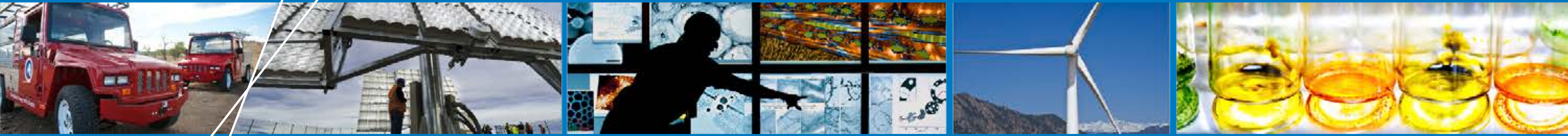
NREL NATIONAL RENEWABLE ENERGY LABORATORY

Fuel Cell MEA Manufacturing R&D



National Renewable Energy Laboratory

Michael Ulsh

May 16, 2012

MN001

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Overview

Timeline

Start: July 2007
End: TBD
% complete: N/A

Budget

Funding received in FY11

- $770,000 (includes $100,000 to LBNL)

Planned funding in FY12

- $575,000 (includes $75K to LBNL)

Barriers

Barrier	Target
B: Cost - fuel cell	$15/kW (2017) at 500,000 stacks/yr
F: Low levels of quality control - manufacturing	50x stack cost reduction

Funded Partners

Lawrence Berkeley National Laboratory
Colorado School of Mines
Hawaii Natural Energy Institute
New Jersey Institute of Technology
DJW Technology

Relevance

	MYRD&DP Milestones
2011	Develop prototype sensors for quality control of MEA manufacturing
2012	Develop continuous in-line measurement of MEA fabrication
2013	Demonstrate sensors in pilot-scale applications for manufacturing MEAs
2013	Establish models to predict the effect of manufacturing variations on MEA performance

	Project Objectives
1	Evaluate and develop in-line diagnostics for MEA component quality control, and validate in-line
2	Investigate the effects of manufacturing defects on MEA performance and durability to understand the accuracy requirements for diagnostics
3	Integrate LBNL modeling to support diagnostic development and implementation

Relevance

- Quality control needs for scale-up of cells and cell component manufacturing confirmed by industry at recent government activities
  - NREL/DOE H_2 & Fuel Cell Manufacturing R&D Workshop, August 2011
  - ONR/ACI/Montana Tech Manufacturing Fuel Cell Manhattan Project, 2010-2011
- Both activities also highlighted the need to better understand the effects of defects on performance and durability of low temperature systems
  - Defines sensitivity requirements for diagnostics
  - Leads toward better production tolerances and lower costs

Collaborations

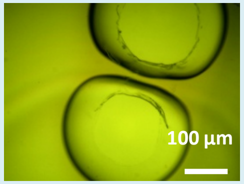
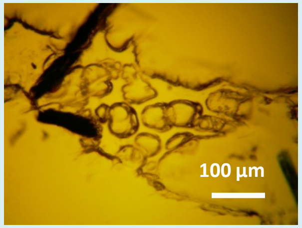
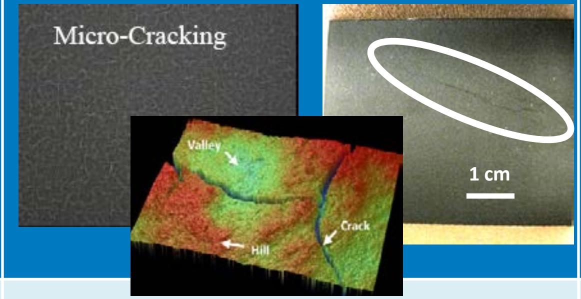
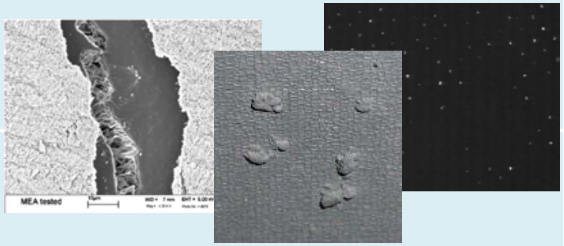
- **3M, Arkema, Ballard Material Products, BASF, Delphi, GM, Johnson-Matthey, W.L. Gore & Associates:** prioritization of diagnostic development, defect selection, sample fabrication
- **NREL National Center for Photovoltaics/New Jersey Institute of Technology**: diagnostics development
- **LBNL**: model development and integration
- **Colorado School of Mines**: diagnostic development, test method development and defect analysis
- **Hawaii Natural Energy Institute**: segmented cell development and defect analysis

Approach

- Understand quality control needs from industry partners and forums
- Develop diagnostics
  - Use modeling to guide development
  - Use in-situ testing to understand the effects of defects
- Validate diagnostics in-line
- Transfer technology

Date	Milestone/Deliverable	Complete
9/11	Demonstrate optical diagnostic for membranes on web-line	100%
9/11	Go/No-go decision for further development of optical diagnostic for platinum measurement → *Conditional No-Go*	100%
6/12	Demonstrate IR/DC diagnostic for CCMs & GDLs on web-line	100%
9/12	Compare model & experiment for IR/RFT and determine critical parameters	25%

Current NREL Diagnostics Overview

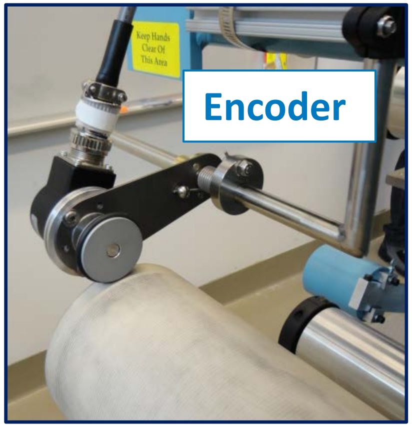
Material	Defect	Examples	Detection	Status
Membrane	Thickness variation, pinholes, bubbles, etc.	 	**Optical reflectometer**	Demonstrated on web-line
GDL	Scratch, agglomerate, fibers		**IR/DC**	Demonstrated on web-line
Electrode	Thickness/ loading, voids, agglomerates		**CCM: IR/DC**	Demonstrated on web-line
			GDE: IR/RFT	Demonstrated on bench-top
MEA	Shorting		**Through-plane IR/DC**	Demonstrated on bench-top with moving substrate

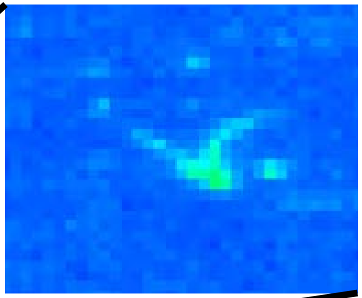
Scope modified according to industry input

