NREL
Transforming ENERGY

In-line, High-throughput Quality Monitoring for Fuel Cell and Electrolyzer Components based on Transmission and Reflection Imaging

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Contents

Background and Goals

Membrane and MEA Quality Control during roll-to-roll (R2R) fabrication

→ Find methods to detect defects and monitor thickness

→ ***Real-time, in-line, high-throughput optical-based*** quality monitoring

→ MEA with opaque coating: **transmission imaging**

→ Transparent membranes: **reflectance hyperspectral imaging**

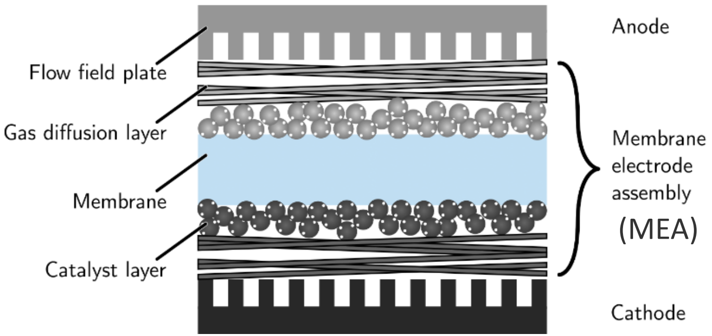


Figure 1. Schematic layout of fuel cell or electrolyzer [1]

[1] Helmholtz-Institut Erlangen-Nürnberg. “Manufacturing of membranes and electrodes.” https://www.hi-ern.de/en/research/electrocatalytic-interface-engineering-1/composite-membrane-analysis-and-design/manufacturing-of-membranes-and-electrodes

Initial Proof-of-Concept Experiments

MEA with opaque coating: **transmission imaging**

- Initial bench-top static experiment has shown that a reliable transmission signals can be obtained with continuous or pulsed light sources.

Sample Transmission Image	Light Source Name	Exposure Time (ms)	SNR	Ave Pixel Value
	Halogen light	1000	613	2912
	Tactical Flashlight	1000	143	1195
	Flashpoint Flashlight	1000	452	3976
	Flashpoint Flashlight	100	1481	4019

Table 1. Comparison of different light sources for an opaque MEA sample

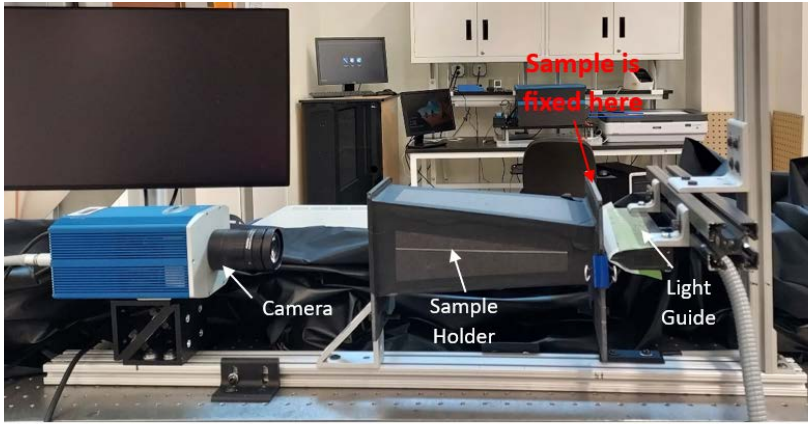


Figure 2. Bench-top transmission setup with continuous light source **with no less than 1s exposure time**

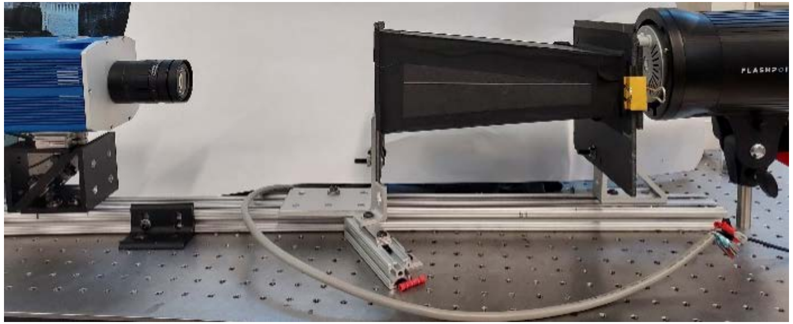


Figure 3. Bench-top transmission setup with pulsed flashlight **with much less exposure time(<< 1 s)**

