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

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Partners
- Lawrence Berkeley National Laboratory (LBNL), Berkeley, CA
- Colorado School of Mines, Golden, CO
- New Jersey Institute of Technology, Newark, NJ
- Automotive Fuel Cell Cooperation, Burnaby, BC, Canada
- General Motors, Pontiac, MI
- Ion Power, New Castle, DE
- W.L. Gore and Associates, Elkton, MD

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

Overall Objectives

- Evaluate and develop inline diagnostics for cell and component quality control and validate diagnostics inline
- Investigate the effects of membrane electrode assembly (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 inline 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, the Office of Naval Research-funded Manufacturing Fuel Cell Manhattan Project, and the 2013 DOE Office of Energy Efficiency & Renewable Energy (EERE) Quality Control Workshop confirmed the importance of continued development of inline 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.

Fiscal Year (FY) 2015 Objectives

- Make a go/no-go decision for further work to transition the through-plane infrared/direct-current (IR/DC) technique for industrially relevant MEA constructions from the benchtop roller system to the web-line
- Make a go/no-go decision for further work to transition through-plane reactive excitation (TPRE) of industrially relevant MEA constructions from an enclosed benchtop system to a system design applicable to the web-line
- Complete upgrades on the optical reflectometry prototype system
- Perform in situ performance and failure studies on MEAs with defined defects

Technical Barriers

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

(A) Lack of High-Volume MEA Processes

(E) Lack of Improved Methods of Final Inspection of MEAs

(H) Low Levels of Quality Control

Contribution to Achievement of DOE Manufacturing R&D Milestones

This project contributes to the achievement of the following DOE milestones from the Manufacturing R&D section (3.5) of the MYRDD Plan:

- Milestone 5.1: Establish models to predict the effect of manufacturing variations on MEA performance. (1Q, 2016)
- Milestone 5.2: Demonstrate improved sensitivity, resolution, and/or detection rate for MEA inspection methods. (4Q, 2016).

FY 2015 Accomplishments

NREL accomplished the following in FY 2015:

- Demonstrated the infrared/reactive impinging flow (IR/RIF) technique on our research web-line, including fabrication of a gas diffusion electrode sheet with defined defects, detection of all defects at web speeds up to 30 fpm, and development of noise reduction strategies to improve defect detection
- Performed modeling of the impinging flow dynamics of the IR/RIF technique to help understand the effects of process variables and configurations and to predict potential process improvements
- Developed automated detection algorithms for optical reflectance detection of membrane and electrode defects
- Further refined the through-plane and in-plane IR/DC techniques and verified their applicability to new industry MEA and subassembly constructions
- Developed improved models for cell performance and utilized these models to predict the effects of electrode layer manufacturing variations on cell performance
- Performed in situ studies of performance effects in cells with as-manufactured and/or created defects
- Designed, built and commissioned a new testbed to study the parametric effects of TPRE of MEAs or subassemblies for the detection of membrane pinholes
- Demonstrated the detection of membrane pinholes at least as small as 150 µm diameter in MEAs and membrane-containing subassemblies using TPRE
- Developed an apparatus and methods for creating pinholes at least as small as 50 µm diameter in membranes and membrane-containing subassemblies with high repeatability
- Continued collaboration with our industry partners 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 that 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 inline quality control of MEA components.

Defects in MEA components differ in type and extent depending on the fabrication process used. The effects of these defects also differ depending on 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 in order 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 tolerances 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 (inline) 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 inline systems; in particular, we are evaluating methods to make areal rather than point measurements such that discrete defects can be identified. We also are 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 LBNL 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 inline implementation. MEA models are also being utilized to understand the in situ behavior of defected MEAs to guide and further elucidate experiments.

