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Effect of tunable hydrophobic level in the gas diffusion substrate and microporous layer on anion exchange membrane fuel cells

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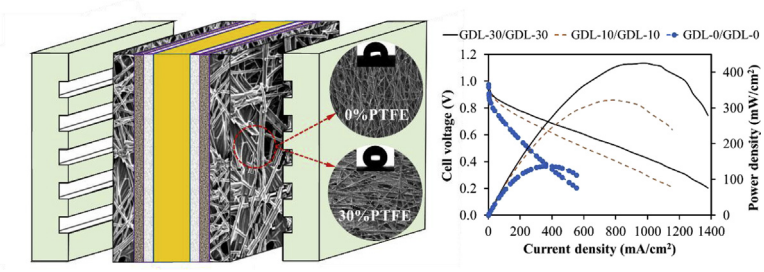
HIGHLIGHTS

- Effect of hydrophobic level in GDS on AEMFC is investigated systemically.
- The amount of PTFE in GDS affects the properties of MPL coating and catalyst layer.
- The distribution of PTFE-induced pores in GDL is critical to AMEFC performance.
- A 46% improvement can be obtained at AEMFC with a sophisticated water control.

GRAPHICAL ABSTRACT



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ABSTRACT

The anion exchange membrane fuel cell, based on hydroxide conduction, has been paid much attention recently due to its strength of improved cathode performance, non-precious metal catalysts, and low-cost electrolyte. However, its electrochemical reaction simultaneously involving in the production/consumption of water at anode/cathode makes it difficult to maintain an optimized hydration of anion exchange membrane and the electrodes, thereby limiting the attainable cell performance. Accordingly, reaching a sophisticated water management is urgently required. Herein, we systemically investigate the hydrophobic effect of gas diffusion substrate, strongly affecting the water condition, on the anion exchange membrane fuel cell. A series of gas diffusion substrates with different hydrophobic level are designed by controlling amount of polytetrafluoroethylene within gas diffusion substrates and with/without microporous layer atop to evaluate single cell performance. Our result shows that a good device performance can be obtained by using the gas diffusion substrate with higher polytetrafluoroethylene loadings and microporous layer both at anode and cathode. It can be mainly attributed to the multifunction of polytetrafluoroethylene in gas diffusion substrate, offering the advantages of the appropriate hydrophobic control and robust supporting for the microporous layer and catalyst layer to achieve a sophisticated water control during the operation.

1. Introduction

Fuel cell device is one of the most promising technologies for future mobile and stationary energy supplies due to its high energy conversion efficiency, high power density, and low pollutant emission as compared with the internal combustion system [1–3]. Several types of fuel cells,

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based on the different employed electrolytes, have been developed for their appropriate applications. The proton exchange membrane fuel cells (PEMFCs), particularly suitable for the vehicle transportation, have been paid much attention because of their features of excellent power-to-weight ratio and high power density at the low operation temperatures. However, while PEMFCs keeps struggling with costly Pt catalyst and acid corrosion environment, anion exchange membrane fuel cells (AEMFCs) with the nature of fast oxygen reduction reaction (ORR) kinetics in alkaline media [4–7] becomes an alternative to offer the possibility of using non-noble, low-cost catalyst and alleviating the potential corrosion issue. The electrochemical reactions of AEMFCs via OH^- conduction within the alkaline membrane can be given as follows.

Anode: $2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$

Cathode: $O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

Overall: $2H_2 + O_2 \rightarrow 2H_2O$

As shown in the reactions, the AEMFC simultaneously involving in the production and consumption of water at the anode and cathode, respectively, complicated water management considerably. Accordingly, providing an appropriate water condition during the AEMFC operation to meet the requirements of adequate water in the membrane and anode/cathode without flooding/dry-out is required [8]. A typical schematic diagram of AEMFC based on a similar PEMFC sandwich structure composed of anode/membrane/cathode is illustrated in Fig. 1.

According to previous studies, the gas diffusion layer (GDL), located between the catalyst layer (CL) and flow field plates, is known to be a vital component of low temperature fuel cells because of its key function to control the flow of hydrogen (anode) and oxygen (cathode) to the CL as well as provide a proper water condition for stable cell operation under a wide range of current density [9,10]. The GDL also requires a robust mechanical ability to support the membrane assembly and serves as a good conductive path between the CL and the current collector [11]. As a result, the desirable structure of GDLs is targeted to meet those requirements by optimizing their microstructures, porosity, hydrophobicity, gas permeability, and water management simultaneously.