Initial Proof-of-Concept Experiments

Transparent membranes: **reflectance hyperspectral imaging**

Hyperspectral Camera

Light Guide and Diffuser

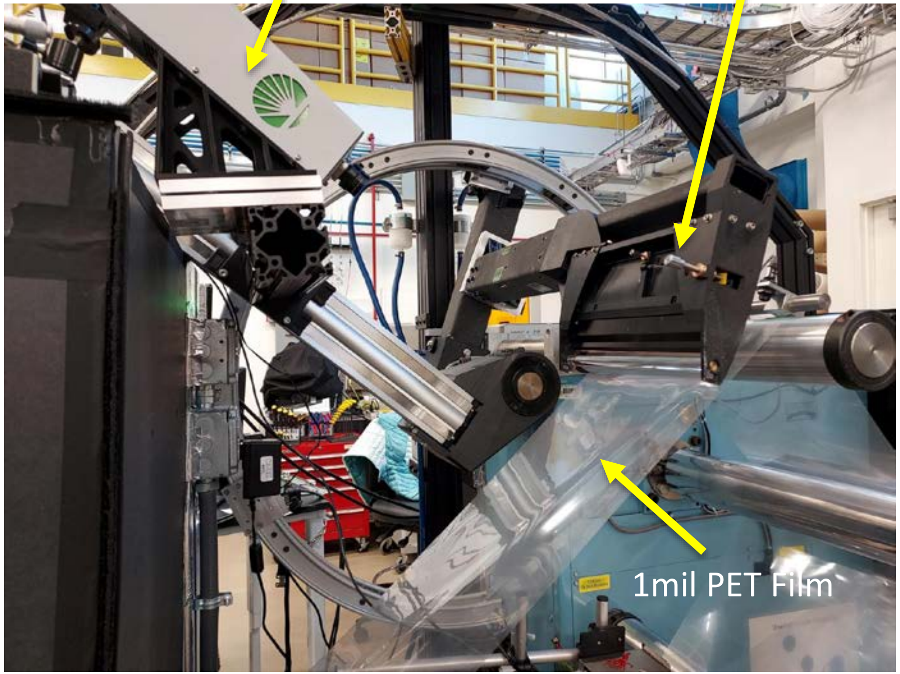
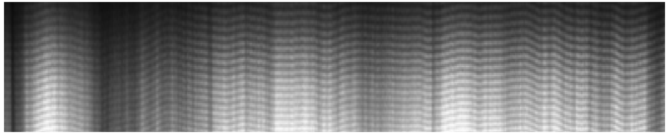


Figure 4. Static HSI imaging setup for 1mil PET film

- Light source: halogen light (used <2% light intensity of an 150W Intralux-dc 1100)
- Frame rate: 100 Hz
- Obtained the following clear fringes:



Thickness results for 1 frame:

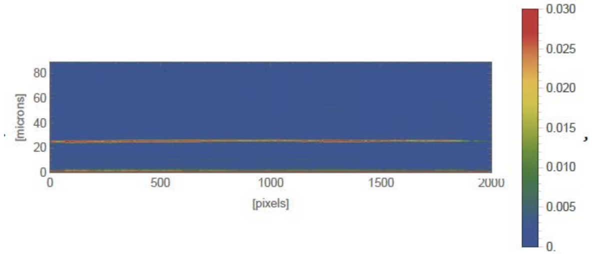


Figure 5. Fringes and Thickness for 1mil PET film

Web-line Experiments

MEA with opaque coating: **transmission imaging**

- In roll-to-roll dynamic configuration, the exposure time was set to 50 ms and the frame rate ~1Hz in 3 runs.

