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Review Article

Gas diffusion layer modifications and treatments for improving the performance of proton exchange membrane fuel cells and electrolysers: A review

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ABSTRACT

Gas diffusion layer (GDL) has a critical role in determining the performance of proton exchange membrane (PEM) fuel cells and electrolysers by facilitating uninterrupted and smooth gas and water transport to and from the electrochemically active areas of these cells. The design of GDLs has been evolved significantly during recent years with the key aim of improving their performance for delivering their role. This paper provides a comprehensive review of modifications introduced to improve the GDL performance to date. The majority of these modifications have been carried out on fuel cells and the GDL in electrolysers has been studied to a lesser extent. The main focus of these modifications was found to be on water management and reactant delivery improvement as per defined for the role of GDLs. This review covers in detail the modifications linked to GDL hydrophobicity, GDL porosity, and engineered perforated GDLs. The effect of introducing a microporous layer (MPL) to the GDL is also reviewed by considering key design aspects such as MPL thickness, pore size, porosity, hydrophobicity and hydrophilicity, and the role of cracks in MPL structure. This review comes up with the key research gaps that are yet to be addressed and the recommendation for future researches to be followed for GDL modifications (i.e. to achieve further improved performance in PEM fuel cells and electrolysers).

Contents

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Introduction

Polymer electrolyte membrane fuel cells (PEMFCs) convert the hydrogen energy into electricity through electrochemical reaction of oxygen and hydrogen. The main advantages of these devices are high electrical energy efficiency (~55%) and power density, light weight, simplicity, and quick start-up [1–3]. These unique characteristics made them to be ideal candidates for a range of stationary and mobile applications [4,5].

The main components of a PEMFC stack, as presented in Fig. 1a, are bipolar plates (BPP), membrane electrode assembly (MEA), and gasket. MEA, Fig. 1b, is the core component of a PEMFC and consists of polymer electrolyte membrane (PEM), gas diffusion layer (GDL), and catalyst layer (CL). Effective transport of reactants and products is essential for PEMFC operation. GDL, a porous medium, facilitates the transfer of the reactants and products to and from the CL. In a PEMFC, hydrogen and oxygen reach the CL from the flow channels through the GDL and the excess water produced at CL is transferred to the flow channels and removed from the cell. Commonly, GDL is composed of a macroporous substrate with or without a microporous layer (MPL). This structure is shown in Fig. 1c. The main substrate is in contact with the BPP and the MPL is next to the CL. The substrate distributes the reactant gases. MPL is usually added to the main substrate forming a dual-layer GDL to improve the electrical conductivity and water management [6,7]. In PEMFCs, commonly carbon paper or carbon cloth is used as the main substrate. This layer, in PEMFCs and unitised regenerative fuel cells (URFCs), is mostly treated with a hydrophobic agent such as PTFE to prevent the liquid water from blocking the pores and provide clear passages for the reactant gases. In PEMFCs, MPL is commonly a mixture of carbon black and PTFE (acting both as binder and hydrophobic agent). However, in PEM electrolysers and URFCs carbon-based substrate and MPL cannot be used due to the corrosive environment of the electrolyser. Therefore, in PEM electrolysers and URFCs, typically titanium-based GDL is used [8,9]. However, development of MPL for these devices has been very limited compared to PEMFCs.

The main roles of GDL in PEMFCs and electrolysers are [10,11]: facilitating the transport and uniform distribution of reactants (i.e. hydrogen and oxygen in PEMFCs and water in electrolysers) and products (i.e. water in PEMFCs and hydrogen and oxygen in PEM electrolysers) between the flow field and the active area; providing structural support to the MEA; and last but not least, electron and heat transfer. Therefore, great deals of research studies are available in the literature that are focused on modifying GDL structure and its properties to improve the fuel cells and electrolysers performances. The majority of these studies have tried to enhance the water management characteristics of the GDL.

For optimal performance of PEMFCs, water management is of great importance [12,13]. Membrane proton conductivity depends on its hydration level. Therefore, enough water should be maintained in the cell to ensure high proton conductivity and minimise ohmic losses. On the other hand,

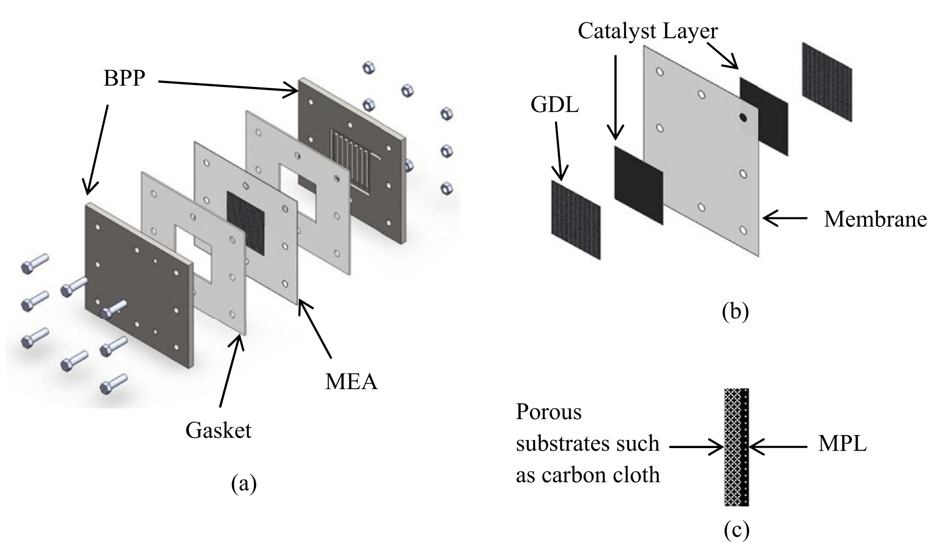

Fig. 1 – Schematic illustration of: (a) exploded view of a single cell PEMFC; (b) exploded view of MEA; (c) duel-layer GDL.