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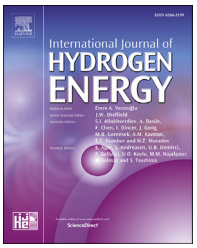

Superhydrophobic PAN nanofibers for gas diffusion layers of proton exchange membrane fuel cells for cathodic water management

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ABSTRACT

Proton exchange membrane (PEM) fuel cells are considered to be promising alternatives to natural resources for generating electricity and various other powers. Optimal water management in the gas diffusion layer (GDL) is critical to the high performance of fuel cells. The basic function of the GDL includes transporting the reactant gas from flow channels to the catalyst effectively, draining liquid water from the catalyst layer to the flow channels, and conducting electrons with low humidity. In this study, poly-acrylonitrile (PAN) was dissolved in a solvent and electrospun at various conditions to produce PAN nanofibers prior to their stabilization at atmospheric pressure at 280 °C for 1 h and carbonization at 850 °C for one more hour. The surface hydrophobicity of the carbonized PAN nanofibers were adjusted using superhydrophobic and hydrophilic agents. The thermal, mechanical, and electrical properties of the new GDLs showed better results than the conventional ones. Water condensation tests (superhydrophobic and hydrophilic) on the surfaces of the GDLs showed a crucial step towards improved water management in fuel cells. This study may open up new possibilities for developing high-performing GDL materials for future PEM fuel cell applications.

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Introduction

General background

Proton exchange membrane fuel cells (PEMFCs), also known as polymer electrolyte membrane fuel cells, use a proton-conducting polymer membrane with platinum-based electrodes for their electrolytes [1]. One of the key parameters of PEMFCs is that they have a high energy density and low operating temperature, which generally ranges from 60 °C to 100 °C. They are considered to be the main types of fuel cells used in most applications. The proton-conducting membrane is a thin sheet of plastic that allows only hydrogen ions to pass through and is coated on both sides with highly dispersed metallic particles made up of platinum nanoparticles, which act as catalyst for hydrogen splitting [1].

A typical PEM fuel cell still contains an anode, cathode, electrolyte, and catalyst. The important part of this fuel cell is the membrane electrode assembly (MEA), which consists of a proton exchange membrane with a layer of catalyst on both sides and a gas diffusion layer (GDL) in contact with the

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catalyst layer. The GDL is one of the critical parts of a fuel cell and has the capability to influence the H_2/air system, because its basic functions are transporting the reactant gas from flow channels to the catalyst effectively, draining liquid water from the catalyst layer to the flow channels, and conducting electrons with low humidity [2]. In proton exchange membrane fuel cells, the GDL allows water to be transferred from the electrode interface into the gas flow passages where it drains out of the fuel cell. Due to the porous property of the GDL, one of its functions is to permit the flow of reactant gases to the electrolyte interface and remove excess water from the catalyst layer [2].

When liquid water accumulates in the GDL, the gas transport from the gas flow channel to the catalyst layer is obstructed, which in turn reduces the power outcome from the fuel. The problem of liquid water is especially acute at the cathode, where water is formed in a catalyst layer at the electrode interface. At high current densities, water accumulation at the cathode prevents oxygen from entering the electrode, and builds up and limits the amount of current density [3].