- Sample Product Name: Electrolyzer NSTF Catalyst Coated Membrane(Experimental)

- Sample Description: mitigated (black) membrane with two catalyst layers

- Web-line moving speed: 5 ft/min

- Tension of the web-line: 1 Pli(pounds/linear inch)

- Sample was spliced adjacent to PET film and enclosed in transparent plastic bags

- Camera and flashlight were synchronized via a cable/relay connection

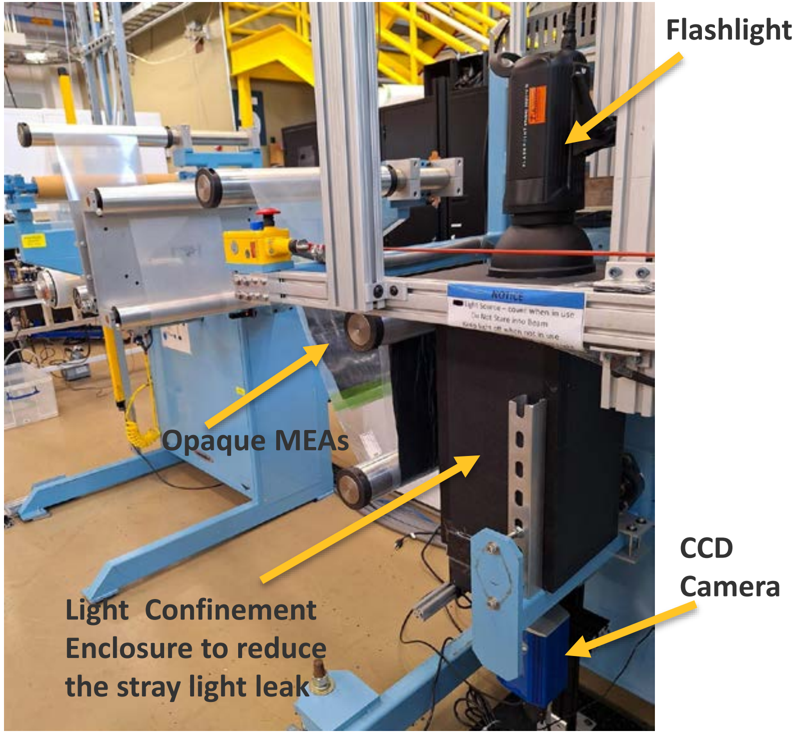


Figure 6. Transmission setup with pulsed flashlight on the moving roll-to-roll system

