High-Resolution/High-Precision PEM Quality Control

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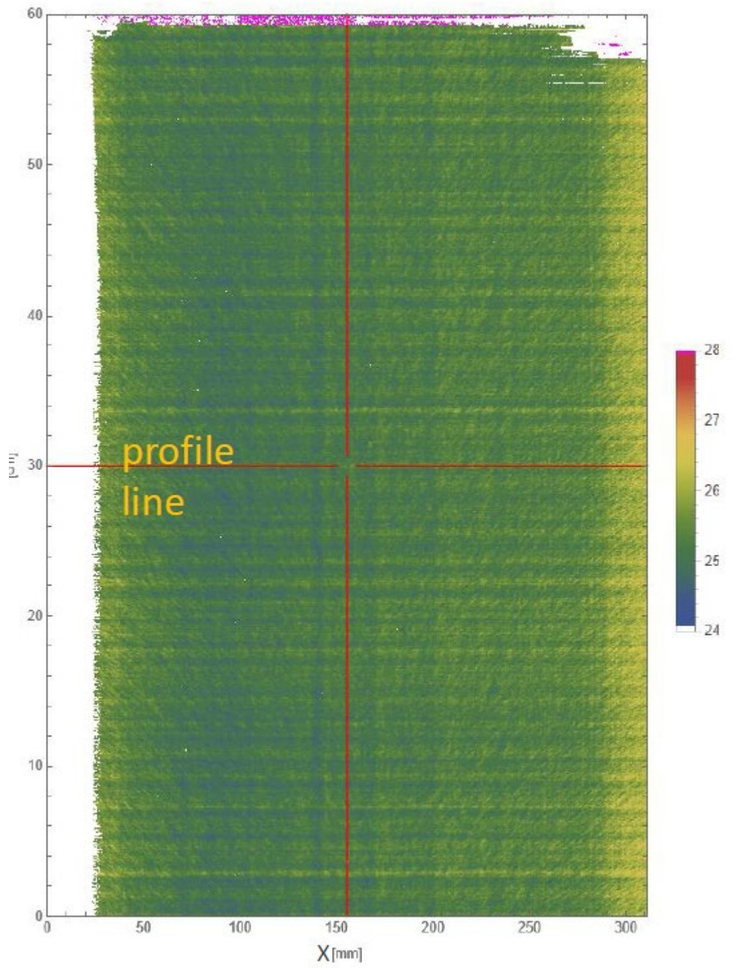
RESONON

Project Goal

Improving measurement capability of fuel cell/electrolyzer membranes at the vendor level may lead to gains in both efficient and durability of the fuel cell/electrolyzer.
Specific project goals:

- Demonstrate that Resonon's commercial hyperspectral imagers can detect thin film interference and produce high-resolution thickness maps of thin membranes.
- Develop a framework for a commercially available thickness mapping system as part of a quality assurance process for membrane manufacturers.



Thickness "map" of Nafion™ NRE212 membrane from Peter Rupnowski, NREL.

Overview

Timeline

- Project Start: June 1st, 2023
- Project End: April 30th, 2024
- No-Cost Extension End Date: September 1, 2024 (In Process)

- ~40% complete*

*As of March 1st, 2024

Budget

- Total Project Budget: $199,900
- Total Recipient Share: $159,400
- Total Contractor Share: $40,500
- Total DOE Funds Spent: $59,818*

*As of March 1st, 2024

Barriers

Thickness mapping creates high data volumes and associated issues:

- For inline QA, fast data processing is required production speeds
- Storage, transfer, and visualization of data products is cumbersome for end users
- Existing technology identifies defects (but not thickness) at higher-speeds/resolution

Partners

- National Renewable Energy Laboratory (NREL) – Peter Rupnowski

Relevance/Potential Impact

Fuel Cells (FCs) and electrolyzers may play a major role in our renewable energy future as a key component in hydrogen production, distribution, and energy storage. Hydrogen-fueled Proton Exchange Membrane (PEM) fuel cells are a leading technology for the decarbonization of propulsion and energy systems.

Key challenges facing the wider spread adoption of PEMFCs include cost, power output, and durability. PEMs are estimated to make up only 10% of total PEMFC cost, however, early failure of PEMFC during operation is often caused by mechanical degradation of the PEM with defects such as cracks, punctures, pinholes and thickness variations counting as significant contributing factors. Thus, improvements in manufacturing quality and Quality Assurance (QA) technology will directly contribute to the durability and affordability of commercial PEMFCs.

PEM thickness is the most fundamental parameter to monitor during coating or extrusion processes. A film thickness “map” with sufficient resolution to detect small defects may enable manufacturers to optimize production methods and improve product quality and uniformity. Therefore, commercializing a film mapping system may allow manufactures to increase the quality of PEM membranes while also reducing cost. The end product would be cheaper, more consistent membranes that could lead to increased longevity in FC and electrolyzer applications.