Furthermore, a GDL is a film stack structure of the gas diffusion substrate (GDS) coated with microporous layer (MPL). The woven

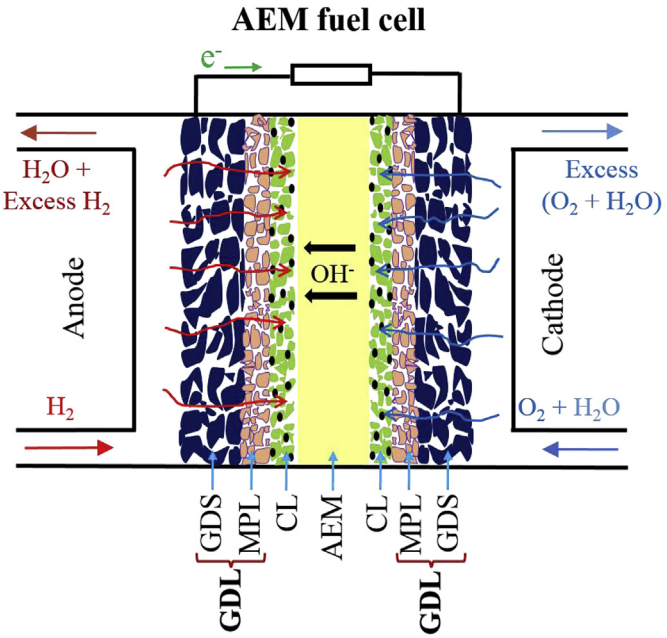

Fig. 1. Schematic diagram of anion exchange membrane fuel cell (AEMFC).

carbon cloth, nonwoven carbon paper, and non-woven carbon felt are commonly chosen as the GDS because of their high porosity and good electric conductivity while the MPL is a mixture of fine carbon particles with hydrophobic agents like polytetrafluoroethylene (PTFE) or fluorinated ethylene propylene (FEP) as a buffer layer between GDS and CL. To reach a better fuel cell performance by optimizing the water management, the GDS is also treated with the hydrophobic agents such as PTFE [12–15] or FEP [16]. Some experimental studies have been also conducted to investigate the effects of PTFE content in GDS and their thickness on PEMFCs performance [12,17–19]. Generally, the optimized content of hydrophobic agent in GDL strongly depends not only on the other external factors such as the fabrication method, and carbon fiber structure but also the fuel cell operation conditions such as cell temperature, reactant humidity, and flow rate. In addition, the insertion of MPL between GDS and CL can improve the cell performance and working stability under the different humidity conditions [20–29] even though the main role of the MPL at the anode/cathode of PEMFC during the operation remains unclear [30,31].

Recent AEMFC studies mostly focus on the understanding of the hydrogen oxidation reaction (HOR) and the oxygen reduction reaction (ORR) mechanisms in alkaline media and the development of new materials such as anion exchange membranes, ionomers, and electrocatalysts [32–41]. In contrast to PEMFC with broad studies on GDL, few efforts seem to put on the AEMFC. For instance, D. Yang et al. [42] investigated the influence of PTFE content and Pt loading in the CL on the AEMFC performance. The optimum content of PTFE and Pt loading in the CL was found to be 20% and 1.0 mg cm^{-2}, respectively. T. J. Omasta et al. [43] also studied the relationship of AEMFC performance among gas diffusion electrodes, dew points and gas flow rates at the anode and cathode while proposing that a well-balanced water condition during the operation is a key to achieve a high performing AEMFC. On the other hand, Y.S. Li et al. [44] reported that the effect of MPL at the cathode on the performance of anion-exchange membrane direct ethanol fuel cells. It was observed that the MPL can function as a barrier to mitigate the water crossover, leading to an improved fuel cell performance. S. Huo et al. [45] conducted experimental and modeling work to explore operating behavior of AEMFC. Their results showed that high permeation of liquid water through the membrane by the increased pressure gradient from anode to cathode is beneficial for the cell performance due to ameliorative reaction kinetics. Some groups also investigated the role of MPL and humidity conditions on the water transport in AEMFCs via mathematical models [46–49].

The above-mentioned studies can be indeed understood with the importance of the sophisticated water management in AEMFC. Unfortunately, the studies of hydrophobic level in GDS, strongly affecting the water condition, during the AEMFC operation remain missing. Accordingly, our work is motivated by the need to understand the hydrophobic effect of GDS and MPL at both the cathode and anode sides on the AEMFC performance because of its complex water situation, as compared with PEMFC which usually concentrated on the cathode side only. A series of GDSs with different hydrophobic conditions were prepared by carbon fibers treated with different PTFE contents and with/without MPL coating in order to evaluate the effects of hydrophobic level in the GDSs and MPL on fuel cell performance. Besides, to correlate the relationship between the physical properties of GDLs and their respective device performances, the analyses of air permeability, through-plane resistance, contact angle, the pore size, and pore size distribution were performed systematically. The surface morphology of various GDLs and GDLs after CLs coating were carried out by field emission scanning electron microscopy (FE-SEM). The current density-voltage characteristics were measured under a high relative humidity (RH) conditions using a small-scale fuel cell with the flow gas of H_2 and O_2 at the cathode and anode, respectively. By the exploration of different hydrophobic GDS with/without MPL coating at the cathode and the anode, the role of GDS on the water management of AEMFC can be understood further. Our result indicates that the best