Project status: Ongoing

PROJECT FACT SHEET

Inorganic/Polymer Composite Materials for High Temperature PEM Fuel Cells

The Energy Institute • www.energy.psu.edu
College of Earth & Mineral Sciences • Penn State University

Goal

The goal of this program is to develop a polymer electrolyte membrane fuel cell (PEMFC) capable of operating at high temperatures of 120-150 °C and low relative humidity (RH), below 50%. The impetus for developing the higher temperature fuel cells is: (1) faster reaction rates and decrease of the need for noble metal catalysts; (2) greater anode tolerance to CO poisoning; (3) mitigation the cathode "flooding" problem; and (4) creation of a greater driving force for more efficient cooling, particularly in automotive applications.

Team

This research program is an interdisciplinary effort of a team experienced in the fields of high temperature electrochemistry and PEMFCs (The Energy Institute's Electrochemical Laboratory), and a research group experienced in the synthesis of inorganic proton conducting materials (Materials Research Laboratory). The U.S. Department of Energy and Oak Ridge National Laboratory support the implementation of this project at Penn State.

Project Discussion

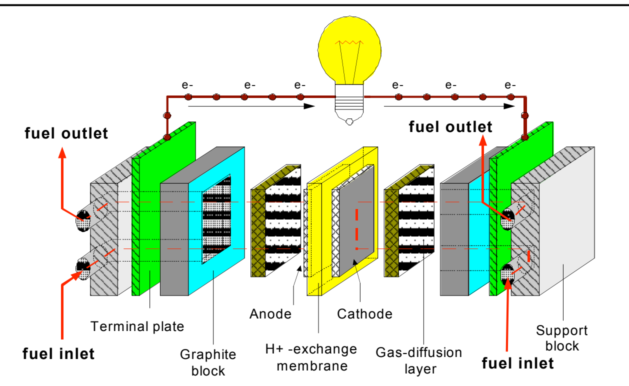
A PEMFC consists of a proton-conducting polymer membrane, sandwiched between two electrodes. The electrodes are in contact with current collectors, which deliver electrons to the external load. Electricity is generated by oxidation of fuel at the anode, which produces electrons, and the reduction of oxygen at the cathode, which consumes electrons.

Current PEMFC technology based on Nafion membranes operating at a typical temperature of 80 °C is limited by the inability of these membranes to operate at elevated temperatures due to severe dehydration. Operating a PEMFC at a higher temperature is highly desirable, particularly for automotive applications. But if a fuel cell is operated at temperatures above 120 °C and under high RH, any efficiency gains reached at these temperatures can be outweighed by the fuel cell pressurization. A possible solution for this problem can be found in the development of membranes capable of operating at elevated temperatures and low RH. To achieve this goal, we pursued extensively the incorporation of proton conductive hydrophilic oxides or framework hydrates into Nafion. They are characterized by high proton conductivity, good water retention properties, and suitably low water solubility. The surface of the inorganic particles can provide the hydrogen-bonding sites for water molecules, and thus prevent water from fast evaporation. As a result, the membrane hydration can be maintained internally without pressurization of the whole PEMFC system.

Background

Creation of new energy conversion devices is a major challenge for sustainable development in our society. The use of fuel cells is a fundamentally different way of generating electrical power from a variety of fuels. The key feature of a fuel cell is its high-energy conversion efficiency. Fuel cells are being developed to potentially replace the internal combustion engines because they are clean, quiet, energy efficient, and fuel-flexible.

According to the President's Hydrogen Fuel Initiative, the USA are spending now about $1.2 billion on hydrogen fuel research to reverse America's growing dependence on foreign oil by developing the technology needed for commercially viable hydrogen-powered fuel cells. DOE established High Temperature Membrane Working Group consisting of government, industry, and university researchers. The goal is to develop high temperature, low RH membrane materials suitable for use in a PEMFC with performance at 120 °C and 25-50% RH exceeding that of Nafion® at 80°C and 100%RH.