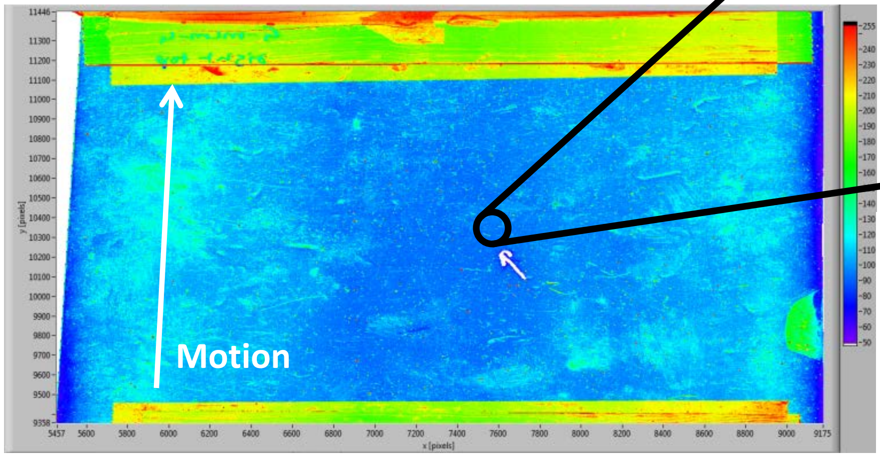
Technical Accomplishments: Optical Diagnostic

Web-line demonstration

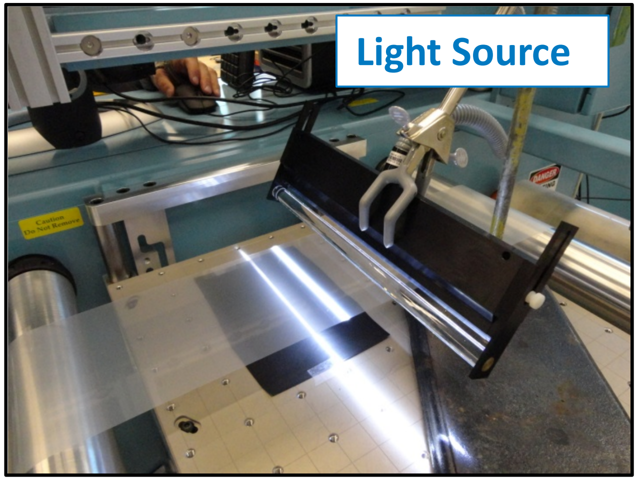
- Thickness imaging, discrete defect detection
- Equipment details
  - Linescan camera (12” field of view)
  - Fiber optic light source with cylindrical lens
  - Encoder for camera timing
  - High performance computer
  - NREL-developed software
- Demonstrated defect detection on PEM membrane at 30 foot per minute
  - Bubbles, scratches, divots
  - Defects ~10-100 µm







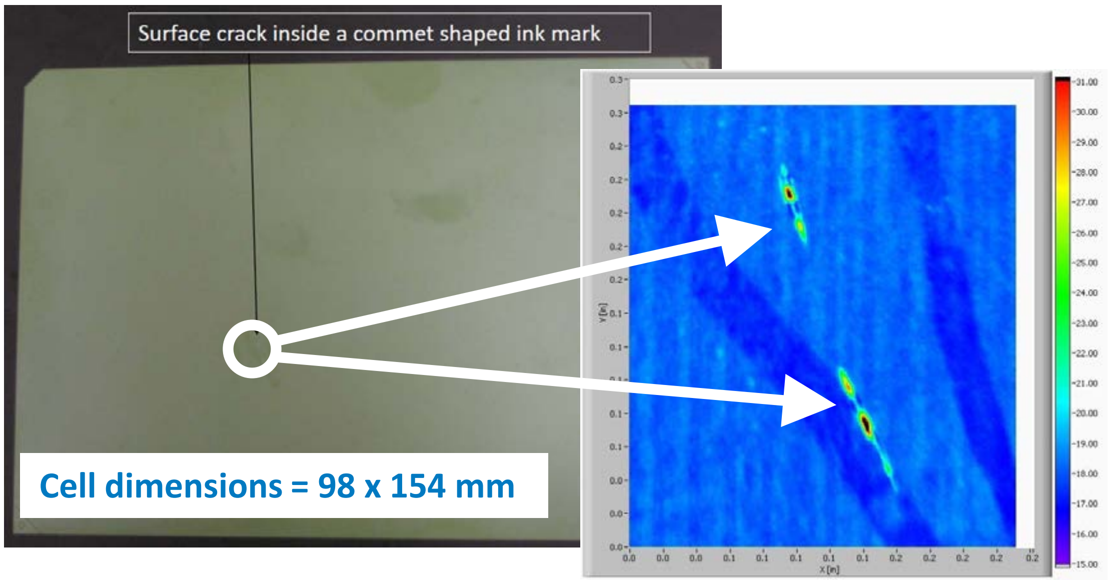
Membrane sample spliced into carrier web, moving at 30 ft/min

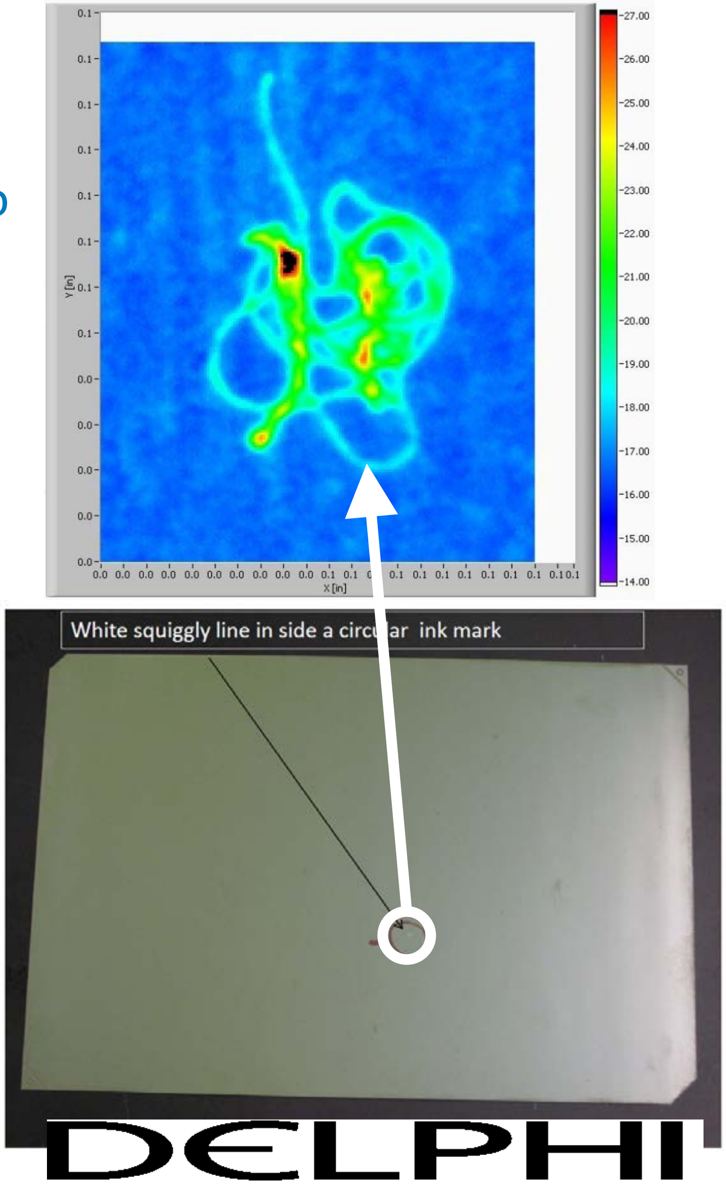


Technical Accomplishments: Optical Diagnostic

Solid oxide cell defect detection

- Detection of electrolyte defects is critical
- Studied fired anode+electrolyte half-cells known to have defects on electrolyte surface
  - 10 µm to 3 mm in dimension
  - Up to ~5 µm depth
- Detected defects with standard equipment setup
  - Applicable to high-rate or in-line measurement

