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Review

Metal bipolar plates for PEM fuel cell—A review

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Abstract

The polymer electrolyte membrane (PEM) based fuel cells are clean alternative energy systems that hold excellent potential for cost effectiveness, durability, and relatively high overall efficiency. PEM fuel cell is recognized by the U.S. Department of Energy (DOE) as the main candidate to replace the internal combustion engine in transportation applications. Metallic bipolar plates and membrane electrode assembly (MEA) are two crucial components of a PEM power stack and their durability and fabrication cost must be optimized to allow fuel cells to penetrate the commercial market and compete with other energy sources.

The bipolar plates perform as the current conductors between cells, provide conduits for reactant gases flow, and constitute the backbone of a power stack. They are commonly made of graphite composite for high corrosion resistance and good surface contact resistance; however their manufacturability, permeability, and durability for shock and vibration are unfavorable in comparison to metals. On the other hand, various methods and techniques must be developed to combat metallic corrosion and eliminate the passive layer that causes unacceptable reduction in contact resistance and possible fouling of the catalyst and the ionomer. Thus recently metallic bipolar plates have received considerable attention in the research community. This paper offers a comprehensive review of the research work conducted on metal bipolar plates to prevent corrosion while maintaining a low contact resistance.

Keywords: Hydrogen fuel cell; Bipolar plate; Review

Contents

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1. Introduction

Bipolar plates constitute the backbone of a hydrogen fuel cell power stack, conduct current between cells, facilitate water and thermal management through the cell, and provide conduits for reactant gases namely hydrogen and oxygen. In the polymer electrolyte membrane (PEM) hydrogen fuel cell design, bipolar plates are fabricated in mass production and they must be made of materials with excellent manufacturability and suitable for cost-effective high volume automated production systems. Currently, graphite composites are considered the standard material for PEM bipolar plates because of its low surface contact resistance and high corrosion resistance. Unfortunately, graphite and graphite composites 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, considerable attention was recently given to metallic bipolar plates for their particular suitability to transportation applications. Metals enjoy 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 handicap of metals is the lack of ability to combat corrosion in the harsh acidic and humid environment inside the PEM 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. Gold-coated titanium and niobium were the materials used by General Electric in the 1960s [1] that were later replaced by graphite composites to reduce cost and weight. In recent years, 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.

Various types of metals and alloys are currently under testing and evaluation by researchers working in the field of PEM fuel cells to develop bipolar plates that posses the combined merits of graphite and metals. The ideal characteristics of a bipolar plate's material is high corrosion resistance and low surface contact resistance, like graphite, and high mechanical strength, no permeability to reactant gases and no brittleness like metals such as stainless steel, aluminum, titanium, etc. The main challenge however is that corrosion-resistant metal bipolar plates develop a passivating oxide layer on the surface that does protect the bulk metal from progression of corrosion, but also cause an undesirable effect of a high surface contact resistance. This causes the dissipation of some electric energy into heat and a reduction in the overall efficiency of the fuel cell power stack. The key characteristics of bipolar plates material that are suitable for transportation applications are as follows:

- high corrosion resistance with corrosion current at 0.1 V and H_2 purge < 16 $\mu A\,cm^{-2}$;
- high corrosion resistance with corrosion current at 0.6 V and air purge < 16 $\mu A\,cm^{-2}$;
- interfacial contact resistance (ICR) @140 $N\,cm^{-2}$ = 20 $m\Omega\,cm^2$;
- does not dissolve and produce metal ions;
- possess steady low Ohmic resistance throughout the operation;
- high surface tension with water contact angle close to 90 °C, i.e. high dehydration;
- light weight;
- high mechanical strength < 200 $N\,m^{-2}$;
- high volume cost-effective manufacturability: US$ 10 kW^{-1}.

2. Background and review

Poco graphite has been considered as the PEM fuel cell industry standard for bipolar plates because of its excellent corrosion resistance, interfacial contact resistance, surface energy, and contact angle. However, its brittleness and lack of mechanical strength combined with its relatively poor cost effectiveness for large volume manufacturing, Poco graphite bipolar plate is deemed unsuitable for automotive application and commercialization. Accordingly, a number of materials are currently being developed and tested in laboratories around the world to produce cost-effective and durable bipolar plates for polymer electrolyte membrane fuel cell (PEM). Varieties of non-coated and coated metals, metal foams and non-metal graphite composites are being reviewed for possible replacement of Poco graphite. Below we describe each of these approaches and their state of advancement for potential application in fuel cells.

2.1. *Precious non-coated metals*

Nobel metals such as gold and platinum perform very similar to Poco graphite bipolar plates [2] and in some cases showed more superior performance. However, the high cost of these metals has prohibited their utilization for commercial use.