VI.1 Fuel Cell Membrane Electrode Assembly Manufacturing R&D

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- Rensselaer Polytechnic Institute, Troy, NY
- 3M, St. Paul, MN
- Arkema Inc., King of Prussia, PA
- Ballard Materials Products, Lowell, MA
- BASF Fuel Cells, Somerset, NJ
- Johnson Matthey Fuel Cells, Sonning Common, Reading, U.K.
- Proton Energy Systems, Wallingford, CT
- W.L. Gore and Associates, Elkton, MD
- National Institute of Standards and Technology, Gaithersburg, MD

Project Start Date: July 16, 2007
Project End Date: Project continuation and direction determined annually by DOE

Objectives

NREL and its collaborators are developing capabilities and knowledge related to in-line quality control that will assist manufacturers of polymer electrolyte membrane (PEM) fuel cell membrane electrode assembly (MEA) components (membranes, coated electrodes, and gas diffusion media) in transitioning to high-volume manufacturing methods. Our main tasks are to:

- Evaluate and develop in-line diagnostics for MEA component quality control and validate diagnostics in-line.
- Investigate the effects of MEA component manufacturing defects on MEA performance and durability.
- Further refine and validate models to predict the effects of local variations in MEA component properties.

These objectives have strong support from our industry partners. Our specific development activities have been and will continue to be fully informed by direct input from industry. As new technologies emerge and as the needs of the industry change, the directions of this project will be adjusted.

Technical Barriers

This project addresses the following technical barriers, from the Manufacturing R&D section (3.5) of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

(A) Lack of High-Volume Membrane Electrode Assembly (MEA) Processes

(F) Low Levels of Quality Control and Inflexible Processes

Contribution to Achievement of DOE Manufacturing Milestones

This project is contributing to achievement of the following DOE milestones, from the Manufacturing section (3.5) of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- Milestone 1: Develop prototype sensors for quality control of MEA manufacturing. (4Q, 2011)
- Milestone 2: Develop continuous in-line measurement for MEA fabrication. (4Q, 2012)
- Milestone 3: Demonstrate sensors in pilot-scale applications for manufacturing MEAs. (4Q, 2013)
- Milestone 4: Establish models to predict the effect of manufacturing variations on MEA performance. (4Q, 2013)

Accomplishments

NREL has accomplished the following:

- Developed a system and techniques to identify by areal infrared thermography various MEA and MEA component defects, such as membrane pinholes, electrode catalyst non-uniformity, micro-cracks in gas diffusion media, and MEA shorting.
- Extended our membrane thickness imaging technique to non-polyfluorosulfonic acid (PFSA) membranes and PEM electrolysis membranes.
- Installed and commissioned a research web-line to simulate continuous roll-to-roll processing of MEA component materials for evaluation of diagnostics under process-like conditions.

- Demonstrated fabrication methods to repeatably create membrane and electrode defects that simulate real as-manufactured defects to study the effects of defects on MEA performance.
- Used LBNL models to qualitatively explain key behaviors of MEAs with defects and to understand the behavior of MEAs under the different excitation diagnostic techniques.
- Continued collaboration with three of DOE's competitively awarded manufacturing research and development (R&D) projects, in accordance with our project charter.
- Completed work on a Phase I Small Business Innovation Research project with partner Proton Energy Systems related to quality control measurements on PEM electrolyzer MEAs.

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Introduction

In Fiscal Years (FYs) 2005-2007, NREL provided technical support to DOE in developing a new key program activity: Manufacturing R&D for hydrogen and fuel cell technologies. This work included a workshop on manufacturing R&D, which gathered inputs on technical challenges and barriers from the fuel cell industry, and subsequent development of a roadmap for manufacturing R&D. In late FY 2007, NREL initiated a project to assist the fuel cell industry in addressing these barriers, initially focusing on in-line quality control of MEA components. The project is relying on and utilizing the unique and well-established capabilities of NREL's National Center for Photovoltaics for developing and transferring diagnostic and process technology to the manufacturing industry.