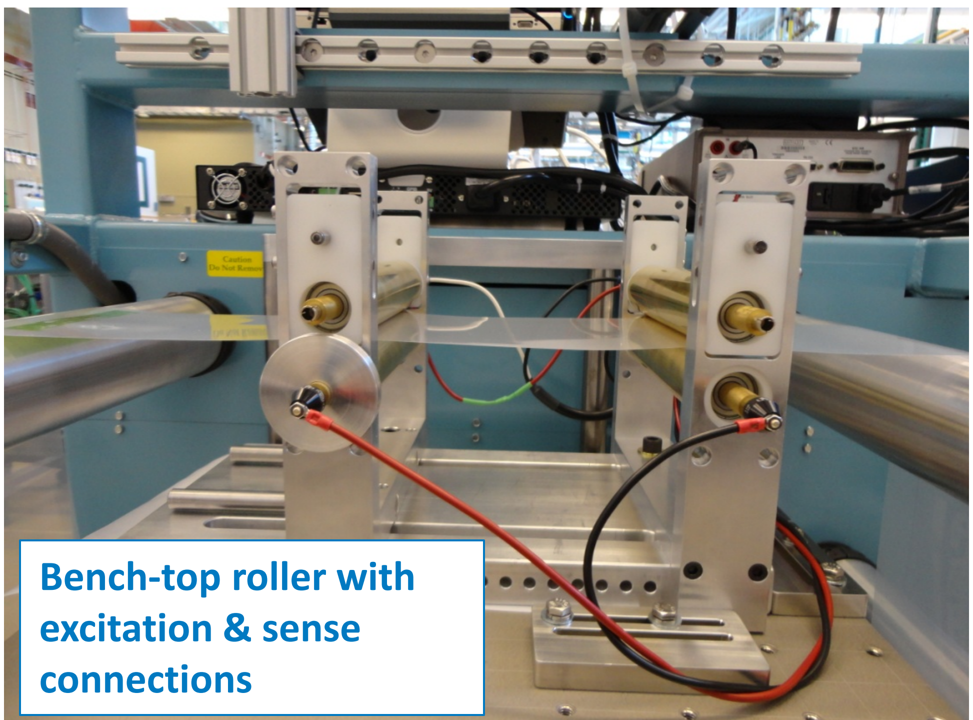




Technical Accomplishments: IR/DC Diagnostic

Web-line set-up

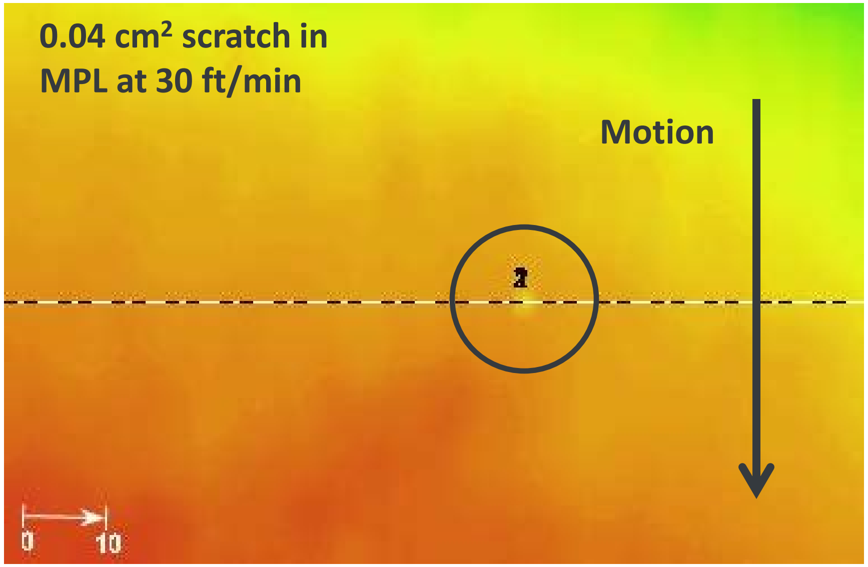
- Installed IR camera, bench-top roller, and excitation source on web-line
- Created defects manually
  - Square scratches from 0.04 – 2 cm^2
  - Surface cuts from 5 – 20 mm long, of different orientation (0°, 45°, 90°)

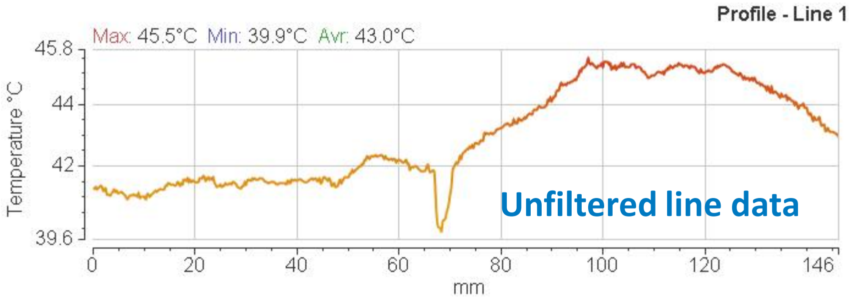


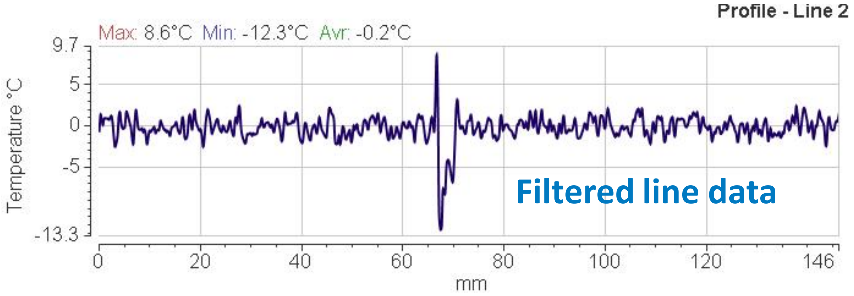
Technical Accomplishments: IR/DC Diagnostic

Web-line demonstration: GDLs

- Used rolls of MPL coated GDL
  - Fabricated by Ballard Material Products
- Ran at **10 and 30 foot per minute**
- Ran at speeds up to 100 foot per minute on bench-top roller
- Nominal detection criteria was ΔT of > 1°C
- Detected all defects
- Data processing enhances detection





