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

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- Rensselaer Polytechnic Institute, Troy, NY
- 3M, St. Paul, MN
- Acumentrics, Westwood, MA
- Ballard Material Products, Lowell, MA
- BASF Fuel Cells, Somerset, NJ
- Delphi, Fenton, MI
- General Motors, Honeoye Falls, NY
- Proton OnSite, Wallingford, CT
- Ultra Electronics – Adaptive Materials Inc., Ann Arbor, MI
- W.L. Gore and Associates, Elkton, MD

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

Fiscal Year (FY) 2012 Objectives

NREL and its collaborators are developing capabilities and acquiring knowledge for in-line quality control during fuel cell manufacturing. We are focusing on membrane electrode assemblies (MEAs) and MEA components (membranes, coated electrodes, and gas diffusion media) of polymer electrolyte membrane (PEM) fuel cells, as well as on cast tapes and fired cells of solid oxide fuel cells (SOFCs), in the transition to high-volume manufacturing methods. Our main tasks are to:

- Evaluate and develop in-line diagnostics for cell and component quality control and validate diagnostics in-line.
- Investigate the effects of MEA component manufacturing defects on MEA performance and durability to understand the required performance of diagnostic systems and contribute to the basis of knowledge available to functionally determine manufacturing tolerances for these materials.
- Use established models to predict the effects of local variations in MEA component properties, and integrate modeling of the operational and design characteristics of diagnostic techniques into the design and configuration of in-line measurement systems.

These objectives have strong support from the industry. Specifically, the outcomes of the 2011 NREL/DOE Hydrogen and Fuel Cell Manufacturing R&D Workshop and the Office of Naval Research-funded Manufacturing Fuel Cell Manhattan Project confirmed the importance of continued development of in-line quality control techniques for cell manufacturing. 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's 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 contributes to the achievement of the following DOE milestones from the Manufacturing R&D section (3.5) of the Fuel Cell Technologies Program Multi-Year Research, Development and Demonstration Plan:

- 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).

FY 2012 Accomplishments

- Demonstrated the detection of defects in gas diffusion media (GDM) roll materials at 30 foot per minute (fpm) line speed on NREL's research web-line using our in-plane infrared/direct-current excitation (IR/DC) technique.
- Demonstrated the detection of defects in catalyst-coated membrane (CCM) sheet materials at 30 fpm line speed on NREL's research web-line using our in-plane IR/DC technique.
- Demonstrated the detection of defects in membrane sheet materials at 30 fpm line speed on NREL's research web-line using our optical reflectometry technique.
- Demonstrated the detection of shorting defects in full MEAs at 30 fpm roller speed on NREL's bench-top roller system using our through-plane IR/DC technique.
- Demonstrated detection of surface defects in planar fired SOFC cells on our bench-top motion stage using our optical reflectometry technique.
- Proved the feasibility of using our infrared/reactive flow-through (IR/RFT) technique to detect coating defects in in-house fabricated gas diffusion electrodes (GDEs).
- Performed modeling of IR/RFT process variables and GDE defect size, and integrated modeling results into further improvement of the technique.
- Used segmented cell testing to understand how variability in GDM polytetrafluoroethylene (PTFE) content and defects in CCM catalyst layers affects local (spatially resolved) and total cell performance.
- Continued collaboration with our industry partners, including three of DOE's competitively awarded Manufacturing R&D projects, in accordance with our project charter.

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Introduction

In FY 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 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 above by evaluating, developing, and validating (in-line) diagnostics that will support the use of high-volume manufacturing processes for the production of MEAs and MEA component materials. Prioritization of this work is based on inputs from our industry partners on their critical manufacturing quality control needs. We are focusing on diagnostic capabilities not addressed by commercially available in-line systems; in particular we are evaluating methods to make areal rather than point measurements such that discrete defects can be identified. We are also developing test methodologies to study the effects of the size and/or extent of each important type of variability or defect. These results will assist our industry partners in validating manufacturing tolerances for these materials, ultimately reducing scrap rates and cost, and improving supply chain efficiency. Finally, predictive models are being used at Lawrence Berkeley National Laboratory to understand the operational and design characteristics of diagnostic techniques by simulating the behavior of MEA components in different excitation modes. These results are being fed back to our design effort in configuring the diagnostics for in-line implementation. MEA models are also being utilized to understand the in situ behavior of defect MEAs to guide and further elucidate experiments.