Defects in MEA components differ in type and extent depending on the fabrication process used. The effects of these defects also differ, depending on their size, location in the cell relative to the reactant flow-field, cell operating conditions, and which component contains the defect. Understanding the effects of these different kinds of defects is necessary to be able to specify and/or develop diagnostic systems with the accuracy and data acquisition/processing rates required for the speed and size scales of high-volume continuous manufacturing methods. Furthermore, predictive capabilities for manufacturers are critical to assist in the development of transfer functions and to enable assessment of the effects of material and process changes.

Approach

NREL and its partners are addressing the DOE Manufacturing milestones listed previously by evaluating, developing, and validating (in-line) diagnostics that will support the use of high-volume manufacturing processes for the production of MEA component materials. Prioritization of this work is based on inputs from our industry partners on critical manufacturing quality control needs. We are focusing on diagnostic capabilities not addressed by commercially-available in-line systems. Understanding that specification of the required accuracy and precision of a diagnostic device to measure or identify material property variability or defects requires information about how this variability affects the functionality of the MEA, we are developing test methodologies to identify threshold values of size and/or extent of each important type of variability or defect. Threshold values are being elucidated by statistically designed experiments using MEA components with created defects of defined size or extent. These results will be validated by MEAs with components having actual as-manufactured defects of similar scale. Key behaviors identified by these tests are being modeled to provide additional understanding and, where modeling capabilities are lacking, additional refinement will be made so that predictive capabilities for the identified effects of defects are developed.

Results

Work continued on the NREL-developed optical instrument. We extended the demonstrated capability to image thickness and identify defects of PFSA-based membranes, non-PFSA membranes, and thicker membranes for applications such as direct methanol fuel cells and PEM electrolyzers, an example of which is given in Figure 1. We also progressed in our assessment of using this same general technique to measure catalyst uniformity in an areal fashion. In addition to this optical platform, we evaluated the feasibility of using infrared thermography as a rapid method to check for MEA and MEA component defects. Using work done by several of our industry partners as a basis, we further developed and refined the excitation methods for a variety of target MEA defects. We also assessed the response time of the technique to better understand how it might be applied to in-line process measurements. As examples of the potential of this technique, Figure 2 shows the identification of a void in an electrode coating, and Figure 3 shows the identification of a micro-crack in the microporous layer of gas diffusion media. The inset in Figure 3 shows an LBNL simulation of this defect modeled as a series of discontinuities of thermal and electrical conductivity. With this modeling, we can better understand how to optimize the measurement technique for in-line use. The electrode sample depicted in Figure 2 also is an example of our work to develop fabrication methods for MEA component defects. In this case, we used ultrasonic spraying as a highly repeatable process with excellent control of spray pattern and catalyst loading. The inset graphic

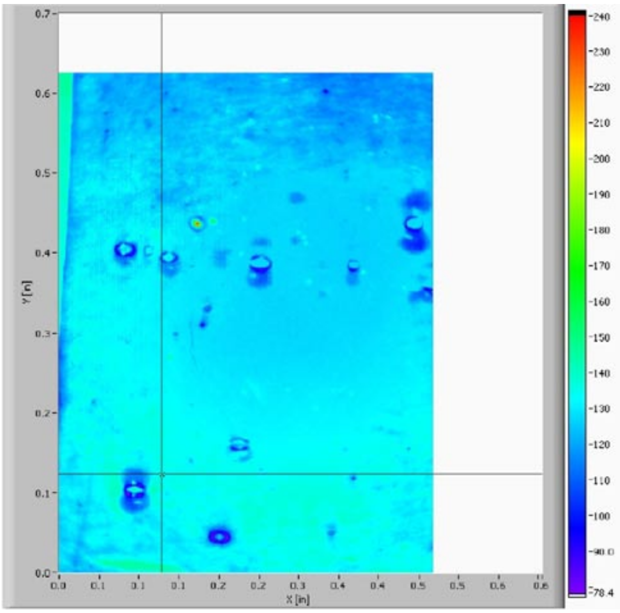

FIGURE 1. Two-dimensional image of an alternate membrane material measured with the NREL optical instrument. The image shows bubble and pinhole defects as well as thickness variations (color contrast). An area approximately 3″ by 2″ is shown.