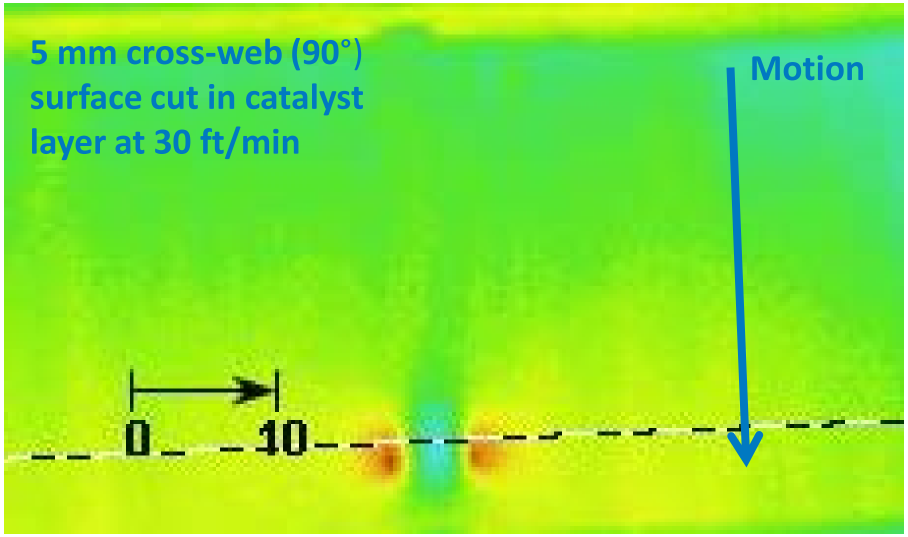


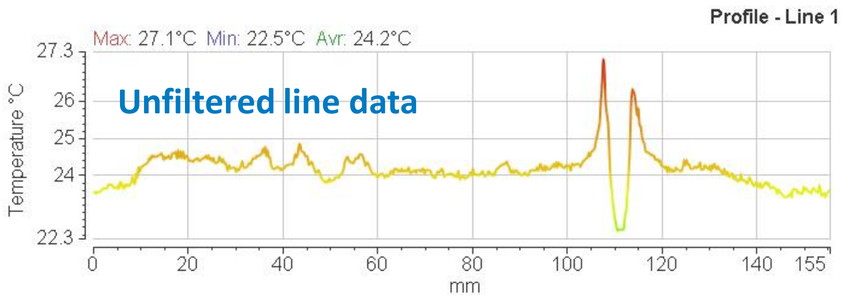
BALLARD

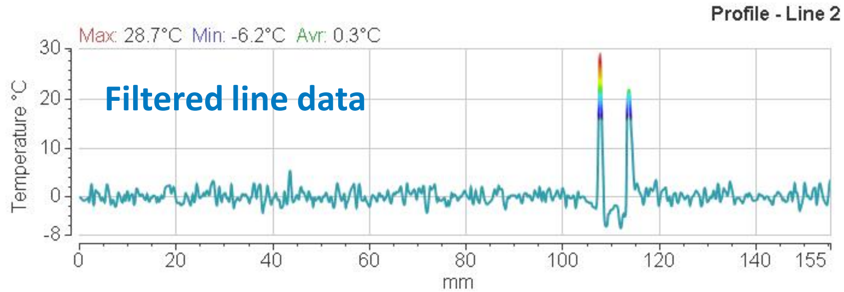
Technical Accomplishments: IR/DC Diagnostic

Web-line demonstration: CCMs

- 2’ x 6” one-side catalyst-coated membrane sheet
  - Fabricated by Ion Power
  - Spliced into PET carrier web
- Ran at **10, 30, and 60 foot per minute**
- Ran at speeds up to 100 foot per minute on bench-top roller
- Nominal detection criteria was ΔT of > 1°C
- Detected all defects except surface cuts in the direction of motion (0°)
  - Improvements under development
  - Data processing enhances detection



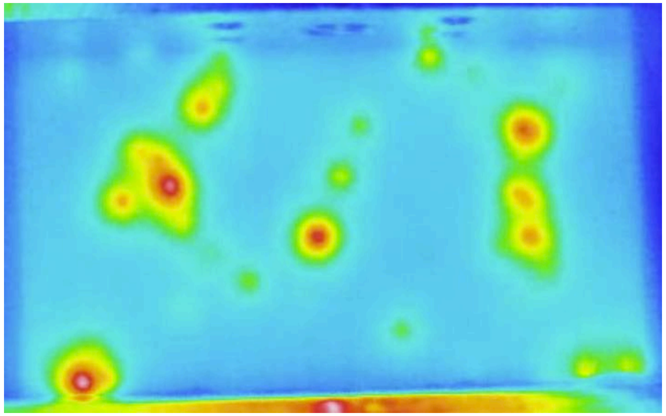




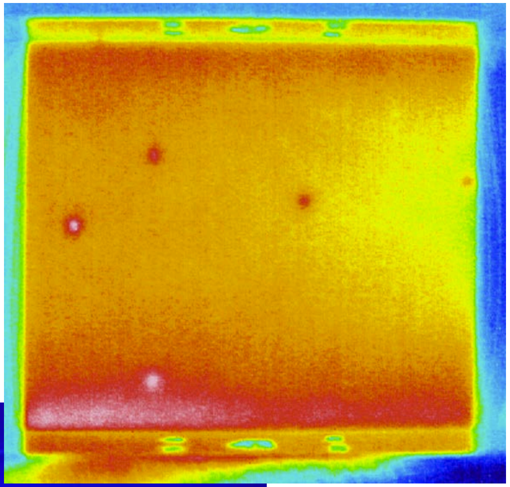
Technical Accomplishments: IR/DC Diagnostic

Demonstration of through-plane measurement for MEA shorts

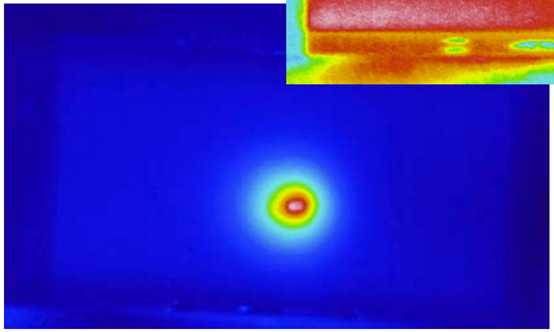
- Studied 50 cm^2 MEAs with optically invisible shorting defects
- Detected various defect types leading to shorting
  - Membrane pinholes
  - GDL fiber protrusion and other surface defects
  - Catalyst agglomerates
- Demonstrated technique on bench-top roller system at speeds of 30 foot per minute and higher
  - Technique promising for high-rate or in-line measurement