Results

A strong focus of our efforts this year was demonstration of diagnostics on our research web-line. We demonstrated use of the in-plane IR/DC technique for the detection of defects in both GDM (with and without micro-porous layer, MPL) materials and CCM catalyst layers on the web-line. In both cases, we manually created defects using roll and sheet materials provided to us by our industry partners. The defects consisted of a series of scratches from 0.04 to 2.0 cm^2 and a series of surface cuts from 0.5 to 2.0 cm long. Detection was demonstrated at 30 fpm line speed, which is consistent with current manufacturing rates for MEA materials. Figure 1

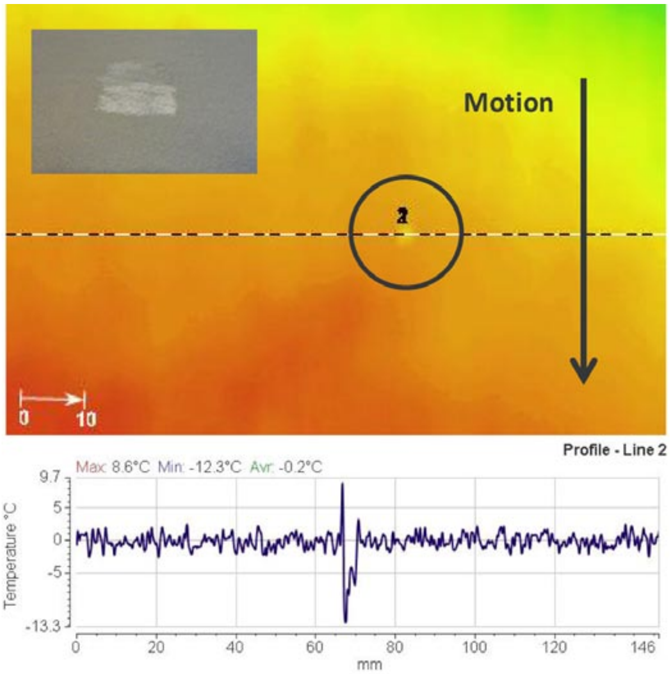

FIGURE 1. Infrared image of a 0.04 cm^2 surface scratch in an MPL (optical micrograph of defect shown in inset) moving at 30 fpm on the web-line, obtained using NREL's in-plane IR/DC technique (top); filtered line data (bottom)

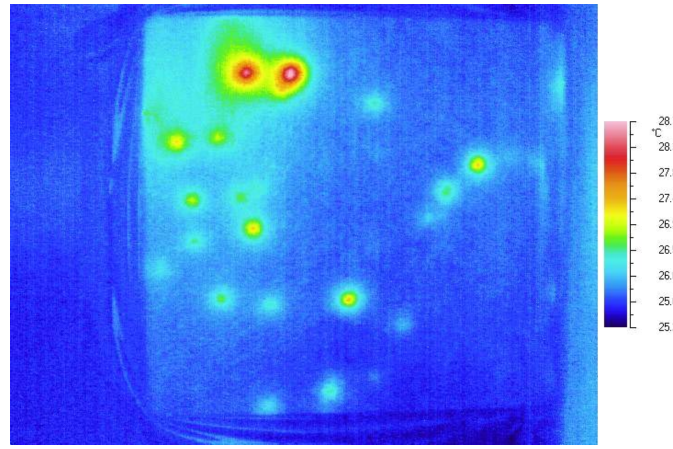

FIGURE 2. Infrared image of an MEA with GDM fibers protruding into the membrane, obtained using NREL's through-plane IR/DC excitation technique. The sample is moving through the roller system at 30 fpm.

is an infrared image showing detection of a small square scratch (top) and the filtered line data along the dotted line in the image (bottom). An optical photograph of the defect is shown in the inset. We also demonstrated use of our optical reflectometry technique to detect membrane defects from 10 to 100 µm. This validation was also performed at 30 fpm line speed.

In more developmental work, we demonstrated that a through-plane, spatially resolved resistivity measurement indicating potential shorting of an MEA can be made on a moving MEA using our bench-top roller system and the IR/DC technique. Figure 2 is an infrared image of an MEA fabricated to have GDM fibers protruding into the membrane. The regions of higher temperature indicate locations of high conductivity through the membrane. In another close industry interaction, we demonstrated that the optical reflectometry technique could be used to identify defects in the electrolyte surface of a planar SOFC cell. Defects as small as 10 µm were detected using our bench-top motion stage. Figure 3 shows a 98 x 154 mm fired half-cell and the zoomed reflectance image of a known defect. We also made progress in the development of our IR/RFT technique. Both experimental and numerical studies improved our understanding of how process variables, GDE materials, and defect size affect the sensitivity of the technique. Finally, various in situ studies were completed or are ongoing exploring the local and overall effects of as-manufactured defects on MEA performance.

