiaotong University, Shanghai 200240, China
[c] Academician Expert Office Workstation (Jiansheng Pan), Lin'an, Zhejiang Province, China

ARTICLE INFO

Article history:
Received 25 January 2014
Received in revised form
13 March 2014
Accepted 18 March 2014
Available online xxx

Keywords:
Physical vapor deposition
Bipolar plates
Aluminum
Surface conductivity
Corrosion resistance
Polymer electrolyte membrane fuel cell

ABSTRACT

Aluminum bipolar plates offer good mechanical performance and availability for mass production while allow up to 65% lighter than stainless steel. To improve the corrosion resistance and surface electrical conductivity of aluminum bipolar plates, several coatings, including TiN, CrN, C, C/TiN and C/CrN, are deposited on aluminum alloy 5052 (AA-5052) by close field unbalanced magnetron sputter ion plating. Scanning electron microscope (SEM) results show that the coatings containing carbon layer are denser than TiN and CrN. Although the potentiodynamic test results show improved corrosion resistance by all the coatings, the potentiostatic test results reveal different stability of these coatings in PEMFC environments. Comparing the SEM images of these coatings after potentiostatic test, C/CrN multilayer coating exhibits the best stability. C/CrN multilayer coated AA-5052 has the lowest metal ion concentration after potentiostatic test, being 11.12 ppm and 1.29 ppm in PEMFC cathodic and anodic environments, respectively. Furthermore, the interfacial contact resistance (ICR) of the bare AA-5052 is decreased from 61.58 mΩ-cm^2 to 4.08 mΩ-cm^2 by C/CrN multilayer coating at the compaction force of 150 N-cm^{-2}. Therefore, C/CrN multilayer coating is a good choice for surface modification of aluminum bipolar plate.

* *Corresponding author*. Shanghai Key Laboratory of Materials Laser Processing and Modification, School of Materials Science and Engineering, Shanghai Jiao Tong University, Shanghai 200240, China. Tel.: +86 21 54745878; fax: +86 21 34203024.
E-mail address: fengkai@sjtu.edu.cn (K. Feng).

http://dx.doi.org/10.1016/j.ijhydene.2014.03.136
0360-3199/

Introduction

The bipolar plate is an important multifunctional component in polymer electrolyte membrane fuel cell (PEMFC) system, which performs duties such as separating individual cells and constituting the backbone of fuel cell stack, distributing reactive gases uniformly over the active areas, collecting the electrons generated by electrochemical reaction in the membrane electrode assembly (MEA), and removing the heat and exhaust water from the fuel cell [1–4]. From the standpoint of practical application, superior electrical and thermal conductivity, high corrosion resistance and gas impermeability, good mechanical performance and low cost are required for bipolar plate materials [5–7].

Little material can satisfy all the desired nature of bipolar plate. Up to now, the most intensively studied metallic materials for bipolar plate is stainless steel because of its good mechanical strength, availability for mass production and low cost [8,9]. As compared to stainless steel, aluminum offers advantages of low density (65% lighter in weight than stainless steel), low bulk electrical resistivity (a fifth of stainless steel) and high thermal conductivity (8.5 times higher than stainless steel) [5,10], and ease of fabrication and considerably less expensive [11,12]. The great potential in weight reduction has obvious advantages in transportation applications because there are hundreds of bipolar plates in each automotive PEMFC stack [11]. Nevertheless, insufficient corrosion resistance and surface conductivity prevent aluminum bipolar plate from wider application. Actually, oxide-free aluminum can meet all of the DOE bipolar plate targets except for corrosion resistance [11,13]. It is reported that the corrosion current density of aluminum is 10 times higher than that of stainless steel 316 L [14]. On the other hand, aluminum is usually encapsulated by a passive film which will significantly increase the interfacial contact resistance (ICR) between the bipolar plate and carbon paper. Therefore, surface modification is a must for aluminum bipolar plate [15].