GDM fibers



Catalyst layer lumps

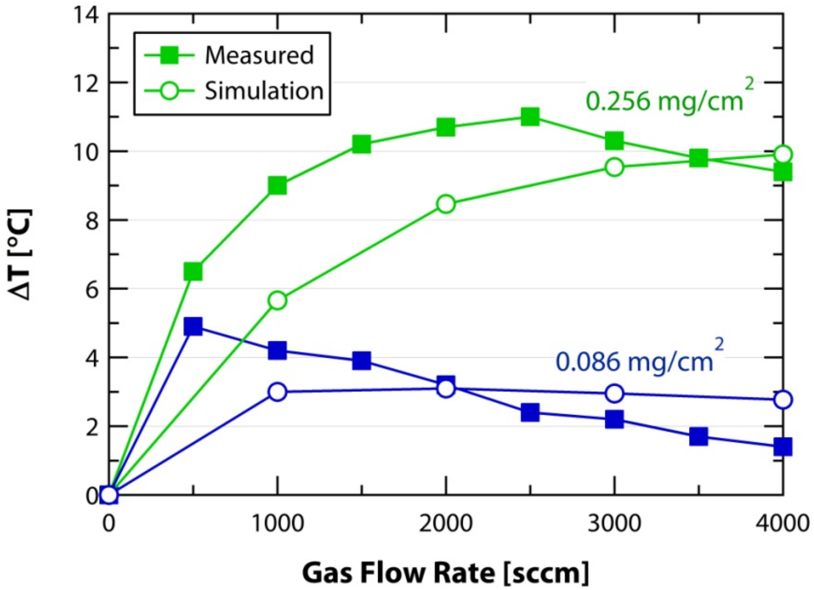


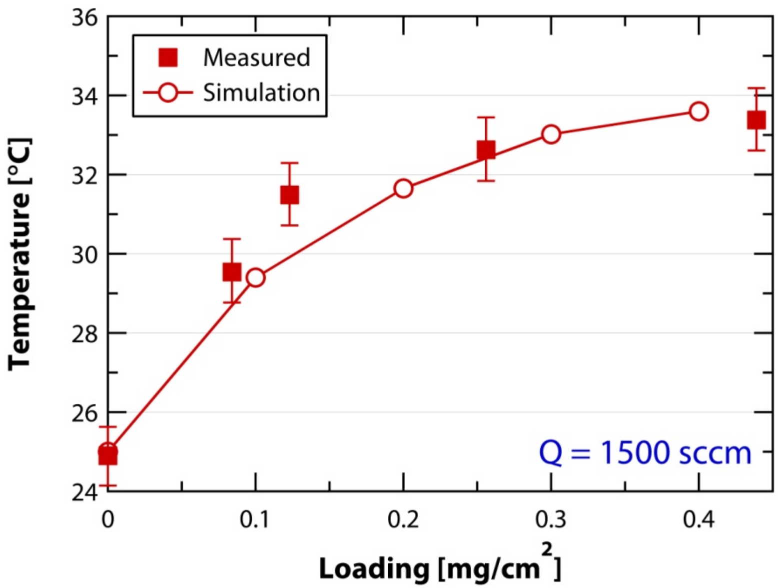
Membrane hole

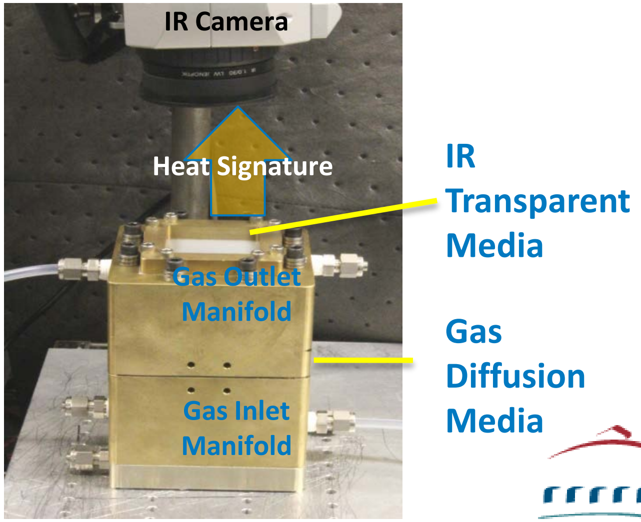
Technical Accomplishments: IR/RFT Diagnostic

IR / Reactive Flow Through technique

- Operation
  - Gas diffusion electrodes (GDE)
  - Flow 0.4% H_2/0.2% O_2 in N_2 through media
  - Measure heat signature with IR camera
- Experimental and numerical studies of pristine samples to understand thermal response
  - Effect of electrode loading
  - Effect of gas flow rate





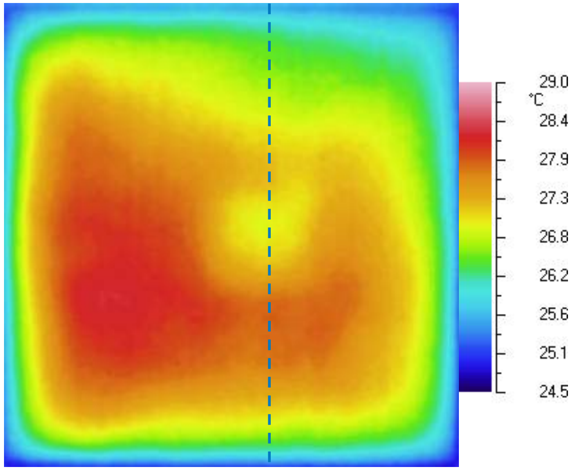


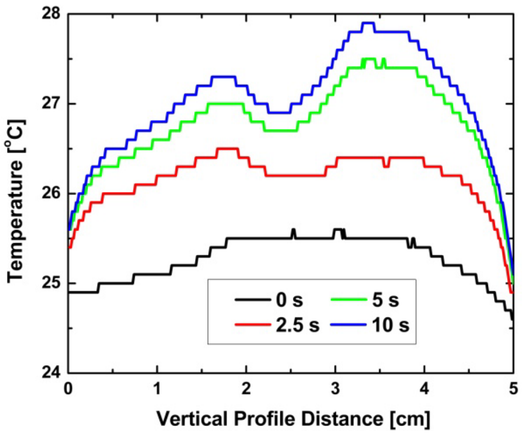
Technical Accomplishments: IR/RFT Diagnostic

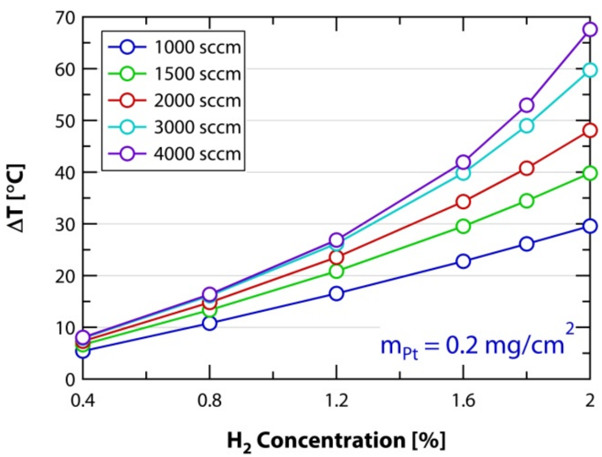
IR / Reactive Flow Through technique

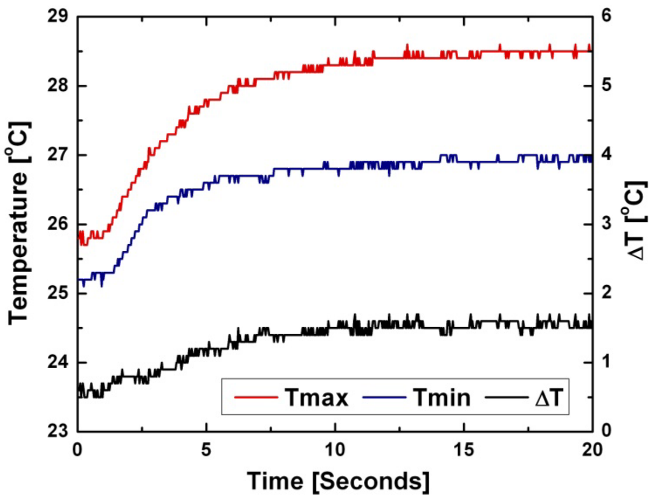
- Experimental and numerical studies of defect samples to understand thermal response
  - Response time
  - Defect size (0.0625 – 2 cm^2) and reduction in loading (25 – 100%)
- Predictive modeling to assess thermal response under other conditions of interest
  - Effect of higher H_2 concentrations & defect reduction in loading
  - Understand limitations of technique
  - Guidance for future experimentation and transition to moving substrates