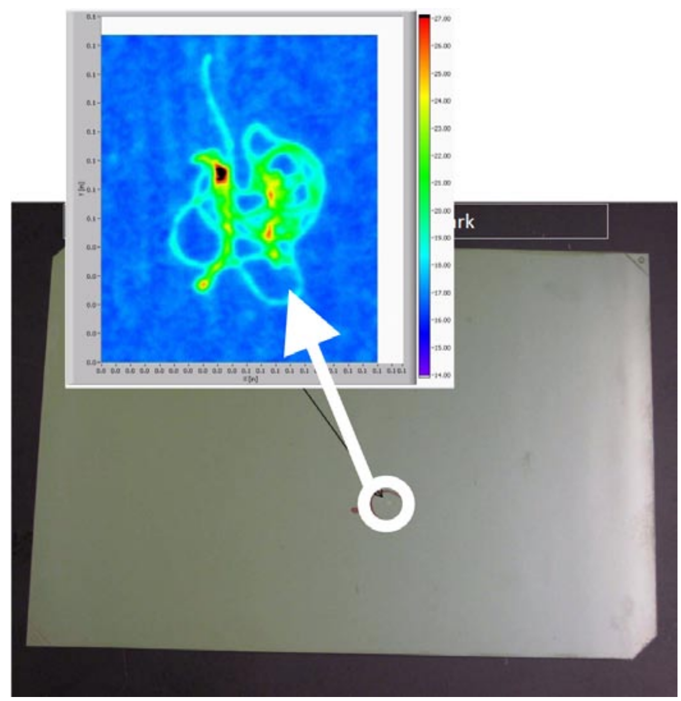

FIGURE 3. SOFC half-cell (bottom) and reflectance image of electrolyte surface defect (top)

Future Directions

- Demonstrate the through-plane IR/DC technique on our bench-top roller system using MEA sheet material provided by our industry partner.
- Determine the feasibility of using the IR/RFT technique in a configuration enabling in-line measurement.
- Determine the feasibility of using optical reflectometry to detect surface defects in SOFC tube cells.

- Continue to use predictive modeling and single and segmented cell test methods to feed requirement and configuration information back to diagnostic development, device design, and detection algorithm assessment.
- Study the effect of as-manufactured defects on MEA lifetime using standard or modified accelerated stress tests.
- Continue to work with our industry partners to ensure the relevance of our studies to their evolving needs and directions, including exploration of new diagnostic techniques.

FY 2012 Publications and Presentations

1. "Fuel Cell MEA Manufacturing R&D," DOE Fuel Cell Technologies Program Annual Merit Review; Washington, D.C.; May 2012.

2. "Applying Infrared Thermography as a Quality-Control Tool for the Rapid Detection of Polymer-Electrolyte-Membrane-Fuel-Cell Catalyst-Layer-Thickness Variations," N.V. Aieta, P. Das, A. Perdue, G. Bender, A. Herring, A. Weber, M. Ulsh; *J. Power Sources*, **211** (2012), p. 4.

3. "2011 NREL/DOE Hydrogen and Fuel Cell Manufacturing R&D Workshop Report," Washington, D.C.; February 2012.

4. "2010 Manufacturing Readiness Assessment of PEM Fuel Cell Systems and Stacks for the Material Handling Equipment and Backup Power Markets," M. Ulsh, D. Wheeler; Fuel Cell Seminar & Exposition; Orlando, FL; November 2011.

5. "Identification of gas diffusion layer PTFE content local anomalies using a segmented cell system," T. Reshetenko, J. St-Pierre, K. Bethune, R. Rocheleau; *ECS Trans.* **41** (1) (2011), p. 539-548.

6. "Spatial performance impact of electrode defects in PEMFC," G. Bender, A. Tsang, N.V. Aieta, A. Perdue, M. Ulsh; National Meeting of the American Chemical Society; Denver, CO; August 2011.

7. "Detecting loading variation in Pt PEMFC electrodes using IR thermography," N.V. Aieta, A. Perdue, P. Das, A. Weber, M. Ulsh; National Meeting of the American Chemical Society; Denver, CO; August 2011.

8. "State of Automation in the Manufacturing of Combined Heat and Power Fuel Cell Systems in the U.S.," M. Ulsh, D. Wheeler, P. Protopappas, N. Garland; 9th ASME Fuel Cell Science, Technology, and Engineering Conference; Washington, DC; August 2011.