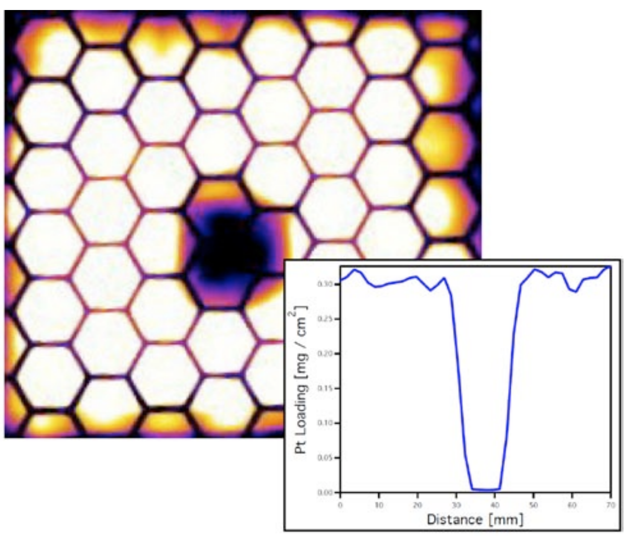

FIGURE 2. Two-dimensional infrared thermography of a 25 cm^2 electrode fabricated with a 1 cm^2 void in the center. White indicates higher loading, dark indicates lower loading, with black signifying the absence of platinum. The inset shows a validation of this measurement using an X-ray fluorescence scan from one edge of the sample to the other, through the void.

is a validation of the intended loading using X-ray fluorescence. To provide a platform upon which to evaluate these and other diagnostics, we installed and commissioned a research web-line, shown in Figure 4. With this unique capability, and using MEA component roll goods from our industry partners, we will assess

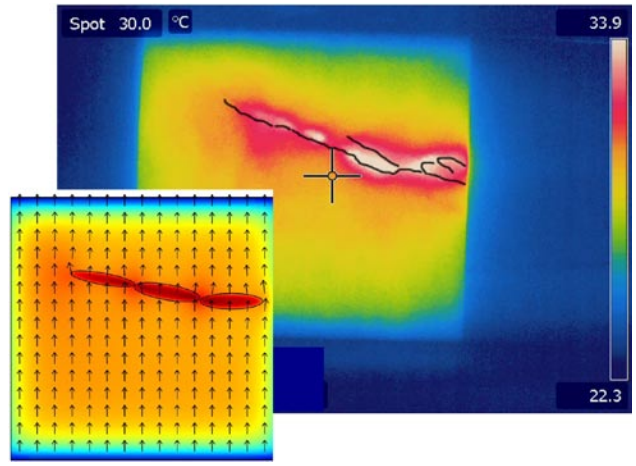

FIGURE 3. Two-dimensional infrared thermography of a commercially-available gas-diffusion layer with a series of micro-cracks in the microporous layer. The inset shows modeling from LBNL simulating this defect as a discontinuity in thermal and electrical conductivity.

FIGURE 4. The Research Web-Line

the accuracy, repeatability, and resolution of different diagnostic techniques under conditions simulating manufacturing process lines.

Future Direction

- Design a prototype in-line configuration for the membrane thickness imaging technique and implement this system on our research web-line.
- Evaluate the feasibility of using infrared thermography as an in-line imaging diagnostic and develop a prototype system to install on the research web-line.
- Complete our evaluation of the NREL-developed optical instrument to measure platinum uniformity of electrodes.

- Use single and segmented cell test methods to understand threshold sizes for critical MEA component defects like membrane pinholes and electrode voids.
- Study the growth rates of as-manufactured defects in cells.
- Continue to gain critical insights on the electrochemical and thermal behavior of MEAs with defects from the LBNL MEA models.
- Continue to work with our industry partners to ensure the relevance of our studies to their evolving needs and directions.

FY 2010 Patents

1. U.S. Provisional Patent Application No. 61/297,937 titled "Optical Techniques for Monitoring Continuous Manufacturing of Proton Exchange Membrane Fuel Cell Components."

FY 2010 Publications/Presentations

1. "A Study of the Effects of Polymer Electrolyte Membrane Thickness Defects on Cell Performance," Danielle K. Williams, John R. Berger, Andrew M. Herring, Michael Ulsh, Huyen N. Dinh, 2009 Fuel Cell Seminar, Palm Springs, CA.

2. "Fuel Cell MEA Manufacturing R&D," DOE Fuel Cell Technologies Program Annual Merit Review, June, 2010, Washington, D.C.