GDE with 0.2 mg/cm^2 nominal loading and 1 cm^2 defect of 50% loading reduction





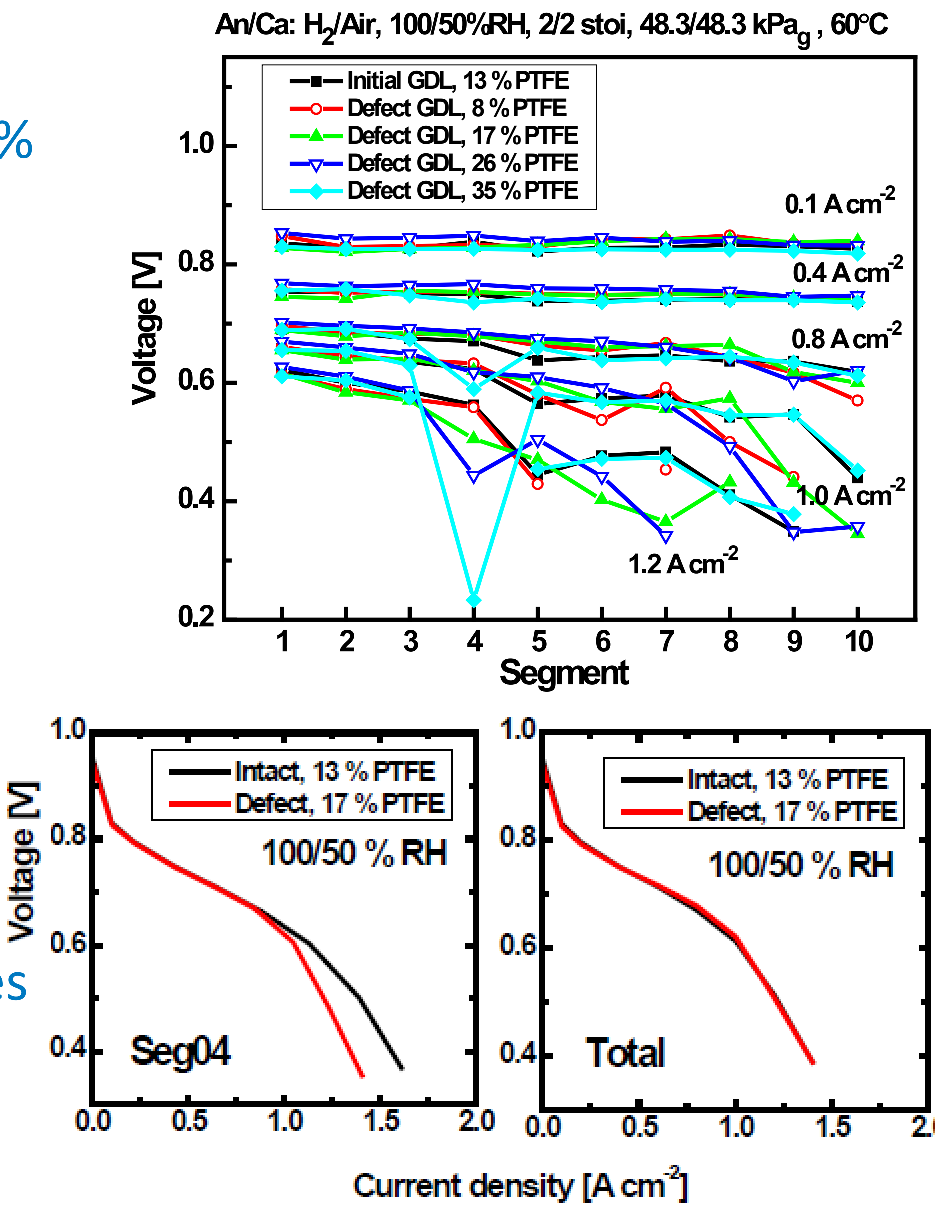




Technical Accomplishments: HNEI Segmented Cell

Segmented cell study of GDL defects

- Question: Is a process tolerance of ±2% of PTFE content sufficient?
- Study: Insert defect over 10% of total cell area
- Results:
  - Local variation in cell performance observed and characterized (indicates need for aging)
  - No difference in total cell performance for a 4% difference in PTFE content
  - Confirmed currently applied manufacturing tolerances
- Implication: Segmented cell is a relevant tool for manufacturing studies



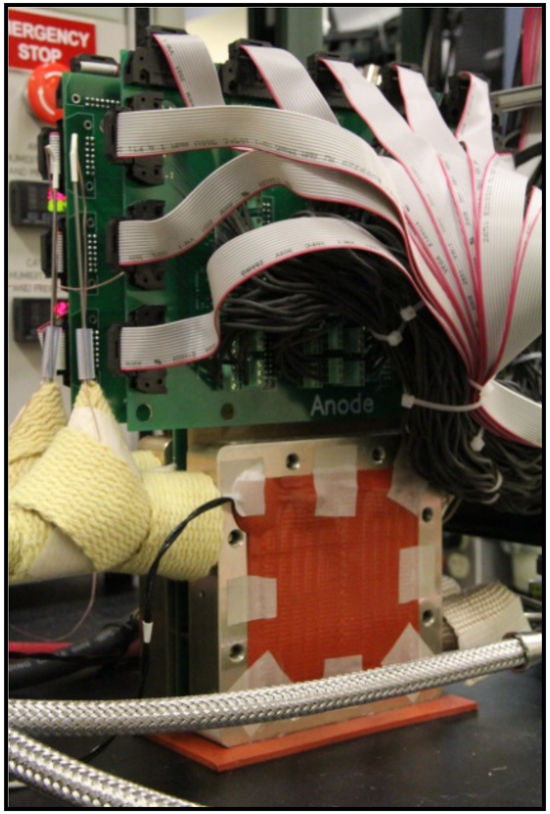
HNEI Hawai'i Natural Energy Institute University of Hawai'i at Mānoa

