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Composite coatings with in situ formation for Fe–Ni–Cr alloy as bipolar plate of PEMFC

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ABSTRACT

Fe–Ni–Cr alloy is a potential material as the bipolar plate for proton exchange membrane fuel cell (PEMFC). However, its interfacial contact resistance is too high and the corrosion resistance is too low to survive in the hostile environment. A novel approach of preparing the composite coating layers by in situ method is reported in this manuscript. The plate is first treated in acid solution, and then is heat treated at low temperature, at last is treated by electrochemical method. The ICR for the treated plate is lower than 10 mΩ cm^2, and corrosion current density is less than 5×10^{-8} A cm^{-2}. Microstructures for differential treatments have been analyzed by FE–SEM, XRD, XPS and AES as well as EPMA. The results indicate that high carbon concentration within surface area has been aroused by solution treatment, and then the conductive Cr_7C_3 layer has been in situ formed by heat treatment. Thereafter electro-chemical treatment has the function of clearing the surface and forming dense Cr_2O_3/Fe_3O_4 layer again upon Cr_7C_3/C layer, which improves the performance of bipolar plate effectively.

1. Introduction

Proton exchange membrane fuel cells (PEMFCs) have attracted much attention recently due to the rising awareness of environment concerns and limited energy resources [1]. The PEMFC uses hydrogen and oxygen or air as fuel, then transforms chemical energy to electrical energy. By comparison with other traditional power sources, the benefits of PEMFC are its higher efficiency, zero emission and lower operation temperature [2]. It has the potential to be used in vehicles and the areas where portable power sources are needed.

The PEMFC single cell consists of proton electrolyte membrane, catalyst layer, diffusion layer (a graphite layer) and bipolar plates. The bipolar plate is a key component for PEMFC. The bipolar plates should possess excellent corrosion resistance, electrical conductivity, mechanical strength, shock resistance, gas impermeability, and ease of manufacturing, etc. [3]. It thus provides multiple functions in a PEMFC. Furthermore, it takes over 80% of the mass and volume of a typical fuel cell stacks [4]. At the moment, graphite is frequently used as the material for bipolar plate because of its good electrical conductivity and corrosion resistance. However, the high processing cost of graphite bipolar plate inhibits its usage in PEMFC. Metallic materials are potential alternatives for their relatively high strength, excellent electrical and thermal conductivities, low machining cost and permeability [5]. Among the available metallic materials, the stainless steel, consisting of iron, nickel and chromium, is considered as a potential candidate because of its suitable physical and mechanical properties.

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Table 1 – The composition of the alloy (at%).				
Ni	Cr	C	O	Fe
32.34	29.17	1.72	0.93	Balance

However, its electrochemical corrosion resistance and surface conductivity are not satisfactory to meet the requirements of PEMFC; improvements on these two aspects are essential in order to apply the stainless steel as the bipolar plate [6].

In order to improve the corrosion resistance of stainless steel, many ceramic materials, such as TiN or CrN, have been coated onto its surface [7–12]. The corrosion resistance of stainless steel is indeed improved through such surface coating technique [13–19]; nevertheless, the pitting-type corrosion can still be found after a long-term usage [20,21]. This problem imposes limit on using the coated stainless steel as the bipolar plates. Furthermore, an extra cost is involved by applying the coating techniques.

An oxide layer is always present on the surface of stainless steel. The oxide layer is too thin to provide a satisfactory corrosion resistance to meet the requirement of PEMFC. Furthermore, the presence of such oxide layer raises the interfacial contact resistance (ICR) [22–26]. Since the ICR affects the output of the cell, many attempts have been made to prepare a coating with high electrical conductivity. However, it is a challenging task to produce a coating that improves both the corrosion resistance and the electrical conductivity.

Composite layer consisted of oxide layer and conductive layer may increase conductivity and corrosion resistance effectively. Such approach of preparing the composite coating layer by in situ method to increase the directional conductivity has never been reported before. The details for the processing and performance of the coated Fe–Ni–Cr alloy are reported in the present study.

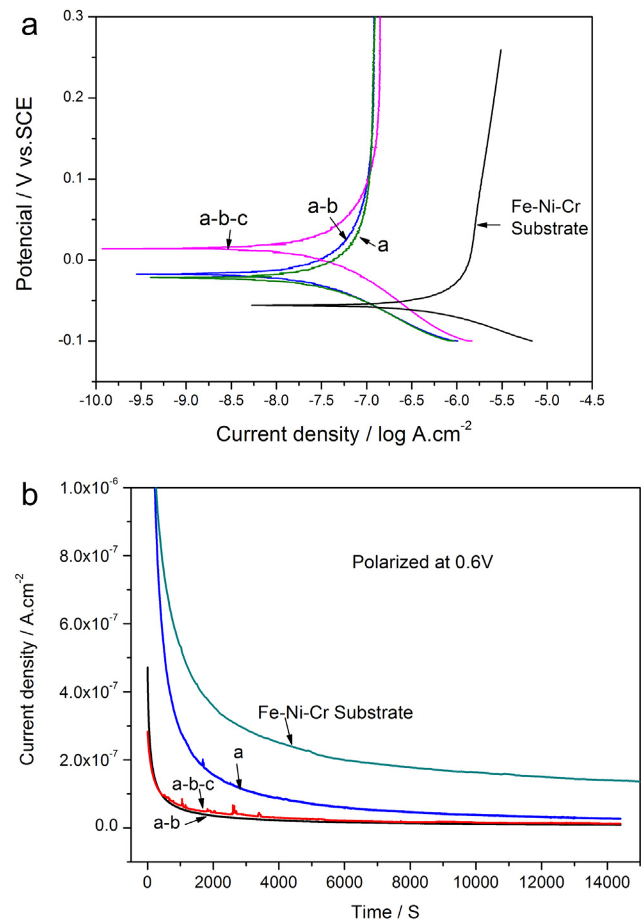

Fig. 1 – Polarization curves in the solution of 0.5 M H_2SO_4 + 2 ppm HF for the Fe–Ni–Cr alloys with differential surface treatments. a: The potentiodynamic polarization; b: The potentiostatic polarization at 0.6 V vs. SCE. (a) Solution treatment; (a–b) solution/heated treatment; (a–b–c) solution/heated/electrochemical treatment.

2. Experimental

A Fe–Ni–Cr alloy with composition listed in Table 1 was prepared by using the vacuum induction melting (VIM) technique. The alloy was then cut into 25 mm × 25 mm × 2 mm plates. The surface of the plates was polished by using SiC polishing papers and alumina paste. The plate was treated with three methods, as listed in Table 2: (1) Solution treatment (a) means the sample is treated in an acid solution with a pH < 3 at room temperature; (2) Solution/heated treatment

Table 2 – The samples with differential surface treatments.				
	Treatment technology	Treatment a	Treatment a–b	Treatment a–b–c
a	Treated in an acid solution with a pH < 3 at room temperature	✓	✓	✓
b	Treated at 220 °C for 2 h in Ar		✓	✓
c	Polarized at 0.6 V vs. SCE for 2 h in solution of 0.5 M H_2SO_4 + 2 ppm HF			✓