Approach

The technical approach consists of integrating NREL developed software and algorithms to Resonon's line of commercial hyperspectral imaging systems.

This approach allows:

- Demonstration proof-of-concept with Resonon hardware in a controlled environment.
- Compatibility with multiple sensor types for improving signal/resolution and range materials and thicknesses that can be mapped.
- Provides a framework for implementing a commercial system.
- Extension to films not used for PEM membranes, and other applications where thin film interference can provide thickness mapping.

Key Milestones:

- Develop R&D prototype
  - R&D hardware and software completed.
- Demonstrate thickness mapping proof of concept with Resonon imagers
  - Observation of fringes from sample PEM films complete.
  - Software for real time processing and visualizing thickness maps is currently in process.
- Finalize design plans for prototype system
  - Application space for a prototype system is unknown. Resonon is currently reaching out to distributors and vendors to determine the application space.

Approach: Safety Planning and Culture

Safety Plan

- Required: No
- No safety hazards were identified for this project.

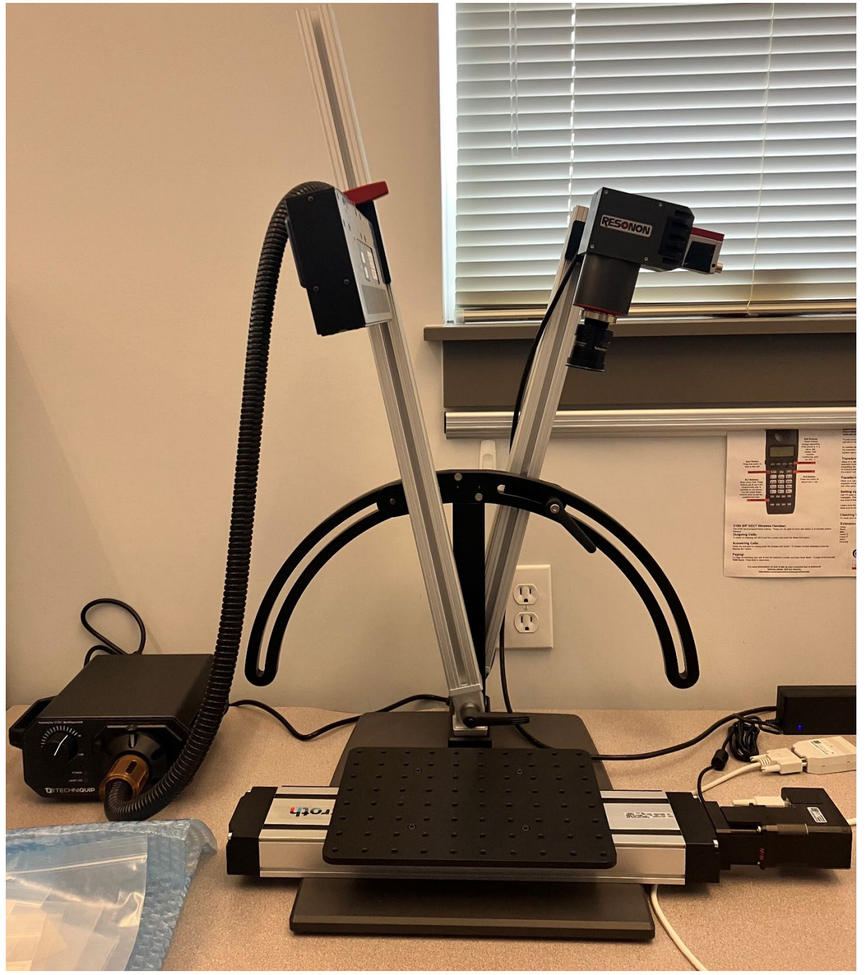
Accomplishments and Progress

Results for New Project (Awarded June 1, 2023):

- Developed R&D prototype
  - System allows scanning films at various lighting incident angles.
  - Compatible with Resonon's entire hyperspectral imager product line (400 nm – 1000 nm and 1000 nm – 1700 nm waveband imagers).

The R&D prototype is the first step in testing and benchmarking the integration of NREL's code with Resonon software and hardware.

The R&D prototype also allows scanning of customer films and membranes.



Thins films R&D prototype scanning system showing linelight and Resonon Pika L UV-VNIR (400 nm – 1000 nm) Hyperspectral imager.