BALLARD

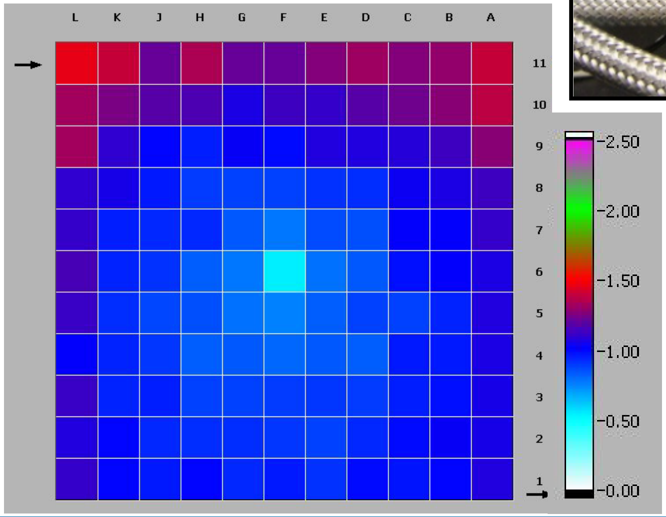
Technical Accomplishments: NREL Segmented Cell

Segmented cell study of electrode defects

- 121 segments over 50 cm^2
- Studied CCMs with square defects fabricated in cathode
  - 0.0625 - 2 cm^2 bare spots
  - 0.2 mg/cm^2 nominal loading
- Demonstrated capability to detect sub-cm^2 electrode defects
- Result: Investigated defects have local performance effects
- Technique enables us to understand the required detection limits of our diagnostics
- Future work will study aging of very small defects to determine if failure points are initiated at the defect location



80°C, 100/50% RH, 1050/3500 sccm H_2/air, 150/150 kPa (an/ca)



Current density plot for 0.5 cm^2 bare spot

Total I	50.49	Avg U	0.584
Avg I	0.417	Avg R	1.400
Avg I Dens	1.010	Avg P	0.244

Future Work

- Continue to refine the configuration and optimize the performance of diagnostics on web-line
- Determine if the IR/RFT diagnostic is feasible for in-line measurement of GDEs
- Prove feasibility of through-plane IR diagnostic on bench-top roller using industrially produced MEA sheets
- Continue to integrate modeling results to support diagnostic development
- Complete electrode defect study using the NREL segmented cell system
  - Identify defect size at which local performance effects are not observed
  - Perform aging studies to determine if failures develop at defect locations
- Assess industry needs and begin to evaluate other diagnostic techniques
- Complete specific partner studies and continue to support the industry
- Complete cost-benefit assessment in collaboration with Strategic Analysis, Inc.

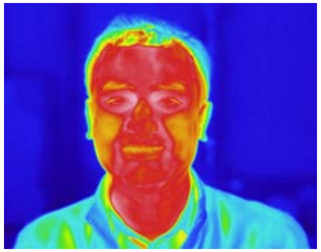
Summary

- Relevance of activity strongly supported by DOE Manufacturing Workshop and DoD Manufacturing Fuel Cell Manhattan Project
- Demonstrated detection of CCM (electrode) and GDL/MPL defects on web-line using continuous webs at speeds of 30 foot per minute and higher
- Demonstrated detection of membrane defects on web-line using continuous webs at speeds of 30 foot per minute and higher
- Demonstrated detection of defects in multi-layer, multi-component membranes
- Demonstrated detection of defects in fired SOFC half-cells
- Demonstrated detection of MEA shorting defects with moving substrates
- Performed experimental and numerical studies to understand sensitivity, detection time, and operating characteristics of the IR/Reactive Flow Through diagnostic
- Completed segmented cell study of GDL PTFE content variability
- Performed segmented cell studies of effects of electrode defects

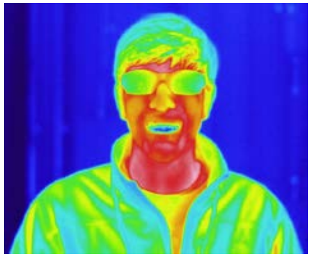
Acknowledgement

NREL
- Mike Ulsh
- Guido Bender
- Huyen Dinh
- Niccolo Aieta
- Bhushan Sopori

LBNL
- Adam Weber
- Prodip Das
- Rohit Pillai



CSM
- Andy Herring
- Austin Manak



NJIT
- Srinivas Devayajanam
- Sudhakar Shet

HNEI
- Jean St-Pierre
- Tatyana Reshetenko

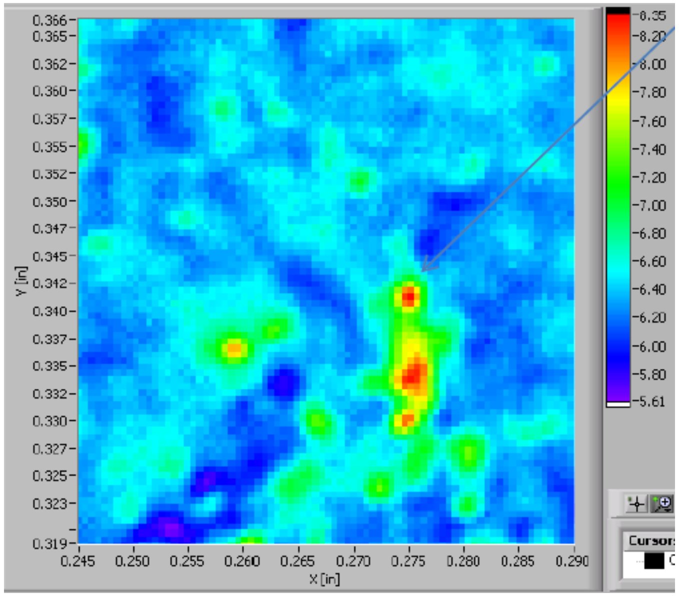
DOE
- Nancy Garland

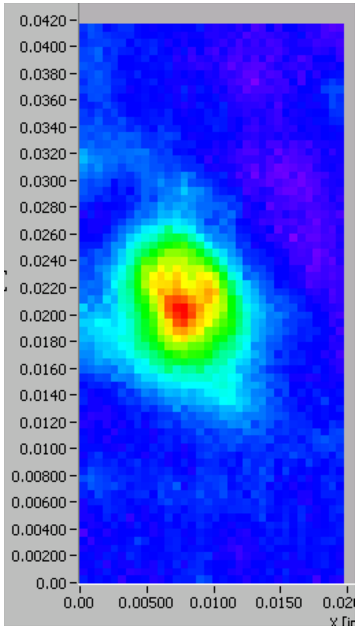
TECHNICAL BACK-UP SLIDES

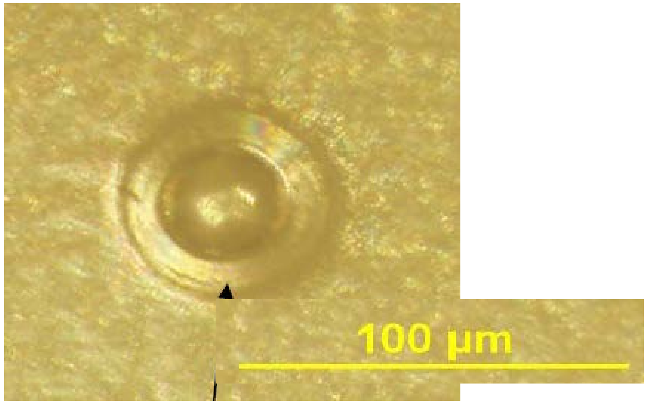
Technical Accomplishments: Optical Diagnostic