RESULTS

Our major milestone for the past year was the demonstration of our IR/RIF technique on our research web-line. In support of this demonstration, we used an ultrasonic spray coating system to fabricate a 3-ft-long section of electrode on a gas diffusion layer/microporous layer sheet having a series of defects ranging in size from 1 cm^2 to 0.0625 cm^2 and with reductions in thickness from 100% (bare spots) to 25%. All of the defects were detected at web speeds of 10 fpm and 30 fpm. Figure 1 shows an example from the data. Additional post-processing was

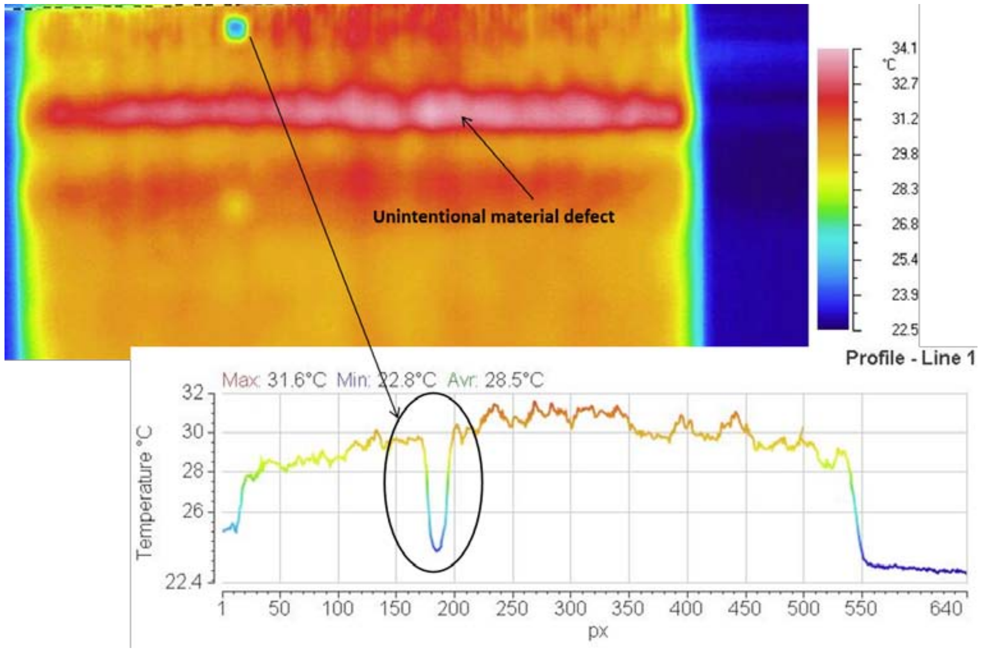

FIGURE 1. IR/RIF data from web-line demonstration, showing detection of a 0.25 cm^2 defect having a 100% reduction in the nominal electrode thickness (a bare spot), at a web speed of 30 fpm. The line graph of cross-web temperature shows the thermal response of this defect. Also shown on the image is indication of an unintentionally created band of thicker electrode coating.

performed to demonstrate the usefulness of a low pass filter to remove high frequency cross web noise in the data and improve sensitivity to small defects. Our partners at LBNL continued to refine their model of the impinging flow configuration, studying detection criteria based on defect size and process parameters, and exploring possible improvements to the technique including different jet array geometries and the addition of a surface behind the gas diffusion electrode (GDE) to increase overall temperature rise for a given excitation. Figure 2 shows the latter modeling result, predicting an increasing temperature differential as the distance between the GDE and the backing surface is decreased.

We completed several optical reflectance studies of GDE and GDE with laminated membrane samples with intentionally created defects in the electrode, including debris particles introduced before and after the electrode coating, pinholes (as small as 150 µm), cuts, scratches, and scuffs in the membrane created before and after lamination of the membrane to the GDE. Figure 3 shows an example of detection of particulates on the GDE surface. All of the defects were successfully detected. In addition, computer algorithms were created to enable automatic detection of these defects during real time post processing of the imaging. The yellow boxes in the image in Figure 3 indicate automated detection of the defects, using the developed algorithm. An associated study was performed to optimize the angle of incident light for these samples.

