Sulfonimide Polyphosphazene-Based Hydrogen/Oxygen Fuel Cell

Serguei. N. Lvov[#], Xiangyang Y. Zhou, Elena Chalkova, and Jamie A. Weston
The Energy Institute &
Department of Energy and Geo-Environmental Engineering

Harry R. Allcock, Michael A. Hofmann, and Catherine M. Ambler
Department of Chemistry

The Pennsylvania State University
University Park, PA 16802, USA

Introduction

Polymer electrolyte membrane fuel cells are efficient electrical power sources. Nafion (DuPont), a perfluorosulfonic acid polymer, is the most widely studied polymeric membrane for fuel cell applications due to its good mechanical properties, chemical stability, and high ionic conductivity. However, Nafion is limited to operating temperatures below 100°C due to tendency of the membrane to dehydrate, resulting in decreased proton conductivity and reduced mechanical stability. Nafion membranes also suffer from high electro-osmotic drag of water as well as high methanol permeability.

To alleviate these problems several approaches have been used to improve Nafion-based MEAs. Polyphosphazene-based proton-exchange membranes are promising materials for use in both H_2/O_2 and direct methanol fuel cells. Polyphosphazenes (POPs) are hybrid inorganic/organic polymers with a **–P=N–** backbone that is particularly stable to free-radical skeletal cleavage reactions. The chemical and physical properties of polyphosphazenes are highly tunable due to the wide array of side groups, which may be incorporated into these polymers. Some of the more thermally and chemically stable polyphosphazenes are the poly(aryloxyphosphazenes). Here we report the performance of a newly developed sulfonimide-functionalized polyphosphazene membrane for use in an H_2/O_2 fuel cell.

Experimental

Sulfonimide polyphosphazene-based MEAs were fabricated in this study. A sulfonimide-functionalized polyphosphazene membrane was synthesized and characterized as described in detail elsewhere [1]. The membrane of 0.01 cm thickness was crosslinked via gamma radiation (40 Mrad). Membrane ion-exchange capacity was 0.99 meq g^{-1}, water swelling was 42%, and proton conductivity was 0.058 S cm^{-1}. Electrodes were prepared by applying an ink, containing Pt on carbon (Vulcan XC-72R), water, an alcohol, and a Nafion solution in a mixture of lower aliphatic alcohols, to ELAT/NC/D5/V2 carbon cloth. The catalyst loading was 0.33 mg cm^{-2} for both the anode and the cathode. The sulfonimide polyphosphazene based MEAs were pressed at elvated temperature and pressure.

For the Nafion based MEA, Nafion 117 (E.I. du Pont de Nemours & Co., Inc.) membranes were pretreated using a common procedure. MEAs were fabricated using direct ink application to the membrane. Ink composition was the same as for the sulfonimide polyphosphazene based MEAs. The Nafion based MEAs were also pressed at high temperature and pressure.

The prepared MEAs were tested in an H_2/O_2 fuel cell that was obtained from Fuel Cell Technologies, Inc. Hydrogen and oxygen were humidified and pre-heated before entering the fuel cell for the 80°C experiments. Flow rates and pressure of gases were monitored. The voltage-current measurements were carried out using an electronic load (Hewlett Packard Co.) and an electrometer (Keithley Instruments, Inc.).

Results and Discussion

The cell voltage and current density of the fuel cell were measured at temperatures of 22 and 80°C [2]. The observed limiting current densities of 1.12 A cm^{-2} and 1.29 A cm^{-2} were found for the sulfonimide polyphosphazene MEA at the ambient and elevated temperatures, respectively. The largest power for the sulfonimide polyphosphazene MEA at 80°C was 0.47 W cm^{-2} and was achieved when hydrogen and oxygen were humidified at 10°C above the fuel cell temperature, which prevented dehydration of the membrane. On the other hand, the greatest power for the MEA at room temperature was 0.36 W cm^{-2} and was obtained without need of humidification. Thus, the maximum power density for the sulfonimide polyphosphazene-based fuel cell was found to be comparable to the home-made Nafion-based MEA as well as to the results of Wilson and Gottesfeld [3] for Nafion 117 based fuel cells. However, the tailorability of the sulfonimide polyphosphazene system permits significant flexibility in possible modifications to the side group structure. This should allow for optimization the MEA preparation process and achievement of a higher fuel cell performance.

Conclusions

Sulfonimide-functionalized polyphosphazenes have been investigated as polymer electrolyte membranes for use in an H_2/O_2 fuel cell. A sulfonimide polyphosphazene-based membrane electrode assembly (MEA) and a Nafion-based MEA with similar catalyst loadings were fabricated and tested within a fuel cell system. The maximum power density for the sulfonimide polyphosphazene MEA was 0.36 W cm^{-2} at 0.87 A cm^{-2} and 22°C, and reached 0.47 W cm^{-2} at 1.29 A cm^{-2} and 80°C. The performance of the sulfonimide polyphosphazene-based H_2/O_2 fuel cell was found to be comparable to that of the Nafion-based fuel cell. Ongoing research is underway to further improve the composition and performance of sulfonimide-functionalized polyphosphazenes and membrane electrode assemblies.

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References

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[#] Corresponding author (814-863-8377, lvov@psu.edu)