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Review

A review of composite and metallic bipolar plates in proton exchange membrane fuel cell: Materials, fabrication, and material selection

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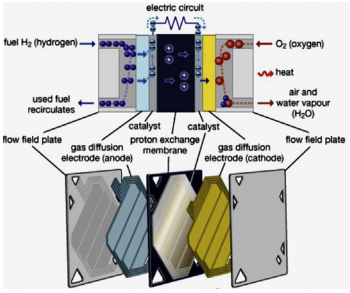
HIGHLIGHTS

- The filler and matrix materials, properties, and production methods of composite bipolar plates.
- Materials, properties, coatings, coating methods, stamping process, and ionic contaminations of metallic bipolar plates.
- Material selection upon eleven bipolar plate materials using the SAWM approach.

GRAPHICAL ABSTRACT



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ABSTRACT

Proton exchange membrane (PEM) fuel cells offer exceptional potential for a clean, efficient, and reliable power source. The bipolar plate (BP) is a key component in this device, as it connects each cell electrically, supplies reactant gases to both anode and cathode, and removes reaction products from the cell. BPs have primarily been fabricated from high-density graphite, but in recent years, much attention has been paid to develop the cost-effective and feasible alternative materials. Recently, two different classes of materials have been attracted attention: metals and composite materials. This paper offers a comprehensive review of the current researches being carried out on the metallic and composite BPs, covering materials and fabrication methods. In this research, the phenomenon of ionic contamination due to the release of the corrosion products of metallic BP and relative impact on the durability as well as performance of PEM fuel cells is extensively investigated. Furthermore, in this paper, upon several effective parameters on commercialization of PEM fuel cells, such as stack cost, weight, volume, durability, strength, ohmic resistance, and ionic contamination, a material selection is performed among the most common BPs currently being used. This material selection is conducted by using Simple Additive Weighting Method (SAWM).

1. Introduction

Proton exchange membrane (PEM) fuel cells have attracted much attention recently due to the increasing awareness of environmental factors and limited energy resources [1] (Fig. 1). PEM fuel cells are devices that convert chemical energy of a fuel directly into electrical energy while allowing for high efficiency, zero emission and low working temperature (70–90 °C) compared to traditional power sources [2]. Thus, PEM fuel cells are one of the most promising power sources in transportation applications, since the use of fossil fuel and concomitant emission to the environment can be reduced [3]. However, currently PEM fuel cells are primarily

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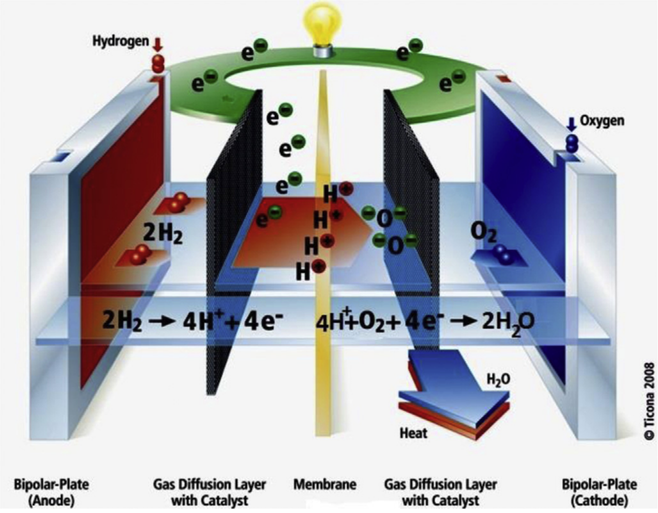

Fig. 1. Schematic figure of PEM fuel cell components.

employed for research and demonstration applications due to remaining barriers of reliability, endurance, mass, and cost that hinder their widespread commercial adoption [4]. Bipolar plates (BPs) which are the key multifunctional component in PEM fuel cells constitute over 80% of the weight, 30% of the total cost and almost all of the volume in a typical fuel cell stack [5,6]. The functions of BPs [6,7] include the following: (1) separating the individual fuel cells, (2) connecting the cathode side of one cell to the anode side of the other one with good conductivity, (3) feeding the reactive gases to the anode side (hydrogen gas) and cathode side (oxygen gas) via flow channels, and (4) removing the heat and reaction products (water). Hence, high electrical conductivity, high gas impermeability, good mechanical performance, good corrosion resistance, and low cost are required for practical applications of BP materials [8]. Based on department of energy (DOE) criteria [9,10], BPs should achieve some properties as follows: through-plane electrical conductivity >100 Scm^{-1}; interface contact resistance (ICR) < 30 $\text{m}\Omega\text{cm}^2$ [11]; chemical stability in the slightly acidic water pH < 4; corrosion resistance <16 μAcm^{-2} [11]; high thermal conductivity >10 W(mK)^{-1} [12]; low permeability to hydrogen and oxygen $<2 \times 10^{-6}$ $\text{cm}^3(\text{cm}^2\text{s})^{-1}$ [11]; flexural strength >59 MPa; and impact strength >40.5 Jm^{-1} [11,12].