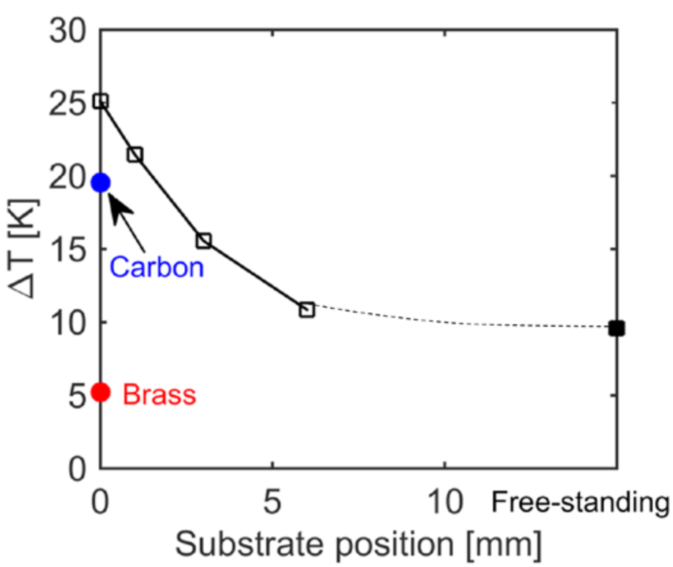

FIGURE 2. IR/RIF modeling result, showing predicted increase in the differential temperature created by a 5 mm electrode bare spot at 10 fpm web speed and 32.5 standard liter per minute jet velocity as a function of backing surface proximity to the back of the GDE.

In preparation for our major milestone at the end of this FY, we designed, built and commissioned a new testbed to study TPRE of MEAs and membrane containing subassemblies for the detection of membrane pinholes. The

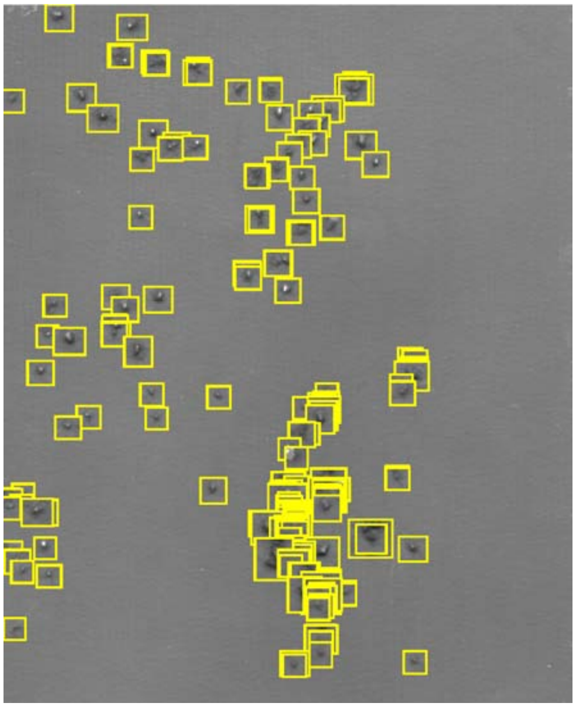

FIGURE 3. Optical reflectance image showing automated detection of particulates on electrode surface of GDE. The individual images of the particles inside the yellow boxes are magnified 10x.

purpose of this testbed is to determine the feasibility of implementing this technique in an inline configuration. As such, the apparatus enables control of reactive gas mixture, flowrate, and exposure time of the sample to the reactive gas. In initial studies, membrane pinholes as small as 150 µm in were detected. In an associated effort, we developed an apparatus and method to create pinholes in membranes and GDEs with laminated membranes with high repeatability. To date, we have been able to create pinholes as small as 50 µm diameter. This technique will be useful for pinhole detection development as well as for in situ studies to understand the effects of pinhole defects.

LBNL used their established cell performance model to perform modeling of electrode defects of different size and location in the cell, and under different operating conditions. These studies continue to guide our experimental in situ work. We continued segmented cell studies of the performance effects of electrode defects, including thin spots and comparison of the effects of defects on the anode vs. on the cathode. Figure 4 gives an example of this work, showing spatially resolved performance data of a MEA with a 1 cm^2 bare spot on the anode. In addition, to support the study of the onset of failure due to defects, we validated an accelerated stress test—based on the development efforts at LANL—that will instigate failure over a period of time.