The ideal GDL allows for water removal from the electrode without obstructing gas transportation. Also, the GDL should be electrically conductive so that it can move electrons between conductors of the flow channel and the catalyst layer. The GDL is both a porous media as well as electrically conductive in order to allow gas flow to the electrode and to provide the required amount of current for the operation of the fuel cell. In order to fulfill these requirements, the GDL should have a high porosity of 50–90% water repellency, high electrical conductivity, and pore size of at least 20–40 μm [4,5]. In some types of fuel cells, such as phosphoric acid fuel cells and alkaline fuel cells, the GDL material is modelled in such a way that it holds the electrolyte between the electrodes. To achieve this property, the carbon GDL is treated with hydrophobic agents to prevent the water from entering through the pores of the GDL and to avoid flooding the flow channels. This accumulated water on the electrolytes is removed either by vaporization throughout the gas flow channels or by a circulation process involving the electrolyte and vaporization of the water. When the GDL is made of a hydrophilic material, water will condense in the layer and hinder the diffusion of oxygen to the cathode/electrolyte interface. However, if the membrane is hydrophobic, then it inhibits water from entering the GDL and the accumulation of water occurs at the catalyst membrane. The chance of absorbing the water into the membrane is very high, which will cause the membrane to swell. Membrane swelling can compress the GDL, thus building sufficient pressure to thrust the water through the hydrophobic pores [5].

The performance of PEMFCs is strongly influenced by interdependent properties of the GDL, such as water management, porosity, and graded structure. The GDL should possess both hydrophobicity and hydrophilicity properties, balanced carefully to ensure that the fuel cell system works without flooding and high humidity. Generally, the GDL is frequently used in combination with the catalyst layer of a MEA and is composed of highly porous and electrically conducting materials, such as carbon cloth, carbon felt or carbon paper. It mainly functions to provide diffusion paths through which reaction gases reach the catalyst layers, thus providing routes for discharge of the water generated at the catalyst layer. This will physically preserve and stabilize the MEA to prevent its swelling over time and supply thermal exchange paths through which heat generated by the electrochemical reaction of the catalyst layer exits [4–8].

Recent progress in GDLs

Extensive research has been performed to improve the GDL and MEA of the fuel cell in order to improve cell performance and to examine the effective diffusivity of the unsaturated and partially saturated GDLs comprising various coatings of polytetrafluoroethylene (PTFE) [6,7]. Yoon and Park [2] enhanced the hydrophobicity of the GDL using a novel coating process. Instead of using PTFE, they coated the GDL with a heptadecafluoro-1, 1, 2, 2-tetrahydrodecyl triethoxysilane (HTTS) derivative, which has strong hydrophobic ligands as well as siloxane bonds. The performance of fuel cells shows the HTTS derivative to be superior to the PTFE-coated carbon paper.

Utilization of the Pt/e-CNF electrode was 69%, while that of Pt/XC-72R was 35%, thus showing higher catalytic activity for the Pt/e-CNF. Spernjak et al. [9] examined the effectiveness of various gas diffusion layer materials in removing water away from the cathode and through the flow field over a range of operating conditions. Polarization curves as well as time evolution studies after step changes in the current draw were obtained with simultaneous liquid water visualization within the transparent cell. The level of cathode flow-field flooding under the same operating conditions and cell current was recognized as a criterion for the water-removal capacity of the GDL materials. When compared at the same current density, a higher amount of liquid water in the cathode channel indicated that water had been efficiently removed from the catalyst layer.

Owejan et al. [10] experimented with water accumulation by using a neutron radiography method to obtain two-dimensional distributions of liquid water in operating 50 cm^2 fuel cells. Flow field channels with a hydrophobic coating retain more water, but the distribution of smaller slugs in the channel area improves fuel cell performance at a high current density. The cells constructed using diffusion media with lower in-plane gas permeability tended to retain less water.

Kandlikar et al. [11] investigated the effect of compression resulting in GDL intrusion in individual parallel PEMFC channels and the resulting behavior of the flow distribution. Two methods were used to determine the intrusion: optical measurement in both the in-plane and through-plane directions of the GDL, and an analytical fluid flow model based on individual channel flow rate measurements. Observation showed an uneven distribution of GDL intrusion into the individual parallel channels. Therefore, uneven intrusion distribution, severe flow misdistribution, and increased pressure drop occurrence were analyzed.

Sinha and Wang [12] researched GDL morphology and wetting properties and found that these are essential to obtaining a clear picture of the occurrence of water flooding and to determining ways to control it. A pore network model

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