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Full Length Article

Ultrathin effective TiN protective films prepared by plasma-enhanced atomic layer deposition for high performance metallic bipolar plates of polymer electrolyte membrane fuel cells

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ABSTRACT

The stainless steel (SS)-based bipolar plate with high conductivity and corrosion resistance is one of the key components in recent polymer electrolyte membrane fuel cells. Therefore, an excellent corrosion protection and good electrical conductivity in SS316L-based bipolar plates can be achieved through plasma-enhanced atomic layer deposition (PEALD) of ultrathin (25–67 nm) TiN thin films. To this end, two types of TiN protective coatings deposited by PEALD using tetrakis(dimethylamino)titanium (TDMAT) and titanium tetrachloride ($TiCl_4$) precursors were evaluated; the evaluations were conducted under conditions simulating the operating conditions of PEMFCs. Regardless of the precursor type, PEALD-TiN onto SS316L resulted in great improvements in electrical conductivity and corrosion resistance. Notably, the TiN thin films prepared using TDMAT exhibited excellent corrosion resistance (< 1 μA/cm^2) compared to those produced using $TiCl_4$ as the precursor. Systematically structural, compositional, and electrochemical analysis revealed that a ~5-nm-thick ultrathin amorphous interfacial layer, formed and played a key role in the corrosion protection using TDMAT. Furthermore, the TiN thin films by TDMAT greatly lowered the interfacial contact resistance of SS316L from 35.868 to 15.239 mΩ·cm^2 at a compaction force of 127 N/cm^2. Our study presents an interesting opportunity for the development of PEALD protective coating materials for SS-bipolar plates.

1. Introduction

In recent years, polymer electrolyte membrane fuel cells (PEMFCs) have received an extensive attention as one of the most promising types of fuel cells for vehicles, stationary power generators, and other portable applications because of their low operating temperatures, rapid start-up, and highly efficient energy conversion [1–7]. For PEMFCs, one of the key components is the bipolar plate, which is the electrode plate that serves not only as a separator promoting the uniform distribution of reactants in a cell stack but also as a current collector between adjacent membrane electrode assemblies; it manages the heat dissipation and water usage of the whole cell [8–10]. Accordingly, the characteristic bipolar plate properties required to ensure acceptable levels of power output are a high corrosion resistance, high electrical conductivity, good mechanical strength, good shock resistance, and a low gas impermeability [11–13]. According to the roadmap of the United States Department of Energy (DOE), the materials for bipolar plates should have an interfacial contact resistance (ICR) lower than 0.02 Ω·cm^2 by the year 2017 and lower than 0.01 Ω·cm^2 by the year 2020. Additionally, the goals of a current density lower than 1 μA/cm^2 and an electrical conductivity greater than 100 S/cm (lower than 10,000 μΩ·cm) should be met by both years [11,14].

Currently, stainless steel is considered as a strong candidate for bipolar plates due to its excellent mechanical and physical properties combined with easy mass production [8–11]. However, stainless steel exhibits relatively low electrical conductivity and is prone to corrosion under the harshly acidic and humid PEMFC operating conditions [13]. Therefore, extensive efforts have been devoted to improving both the electrical conductivity and the electrochemical corrosion resistance of stainless steel by applying adequate protective coatings to meet the strict aforementioned DOE requirements for high-performance bipolar plates [12,13]. For this reason, various surface coating techniques,

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