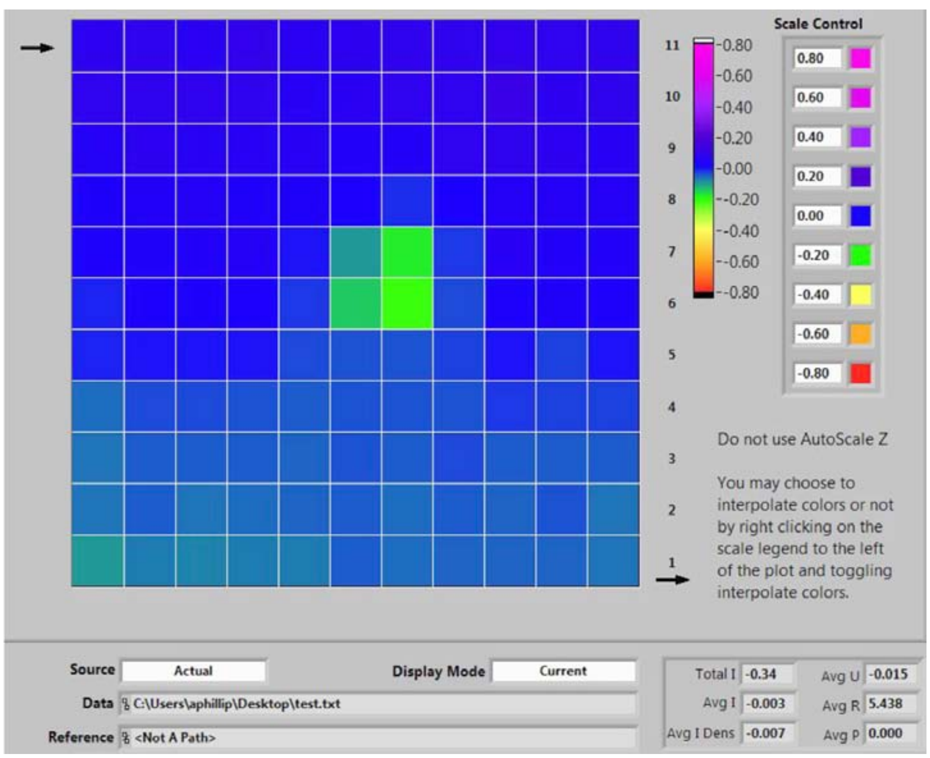

FIGURE 4. Segmented cell data showing the spatially resolved performance effect of a 1 cm^2 bare spot in the anode at a total cell current density of 1.2 A/cm^2. The color scale shows the difference in local current performance between the defected cell and a pristine cell. The cell is operated at anode/cathode conditions of 100/50% relative humidity, 150/150 kPa, 1.5/2.0 stoich, hydrogen/air, and a cell temperature of 80°C.

Based on this work, we will customize a stress test to capture the development of the failure.

FUTURE DIRECTIONS

- Apply our toolbox of techniques to industry-relevant MEA constructions and subassemblies, particularly focusing on near-term commercialization opportunities such as scale up of automotive fuel cells
- Use modeling and experimental studies to refine and improve the performance of the IR/RIF technique for GDE defect detection
- Determine the feasibility of TPRE for web-line implementation
- Continue to use predictive modeling and single and segmented cell test methods to study the effects of as-manufactured defects on MEA performance and lifetime using standard or accelerated stress tests
- Continue to work toward the implementation of more of our techniques on industry production lines

FY 2015 PUBLICATIONS/PRESENTATIONS

1. Rupnowski, P.; Ulsh, M.; Sopori, B. "High Throughput and High Resolution In-line Monitoring of PEMFC Materials by Means of Visible Light Diffuse Reflectance Imaging and Computer Vision," ASME Power and Energy Conversion Conference, San Diego, CA, July, 2015. *PowerEnergy2015-49212*.

2. Ulsh, M. "Fuel Cell MEA Manufacturing R&D," DOE Hydrogen Program Annual Merit Review, Washington, D.C., June, 2015.

3. Ulsh, M. "In-line Quality Control for MEAs," LBNL Energy Technologies Area Seminar, Berkeley, CA, February, 2015.

4. Ulsh, M.; Garland, N. "EERE Quality Control Workshop: Summary and Implications," Fuel Cell Seminar & Exhibition, Los Angeles, CA, November, 2014.

5. Wheeler, D.; Ulsh, M. "Balance of Plant Issues for PEM Fuel Cells," 226th Meeting of the Electrochemical Society, Cancun, Mexico, October, 2014.

6. Wheeler, D.; Ulsh, M. "Manufacturing Readiness and Cost Impacts for PEM Stack and Balance of Plant," *ECS Transactions* (64:3), 2014; pp. 897–908.

7. Ulsh, M. "Fuel Cell Manufacturing R&D," USCAR Fuel Cell Tech Team, Southfield, MI, October, 2014.

8. U.S. Provisional Patent Application 62/130,346, "Batch and Continuous Methods for Evaluating the Physical and Thermal Properties of Thin Films."