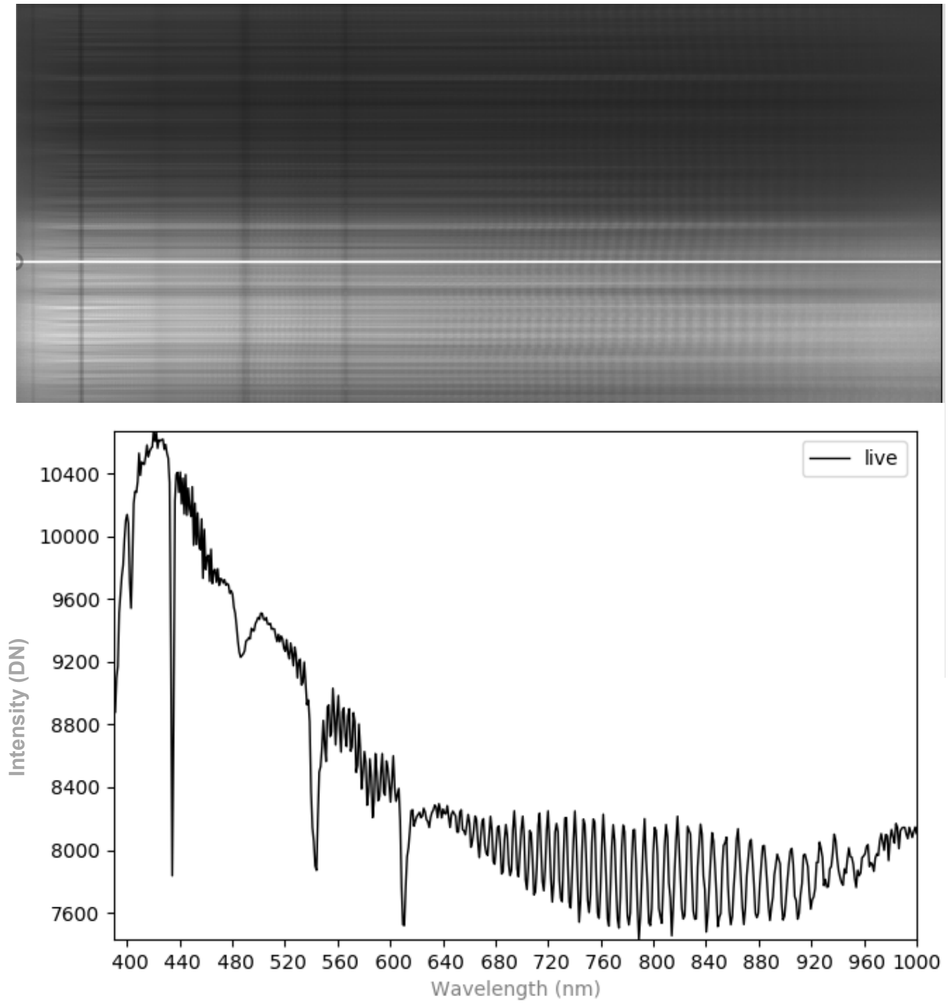
Accomplishments and Progress

Results for New Project (Awarded June 1, 2023):

- Demonstrate Proof of concept
  - Thin film interference causes intensity modulations in the spectrum of a thin membrane that can be detected by a Hyperspectral imager.
  - The frequency of the intensity modulation in the spectrum corresponds directly to thickness of the material at each pixel.

Resonon software/hardware detects fringes for several thicknesses of Nafion™ PEM membranes and PET protective sheets.

Development of software to process and display this data as a real-time thickness “map” is currently in progress.



Top panel: Intensity image of Nafion™ NR-212 Membrane. Bottom Panel: Horizontal cross section of top image showing interference fringes as a function of wavelength.

Accomplishments and Progress

Responses to Previous Year Reviewers' Comments

- Response required: No
- This is a new project that has not been previously reviewed at an AMR.

Collaboration and Coordination

Subcontractors

Peter Rupnowski - National Renewable Energy Laboratory - Chemistry and Nanoscience Center.

- Developed and patented technique for sensing thin film interference from transparent materials in web-line production.
- Demonstrated inline processing at 100 frames/sec.
- Provides patent and software license for further research and development of the technology.
- Provides support for integration of the technology to Resonon's systems.

Remaining Challenges and Barriers

- Fringes have been detected, but development of integrated software package has been delayed.
- The end use case for the technology remains poorly defined, which affects the direction of the proposed development:
  - What are acceptable thickness variations for PEM membranes?
  - What should a vendor or user do with a map of membrane thickness?
  - Can the thickness map be used in a closed loop, real-time feedback cycle to improve membrane quality?
  - Are there other critical membrane applications?

Proposed Future Work

Expected project completion is September 1, 2024 pending approval of No-Cost Extension.

Remaining Milestones:

- Complete software integration/proof of concept
  - Output GUI display/thickness map to end user
  - Speed test/benchmark real-time processing speeds with Resonon hardware/software
- Complete prototype designs
- Write final report

Outside of DOE-funded project timeline:

- Resonon will query distributors for applications/alternative applications of the technology.

Summary

- Administrative delays led to scheduling conflicts – No-cost extension has extended the timeline of the Phase I.
- R&D protype scanning system has been implemented.
- Proof of concept has been demonstrated with Nafion™ PEM films
- Software and hardware integration is ongoing.
- No further technical barriers are foreseen, however further development of the technology needs to be guided by feedback form thin film manufacturers and vendors.