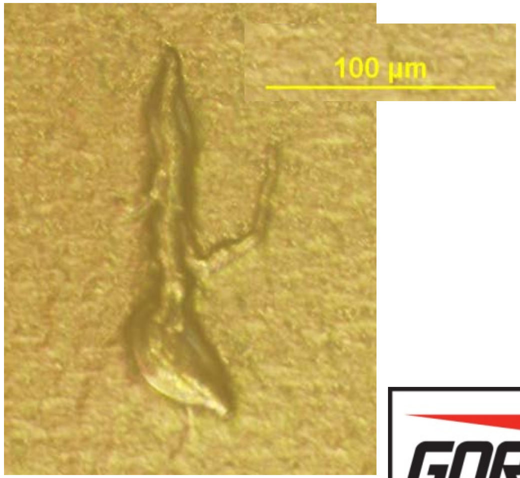
Gore membrane defect detection

- Studied experimental membranes for defect analysis
  - Gore PFSA ionomer + ePTFE reinforcement
  - Defects ~10-100 µm
- Detected defects with standard equipment setup
  - Applicable to high-rate or in-line measurement







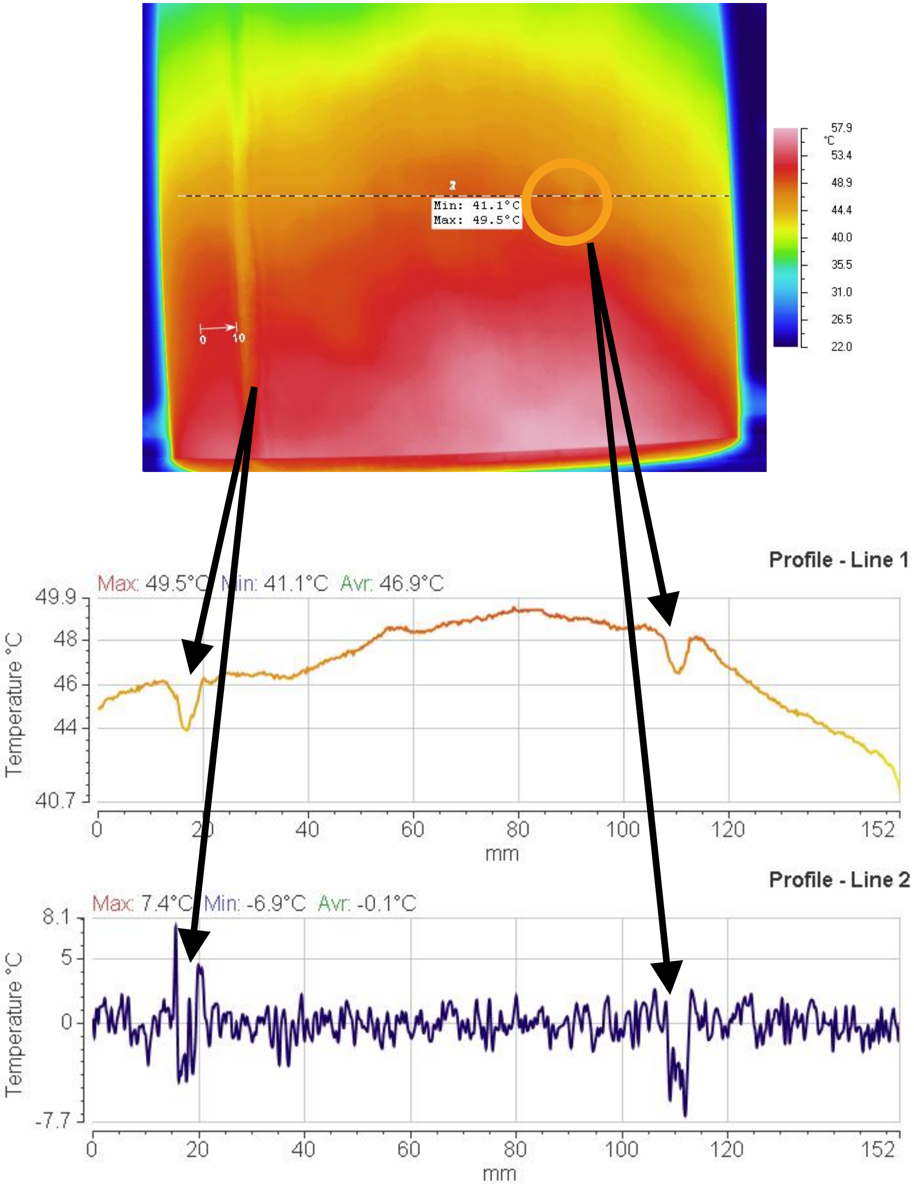


Creative Technologies Worldwide

Technical back-up slides: IR/DC

GDL/MPL defects

- Continuous roll of GDL with multiple MPL coatings
  - Fabricated by Ballard Material Products
  - Streak in first MPL coating, subsequently over-coated by 2nd and 3rd coatings
  - Repeating scratch (“dot”)
- Detected streak defect in first MPL layer on web-line at 10 foot per minute
  - Also detected dots
  - Did not detect streak after over-coating, indicating the streak was leveled or filled by subsequent coats

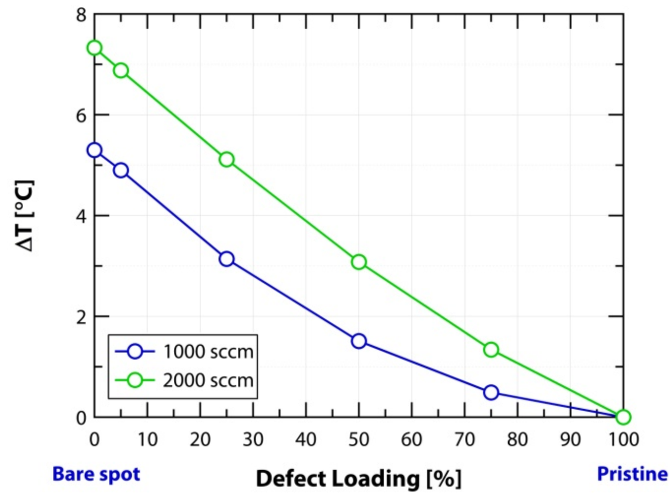


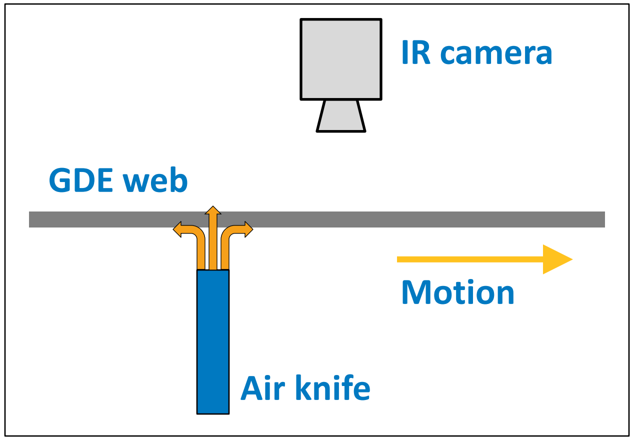
BALLARD

Technical back-up slides: IR/RFT

Electrode Defects

- Response to reduction in defect loading (modeling)
- Response to flowrate as a function of substrate
- Repeatability





IR/RFT web-line concept