To protect the aluminum from electrochemical corrosion while enhancing surface electrical conductivity, various coatings have been investigated in simulated PEMFC environment. Lin et al. [16] deposited Ni–P coating by electroless deposition and indicated that Ni–P coated aluminum bipolar plate was more hydrophobic and 1 order of magnitude lower in corrosion current density than that of the bare one. Hung et al. [17,18] compared carbide-based alloy coated aluminum bipolar plate with graphite composites bipolar plate. They found that the treated aluminum bipolar plate provided at least a 22% savings in hydrogen consumption compared to graphite and showed no indication of power degradation due to metal corrosion for at least 1000 h. Mawdsley et al. [11] applied composite coatings of graphite, TiC, and ethylenetetrafluoroethylene (ETFE) to the aluminum substrates by wet spraying followed by heat treatment. They found that composite-coated aluminum plate met the US DOE targets for in-plane conductivity, flexural strength and cathodic corrosion resistance, but through-plate area specific resistance and anodic corrosion resistance were not met due to an undesirable layered microstructure with connected porosity and pinholes. Fetohi et al. [19] deposited Ni–P and Ni–Co–P coatings on aluminum alloy 5251 using electroless and electroplating deposition techniques. The current density of Ni–Co–P was stabilized at a value lowered by 4 times relative to that of bare AA5251 substrate and ICR values of Ni–P and Ni–Co–P coatings prepared by electroplating were lower than those prepared by electroless plating. Tsai et al. [20] produced Au/Ni–P multilayer coatings on Al–alloy 5052 by electroless Ni–P along with immersion gold techniques and disclosed that Au/Ni–P multilayer coatings exhibited better corrosion resistance and surface conductivity than the bare one. El-Enin et al. [21] investigated several electroplated nickel alloys on aluminum alloy and Ni–Mo–Fe–Cr coating annealed at 400 °C for 1 h was recommended to be used as a new bipolar plate for PEMFC. Lee et al. [22] developed polypropylene composite-coated Al alloy 6061 as bipolar plate and the results indicated the corrosion resistance was improved while the contact resistance was greatly increased. Barranco et al. [23] deposited CrN coating on Al alloy 5083 by physical vapor deposition (PVD) and investigated the influence of coating thickness on the corrosion resistance and ICR in simulated PEMFC environment. The results disclosed that the corrosion current density and ICR of Al alloy 5083 were decreased by 2 orders of magnitude and 5 times, respectively. Lee et al. [24] developed multilayer coating composed of TiN, TiCN, TiC, and Cr coated aluminum plates by PVD technique. It is reported that the multilayer coating coated aluminum had good corrosion resistance and surface conductivity in simulated PEMFC environment.

Close field unbalanced magnetron sputter ion plating (CFUBMSIP) [25] is an advanced and well-established PVD technology that generates much more ion current density surrounding the substrates than traditional magnetron sputtering. Thus it enables the deposition of coatings with dense, good adhere and low internal stress. In previous works, we have fabricated amorphous carbon (a-C) coating and C/CrN multilayer coating on stainless steel 316 L as bipolar plate in PEMFC [26–28]. Our approach combines the advantages of stainless steel such as good mechanical strength and extremely low hydrogen permeation with the advantages of graphite (high chemical inertness and surface conductivity). In this study, several coatings such as TiN, CrN and C single-layer as well as C/TiN and C/CrN multilayer coatings are deposited on aluminum alloy 5052 (AA-5052) by CFUBMSIP. The surface topography of these coatings before and after potentiostatic test is observed by scanning electron microscope (SEM). The corrosion resistance and ICR in simulated PEMFC environment are investigated systematically.

Experimental details

Substrate and coating process

AA-5052 was chosen as the substrate materials. The chemical composition of AA-5052 was shown in Table 1. The samples were cut into 12 mm × 12 mm pieces with 4 mm in thickness, polished up to No. 1500 SiC waterproof abrasive paper,

Please cite this article in press as: Li Z, et al., Investigation of single-layer and multilayer coatings for aluminum bipolar plate in polymer electrolyte membrane fuel cell, International Journal of Hydrogen Energy (2014), http://dx.doi.org/10.1016/j.ijhydene.2014.03.136