Study of Interfacial Contact Resistance Behavior of Plasma Nitride 304 Stainless Steel Bipolar Plates

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Abstract: Stainless steels are the promising materials for bipolar plate of proton exchange membrane fuel cell (PEMFC) due to low cost, ease stamping manufacture, good heat and electric conductivity. A surface modification improves the Interfacial Contact Resistance (ICR) of AISI 304 steel. Here the surface improvement was carried out by using Plasma nitriding. It was carried out on AISI 304 stainless steel samples at 400°C under 3 mbar pressures for 5 hr in the presence of N_2:H_2 gas mixtures of 4:1 ratio. X-ray diffractograms reveal that the untreated sample consists of characteristics γFe whereas, the plasma nitrided samples consist of mixed phase of Fe_3N, CrN, and Fe_4N phase. The results show that ICR is reduced markedly and corrosion resistance is better than the untreated substrate steel. The modified stainless steel with high Cr surface may be better candidate for the bipolar plates of PEMFC.

Keywords: Plasma nitriding, Stainless steel, Hardness, Conductivity

I. INTRODUCTION

Bipolar plates in the fuel cell works as a spine for the operation of the hydrogen fuel cell because it facilitates the conduction process between the anode and cathode through channelizing the reactant gases namely hydrogen and oxygen [1-5]. For fuel cell stack designing, the materials for the plates must be excellent manufacturability and suitable for cost-effective high volume automated production systems. Currently, graphite or its composites are used as a standard material for fuel cell bipolar plates because of its low surface contact resistance and high corrosion resistance. Unfortunately, they are classified as brittle and permeable to gases with poor cost effectiveness for high volume manufacturing processes relative to metals such as aluminum, stainless steel, nickel, titanium, etc. Since durability and cost represent the two main challenges hindering the fuel technology from penetrating the energy market and competing with other energy systems [3-6]. In recent years, the considerable attention was given to metallic bipolar plates due to higher mechanical strength, better durability to shocks and vibration, no permeability, and much superior manufacturability and cost effectiveness when compared to carbon-based materials, namely carbon-carbon and carbon-polymer composites. However, the main disadvantages of metals is the lack of ability to combat corrosion in the harsh acidic and humid environment inside the fuel cell without forming oxidants, passive layers, and metal ions that cause considerable power degradation. Considerable attempts are being made using noble metals, stainless steel and various coated materials with nitride- and carbide-based alloys to improve the corrosion resistance of the metals used without sacrificing surface contact resistance and maintaining cost effectiveness. Due to lack of graphite durability under mechanical shocks and vibration combined with cost effectiveness concerns of its high volume manufacturability, considerable research work is currently underway to develop metallic bipolar plates with high corrosion resistance, low surface contact resistance, and inexpensive mass production [2-5].

Here, we report our brief study on the electrical behavior of the AISI 304 plasma nitride stainless steel.

II. EXPERIMENTAL PROCEDURE

AISI 304 stainless steel having compositions C: 0.15, Si: 1.0, Mn: 2.0, Cr: 18.0, Ni: 8.0, balance Fe was used as substrate materials in for plasma nitriding process. The samples of square shape of 10 mm × 10mm size were cut and polished respectively with

240, 500, 800 grit SiC abrasive papers, and finally on diamond paste for mirror like finish in order to maintain less rough surface, then rinsed with acetone and alcohol, and dried. Two step surface modifications were adopted. Firstly, the samples were sputtered cleaned with Ar and H_2 of 2:1 ratio for 1 h at 1 mbar. After the sputter cleaning, the plasma nitriding was carried out in presence of N_2 and H_2 gas environment of 2:1 ratio for 5 h at 3 mbar at 400°C. The plasma nitride samples were characterized by using XRD, optical microscope, and conductivity measurement.

III. RESULTS AND DISCUSSION

Figure 1(a & b) shows the X-ray diffraction patterns of untreated and plasma nitrided samples. All the characteristics peak of γFe in austenitic steel is well resolved. However, after plasma nitriding, the pure iron phase converts into Fe_3N and Fe_4N along with CrN phase.

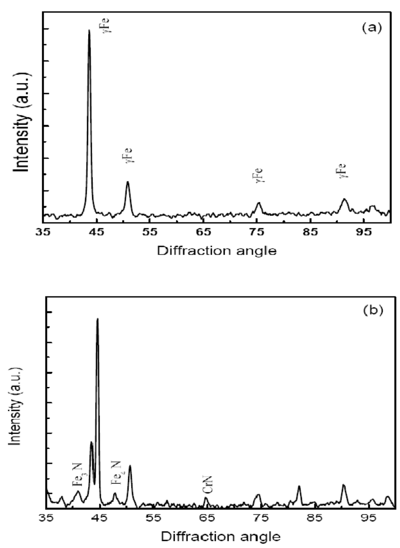

Figure 1: XRD of (a) Untreated and (b) Plasma nitride.

The optical micrograph revealed the nitrogen diffusion depth around 10 microns with non-uniform thickness. Figure 2 represents the schematic of the apparatus used for measuring the interfacial contact resistance (ICR) between the stainless steel and carbon paper. The ICR of specimens was evaluated by measuring the potential value when a current in the range of -50 mA to 50 mA was continuously applied to two copper end plates. Conductive carbon paper used was located between them. The total measured resistance is the sum of four interfacial components: two carbon paper/copper plate interfaces ($R_{C/Cu}$), one carbon paper/ surface of sample interfaces ($R_{S/C}$) and one carbon paper/bare surface of sample interfaces ($R_{bare\ S/C}$), two bulk resistances of the copper plate and the wire ($R_{Cu/wire}$), two bulk resistances of the carbon paper (R_C) and the bulk resistance of the SS 304 (R_{Sample}).

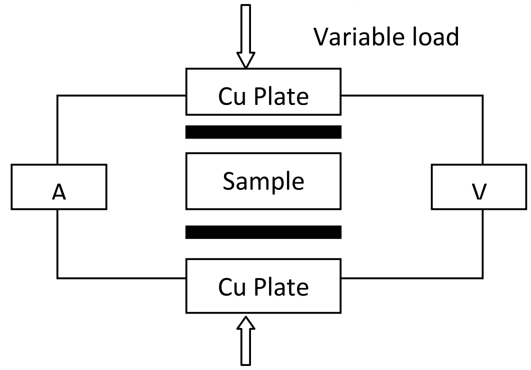

Figure 2: A schematic of the test assembly for measurement of the interfacial contact resistance

The ICR is measured between the samples and carbon paper at different compaction forces. With increasing compaction forces, the contact resistance decreased rapidly at low compaction forces and then decreased gradually at high compaction forces. The contact resistance is 15 mΩcm^2 for treated steel and 87 mΩcm^2 for the substrate at a load of 150 N cm^{-2}, respectively. In general, the ICR decreases slightly with the Cr content of the alloys so the treated steel shows sharply lower values than the substrate.

IV. CONCLUSION

Plasma nitriding is a novel process for the diffusion of nitriding into AISI 304 steel in order to improve the interfacial conductivity and corrosion resistance of as the bipolar plate for PEM fuel cell. The results obtained by XRD and optical micrograph confirm the formation of nitride layer. After nitriding, the decrease in ICR value indicates the feasibility of this process of the development of bipolar plates of steel materials.

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