BASIC COMPONENTS OF PEMFC

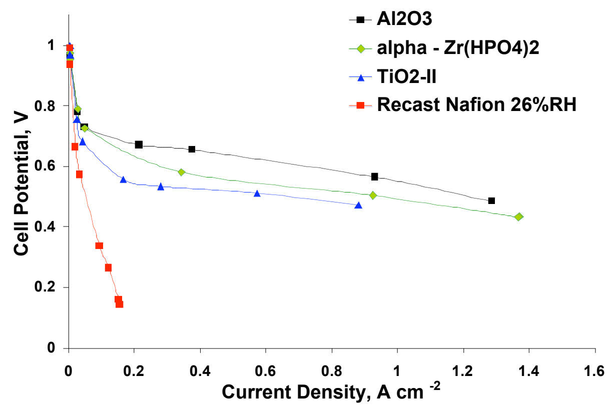
Results

Powders of inorganic additives were synthesized, cleaned, and characterized. A comprehensive experimental and theoretical study of solid nanomaterials for use in composite proton exchange membranes for high temperature PEMFC was conducted. A number of prospective hydrophilic inorganic compounds, including ZrO_2, TiO_2, Al_2O_3, SiO_2, α-$Zr(HPO_4)_2$, and $H_3OZr_2(PO_4)_3$ were analyzed with respect to their acid-base properties. Nafion/inorganic additive composite membranes were fabricated using different techniques and tested in a H_2/O_2 PEM fuel cell over a range of RH from 13 to 100% at temperatures of 80 and 120 °C. The incorporation of selected inorganic additives led to significant improvement of the membrane water retention properties and the PEMFC performance, especially, at low RH.

Effects of TiO_2 content and TiO_2 surface properties such as specific surface area (SSA), morphology, and electrochemical properties on the performance of Nafion/TiO_2 composite membranes in PEMFCs were studied at RHs from 13 to 100% at temperatures of 80 and 120 °C. The Nafion/TiO_2 composite membranes showed a marked improvement over unmodified Nafion membranes when operated at 120 °C and reduced RH. For instance, at 50% RH, the Nafion/20%-TiO_2 membrane demonstrated performance comparable to that of bare Nafion at 80°C.The composite membranes containing TiO_2 with SSA of 15.5 m^2g^{-1} showed a significant advantage over the membranes containing TiO_2 with SSA of 2.9 m^2g^{-1}. Thus, they provided much higher fuel cell performance at 120 °C and reduced RH presumably due to an increased number of hydrophilic sites inside the membrane. The higher zeta potential at TiO_2/water interface is believed to be also an important characteristic responsible for the significant boost of the fuel cell.

Nafion/zirconium phosphate (ZP) composite membranes with ZP of different structures were studied in an H_2/O_2 PEMFC at the same conditions. The incorporation of all types of ZP into Nafion led to significant improvement of the PEMFC performance. The highest performance at 120 °C and reduced RH was demonstrated by Nafion/α-$Zr(HPO_4)_2$ with layered structure. Research on a new type of composite membranes (Nafion/Al_2O_3 membranes) is in progress. In an initial test, these membranes demonstrated performance even higher than that of Nafion/α-$Zr(HPO_4)_2$ membranes.

The observed improvement in the performance of composite membranes is mainly attributed to two factors: (1) enhanced water retention of the new membranes due to hydrophilicity of inorganic particles, which in turn maintains high Nafion conductivity and (2) enhanced proton conductivity of the membranes due to the contribution of the highly protonated surface of inorganic additives.



Performance of H_2/O_2 PEMFC based on Nafion composite membranes with different inorganic additives at 120 °C, 2 bar, and 13% RH.

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Key Publications

E. Chalkova, M.V. Fedkin, D.J. Wesolowski, and S.N. Lvov, J. Electrochem. Soc. 2005, in press.

E. Chalkova, M.B. Pague, M.V. Fedkin, D.J. Wesolowski, and S.N. Lvov, J. Electrochem. Soc. 152, 6, A1035, 2005.

M.V. Fedkin, X.Y. Zhou, J.D. Kubicki, A.V. Bandura, S.N. Lvov, M.L. Machesky D.J. Wesolowski, Langmuir 19, 3797, 2003.

M.V. Fedkin, High Temperature Microelectrophoresis Studies of the Solid Oxide/Water Interface, PhD Thesis, The Pennsylvania State University, 2003.

E. Chalkova, X.Y Zhou, C.M Ambler, M.A Hofmann, J.A Weston, H.R Allcock., and S.N. Lvov, Electrochem. and Solid State Letters, 5, 10, A 221, 2002.