BPs have traditionally been fabricated from high-density graphite on account of its superior corrosion resistance, chemical stability, high thermal conductivity, and availability. However, due to its molecular structure, it exhibits poor mechanical properties, high manufacturing cost, and it is difficult to work with. Nevertheless, graphite has established itself as the benchmark material for fabrication of bipolar plates, against which all other materials are compared [1,6]. However, it is not suitable for either transportation applications that require good structural durability against shock and vibration or large-scale manufacturing because of its poor mechanical strength. The thickness of the graphite plates cannot be reduced, resulting in bulkiness and heaviness [13]. As a result, recent studies have moved away from graphite in the direction of developing and optimizing more cost effective materials such as metals and composites. Metallic materials are another choice for BPs because of their good mechanical strength, high electrical conductivity, high gas impermeability, low cost, and ease of manufacturing [14–17]. The most advantage of metallic BPs is stampability and reducing the thickness plate to about 1 mm. Stainless steel is considered one of the promising candidates in BPs. On account of its self-passivating ability, stainless steel is usually encapsulated by a passive film which can prevent the bulk materials from further corrosion. The thickness of the passive film is typically in the range of 1–3 nm, which is affected by the environment and steel grade. Although the passive film can decrease the corrosion rate of stainless steel, it will significantly increase ICR between the BP and carbon paper [18]. In a PEM fuel cell, the stainless steel will also experience passivation, but the thickness and the composition of the passive film will depend on the composition of the stainless steel and the surroundings such as pH values, applied potential, and ions in the solution [8,14,18–20]. In addition, the passive film will dissolve and reform when the environment conditions change leading to release metallic ions and contamination.

Recently, polymer–carbon composite BPs have been investigated due to their lower cost, less weight, and higher corrosion resistivity in comparison with available materials such as graphite or metallic BPs [21]. The disadvantages of composite BPs are non-stampability, lower electrical and mechanical properties than those of metallic BPs. In this article, a review will be performed on the metallic and composite BPs in respect of materials, properties, and fabrication methods.

Since BPs must possess the combined advantages of both metals and graphite composites in the fuel cell technology, various methods, and techniques are being developed to combat metallic corrosion and eliminate the passive layer formed on the metal surface that causes unacceptable power reduction and possible fouling of the catalyst and the electrolyte. The main objective of this study is to explore the possibility of producing efficient, cost-effective and durable metallic BPs that were capable of functioning in the highly corrosive fuel cell environment. In order to commercialize the PEM fuel cells, the BP type should be selected based on the commercial parameters such as weight, volume, and performance. In the literature, a comparative evaluation between the metallic and composite BPs focusing on commercial parameters has not yet been performed.

There are some review papers on materials and manufacturing methods of BPs. Tibbetts et al. [22] in many years ago (2007) has summarized the wide variety of composite properties and fabrication methods achieved with vapor-grown carbon nanofiber/polymer composites. V. Mehta and J.S. Cooper [23] in many years ago (2003) have been published one review on materials, fabrication, and coating methods of membrane electrolyte assembly (MEA) and composite, graphitic, and metallic bipolar plates. S. Karimi et al. [24] recently (2012) were investigated materials and fabrication methods of metallic bipolar plates. This paper offers a comprehensive review of the current researches being carried out on metallic bipolar plates, covering materials and fabrication methods. R. Sengupta et al. [25] in some years ago (2011) have published a review of the mechanical and electrical properties of graphite and modified graphite reinforced polymer composites. Here, the blending and polymerization methods of polymer-based carbon composite with an interest in nanofillers such as graphene, carbon nanotube, and expanded graphite were investigated. However, the main subject of this paper is general, without regard to composites BP.

In the mentioned papers the ionic contaminations have not be investigated. In addition, a comparison between composite and metallic BP from the viewpoint of commercialization interests (such as cost, volume, weight, and durability) would be necessary. This paper reviews the last findings about materials (different polymers and fillers used for composite BPs and different substrates and coatings used for metallic BPs) and production methods (compression and injection molding in composite BPs and stamping and hydoforming methods in metallic BPs), as well as ionic contamination were investigated. In this paper, a material selection is also performed between metallic and composite BPs from the viewpoint of commercial parameters. M.C. Oliveira et al. [26] recently (2012) employed the Ashby approach for selecting