Web-line Experiments

Transparent membranes: **reflectance hyperspectral imaging**

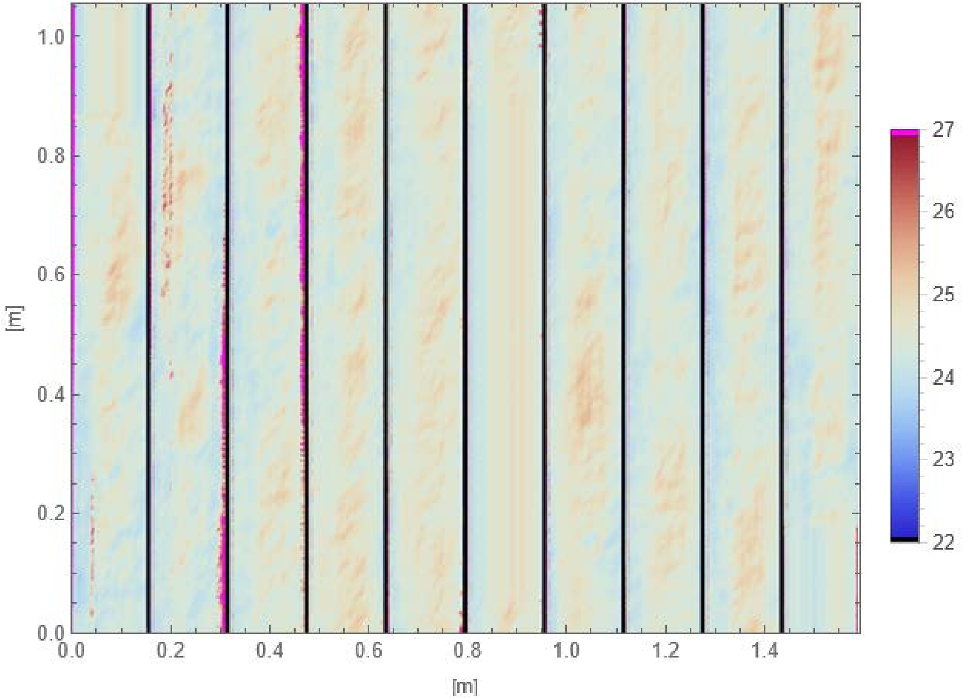


Figure 7. 2nd layer(PET) thickness map of NRE 211

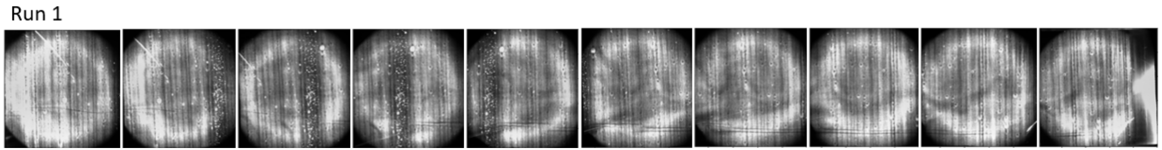
Figure 8. Transparent membrane thickness mapping through reflectance hyperspectral imaging while running the roll-to-roll system

Image Processing

MEA with opaque coating: **transmission imaging**

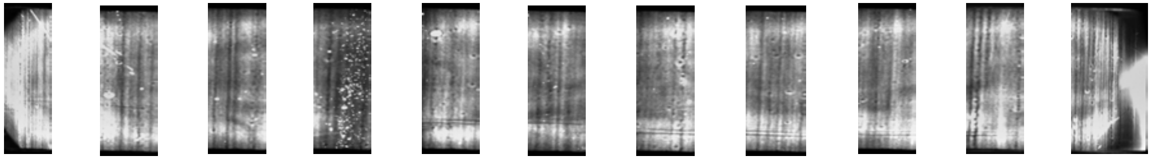
Batch Image Processing Routine written in Python Jupyter Notebook

Calculate the translational displacement per frame



↓

Crop each frame



↓

Combine the cropped images into a whole sample image

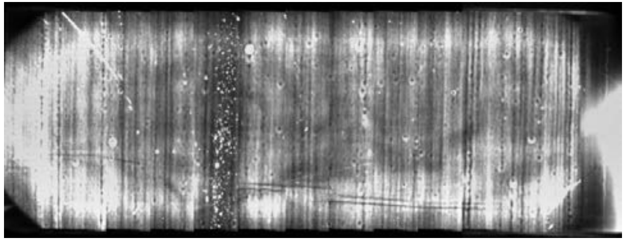


Figure 9. Image processing steps for highly absorbing MEAs

Image Processing

Transparent membranes: reflectance hyperspectral imaging

Convert raw MSV-500 camera data to TIF files (1)

Generate Configuration files to show the refractive index per layer within certain vertical length range (1) (2)

Thickness Mapper

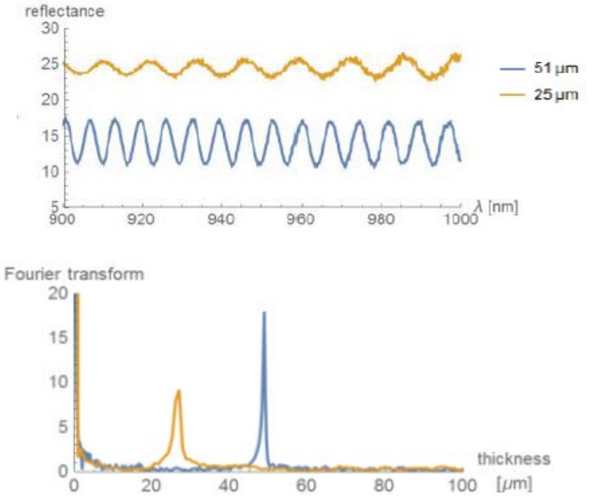
(1) (2)

