Optimization of Hybrid Fuel Cell Designs and Materials

Fausto Mares-Davila
Chemical Engineering, The University of Arizona

NNIN REU Site: Institute for Electronics & Nanotechnology, Georgia Institute of Technology, Atlanta, GA
NNIN REU Principal Investigator: Dr. Paul Kohl, Chemical and Biomolecular Engineering, Georgia Institute of Technology
NNIN REU Mentor: John Ahlfield, School of Chemical and Biomolecular Engineering, Georgia Institute of Technology
Contact: maresdavila@email.arizona.edu, paul.kohl@chbe.gatech.edu, john.ahlfield@chbe.gatech.edu

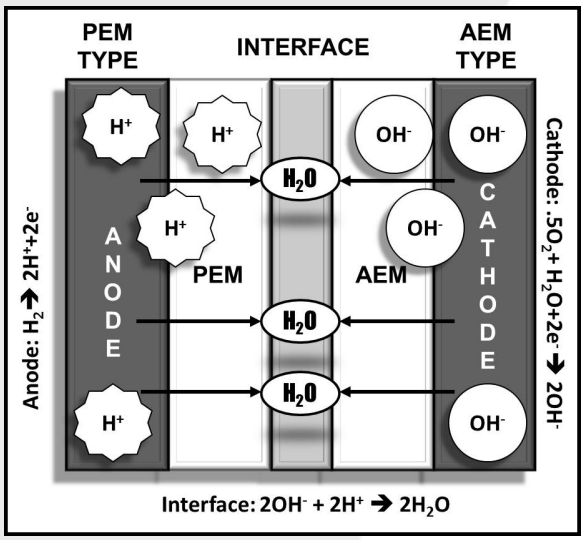

Figure 1: The membrane electrode assembly and hybrid fuel cell electrochemical reactions are shown.

Introduction:

A hybrid fuel cell (HFC) produces electricity by means of an electrochemical reaction. The membrane electrode assembly (MEA) and electrochemical reactions are shown in Figure 1. The hybrid fuel cells studied combine elements from a proton exchange membrane (PEM), which only conducts protons, and an anion exchange membrane (AEM), which only conducts hydroxides. HFCs have the potential to provide quiet, efficient, and zero emissions energy without the need for a water management system. Some problems with HFCs are expensive components such as platinum catalysts, low performance values, and AEMs that are not durable.

The main focus of this research was on the interface material that is positioned between the PEM and AEM in the fuel cell. This region is important because it provides the adhesion between the AEM and PEM, and water is created at this interface when the hydrogen and hydroxide ions combine. Two hybrid fuel cells were assembled with different interface materials. The interface material in HFC 1 was a polymer that interacts with hydrogen and hydroxide ions. The interface material in HFC 2 was a hydroxide conductive ionic liquid. Voltammetry, impedance spectroscopy, and chronoamperometry were the electrochemical analyses performed on both cells to determine which interface material works better.

Experimental Procedure:

The cathodes and anodes were made using the recipe described in the literature, except the AEM cathode was made with toluene instead of dimethylformamide [1]. The material used as the PEM was Nafion® 117 and the material used for the AEM was Tokuyama a201. To assemble the MEA for HFC 1, the electrodes were sprayed with ionomer solution. The PEM was sprayed with neutral epoxy, ionomer interface material, which was made of polynorbornene, Nafion ionomer, and trimethylolpropane triglycidyl ether. The electrodes, PEM, and AEM were then stacked on top of each other in the order shown in Figure 1 and put into the hot press for 10 minutes at 2 MPa and 212°C to bond the layers together.

The same procedure was used to make the MEA of HFC 2 except the PEM was sprayed with ionic [bmim][OH] interface material. During the electrochemical analysis, each fuel cell was connected to a FCT 150S test station and a PARSTAT 2773, which is a combined potentiostat and galvanostat. The fuel cell test station and FC Lab V5.22 software were used to control the fuel cell temperature, relative humidity, and gas flow. The potentiostat was used to perform the voltammetry, impedance spectroscopy, and chronoamperometry. All of the electrochemical analyses were performed at 100% R.H and 55°C. At the anode, hydrogen flowed in at 10 mL/min. At the cathode, oxygen flowed in at a rate of 25 mL/min.

