Journal of Membrane Science 501 (2016) 15–23

Contents lists available at ScienceDirect

Journal of Membrane Science

journal homepage: www.elsevier.com/locate/memsci

SPPO pore-filled composite membranes with electrically aligned ion channels via a lab-scale continuous caster for fuel cells: An optimal DC electric field strength-IEC relationship

Ju-Hyuk Lee, Ju-Young Lee, Jae-Hun Kim, Jiyong Joo, Sandip Maurya, Myounghoon Choun, Jaeyoung Lee, Seung-Hyeon Moon *

School of Environmental Science and Engineering, Gwangju Institute of Science and Technology (GIST), 123 Cheomdan-gwagiro (Oryong-dong), Buk-gu, Gwangju 500-712, Korea

ARTICLE INFO

Article history:
Received 10 July 2015
Received in revised form
14 November 2015
Accepted 19 November 2015
Available online 2 December 2015

Keywords:
Ion exchange membrane
Aligned ion channel
Pore-filling method
Displacement current
Through-plane proton conductivity

ABSTRACT

In this paper, novel composite membranes with electrically aligned ion channels in the thickness direction are presented for fuel cell applications; a fabrication method in the scale-up system and continuous mode is also suggested. The sulfonated poly(2,6-dimethyl-1,4-phenlyene oxide) (SPPO) polymer filled porous polyethylene (ρPE) films were prepared using a lab-scale continuous caster and simultaneously a direct-current (DC) electric field was applied for the alignment of ion channels in SPPO. Importantly, the proton conductivity of aligned-composite membranes with various ion exchange capacities was enhanced by three to five times than the non-aligned SPPO composite membranes. Finally, the optimized aligned composite membranes with the highest transport number were only applied for the fuel cell test. The optimized aligned composite membrane revealed the highest maximum power density than other fabricated composite membranes and Nafion® 115. Especially, the normalized maximum power density for unit conductivity value was introduced to confirm the effects of alignment of ion channels in a practical electrochemical system. The normalized maximum power density for unit conductivity value for the optimized aligned composite membrane was also stood 43% higher than that of Nafion® 212. According to all properties in this study, understanding the technique of alignment the ion channel in composite membranes offers a great possibility for improving the performance of the ion exchange membrane.

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1. Introduction

Proton exchange membranes (PEMs), which not only act as proton conductors but also block electrons, have been considered as a core component of electrochemical systems on the basis of galvanic and electrolytic cells [1,2]. In general, Nafion®, a state-of-the-art sulfonated perfluoropolymer, is most commonly used as PEMs in fuel cell owing to its high power density and high proton conductivity [3]. However, some disadvantages, such as high costs, high methanol permeability, and environmental unfriendliness limit their industrial application [4]. Alternatively, non-fluorinated hydrocarbon polymer, such as sulfonated poly (2,6-dimethyl-1,4-phenylene oxide) (SPPO), sulfonated poly(aryl ether ketone) (SPAEK) [5,6], sulfonated poly(ether ether ketone) (SPEEK) [7,8], and sulfonated polyimide (SPI) [9,10], are considered a more promising material for PEMs than Nafion® as they are less expensive, commercially available, and their structure allows the introduction of ion exchange groups [11–15].

Until now, researchers mainly have focused on the enhancement of proton conductivity in sulfonated hydrocarbon polymer electrolyte by increasing its ion exchange capacity (IEC). However, high IEC polymer electrolytes are prone to excessive swelling under fully hydrated conditions; the dimensional instability of sulfonated hydrocarbon polymer electrolyte induces performance deterioration in the electrochemical system [16–18]. In this way, controlling the swelling as well as the stability of PEMs are the key issues for the fabrication of a high-performance PEMs. In order to reduce excessive swelling of PEMs with high IEC, the pore-filling method is used to suppress swelling in the sulfonated hydrocarbon polymer, which was first introduced by Yamaguchi et al. [19]. In our previous study, we have successfully investigated the end-group cross-linked porous substrate reinforced membrane for its good durability and high power density in polymer electrolyte

* Corresponding author.
E-mail address: shmoon@gist.ac.kr (S.-H. Moon).

http://dx.doi.org/10.1016/j.memsci.2015.11.023
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