Results:

The voltammetry results for the HFCs are shown in Figure 2. The max current density for HFC 1 was 28 mA/cm^2. The max current density for HFC 2 was 38 mA/cm^2. HFC 1 produced 3.9 mW/cm^2 and HFC 2 generated 5.1 mW/cm^2. The power density indicates how many watts are produced per square centimeter of MEA. Chronoamperometry was performed on each HFC for five hours. The results are shown in Figure 3. HFC 1 produced a steady 0.05 A. HFC 2 produced an initial 0.13 A, then dropped to a steady 0.11 A.

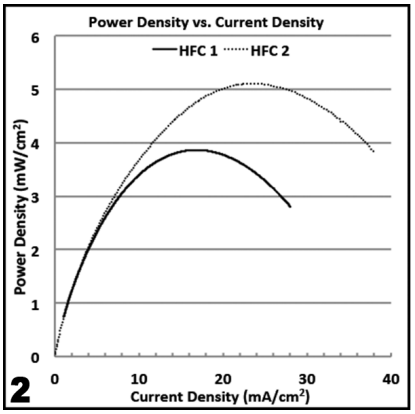

Figure 2: The results of the voltammetry experiment for HFC 1 and 2 are shown.

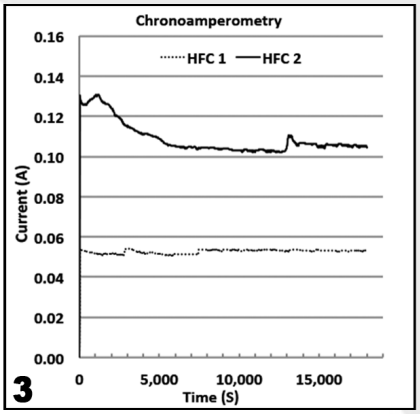

Figure 3: The chronoamperometry results of both HFCs are shown in the graph. The experiment was run for five hours.

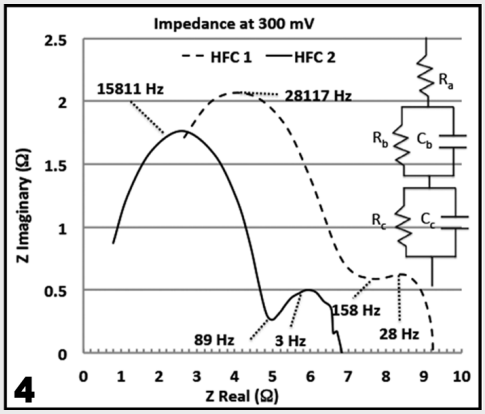

Figure 4: The chart shows the impedance spectroscopy results for both of the HFCs. The HFCs were tested at the same frequencies 0.05 Hz – 88913 Hz. Both HFCs have the same equivalent circuit shown in the graph.

It is believed that HFC 2 generated a large current because it had less resistance than HFC 1. HFC 2's low resistance can be attributed to the conductivity of the [bmim][OH].

Impedance spectroscopy measurements were taken at 300 mV from 0.05 Hz - 88914 Hz. The impedance data is shown in Figure 4. The impedance data shows the membrane, anode, and cathode resistance. The length between the first data point and the y-axis is the membrane resistance in ohms. The radius of the first peak is the anode resistance. The radius of the first valley is the cathode resistance. Both of the HFCs had the same equivalent circuit that is shown in Figure 4. An equivalent circuit may have resistors, capacitors, and inductors, but low testing frequencies eliminated the need for inductors [2]. The equivalent circuit was refined until it produced impedance values that were similar to the experimental values. The equivalent circuit and the impedance data show that HFC 2 has less resistance, which means there is less power loss to resistance.

Conclusions:

Both of the HFCs performed better than previous designs without an interface material. The ionic [bmim][OH] interface material in HFC 2 performed better than the neutral epoxy and ionomer interface material in HFC 1 in all the electrochemical analyses. The impedance spectroscopy data indicates the [bmim][OH] decreases resistance in a HFC. It is believed the [bmim][OH] decreases resistance by conducting the incoming hydroxide ions better than a neutral interface material. The large steady current values and high power density of HFC 2 is a result of less resistance in the interface material.

In the future, it is likely that an HFC with a proton conducting interface material will be tested.

Acknowledgments:

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References:

[1] Murat Ünlü, Junfeng Zhou, Paul A. Kohl. "Hybrid Anion and Proton Exchange Membrane Fuel Cells." The Journal of Physical Chemistry 113.26 (2009): 11416-11423. Print.

[2] Monk, Paul. Fundamentals of Electroanalytical Chemistry. Chichester: John Wiley & Sons Ltd, 2001. Print.