Obtain the thickness maps in H5 formats

(1) Offline Mode

(2) Online Mode

As an example, reflectance spectra for two PSFA films of thicknesses 25 and 51μm are shown below



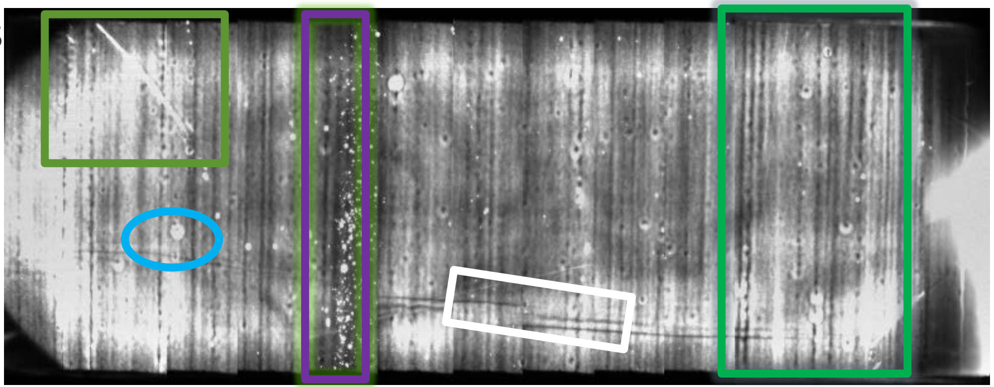
[2]

[2] Rupnowski, P. (2022). *In-Line Membrane Thickness Mapping with Real-Time Data Processing* (No. NREL/PO-5900-82774). National Renewable Energy Lab.(NREL), Golden, CO (United States).

Experimental Results

MEA with opaque coating: **transmission imaging**

Features are detected during web-line scanning:



1. Non-uniformity of the opaque MEAs
   - white diagonal line
   - circular white spots
   - cross-web bands
   - dark CW stripe with white speckles
2. Wrinkles on the transparent bags that enclosed the MEAs
3. Non-uniformity of the light

- 2 and 3 can be eliminated or corrected for

➢ We do not know which layer is nonuniform (Pt and Ir could be distinguished using XRF or through Reflectance imaging)

➢ Correlation between T variation and loading variation is not established here.

Experimental Results

Transparent membranes: **reflectance hyperspectral imaging**

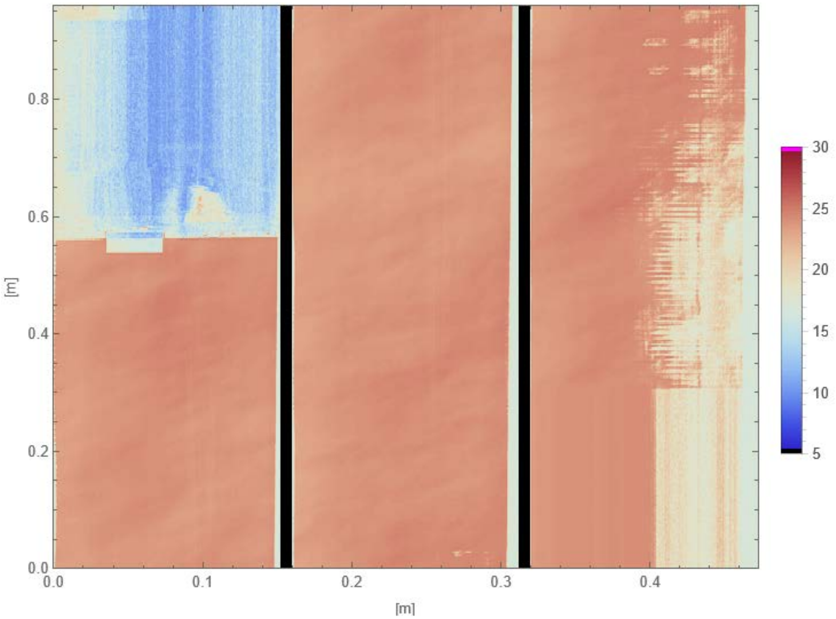


Figure 10. NRE 212 Layer 1(PET) Thickness Map

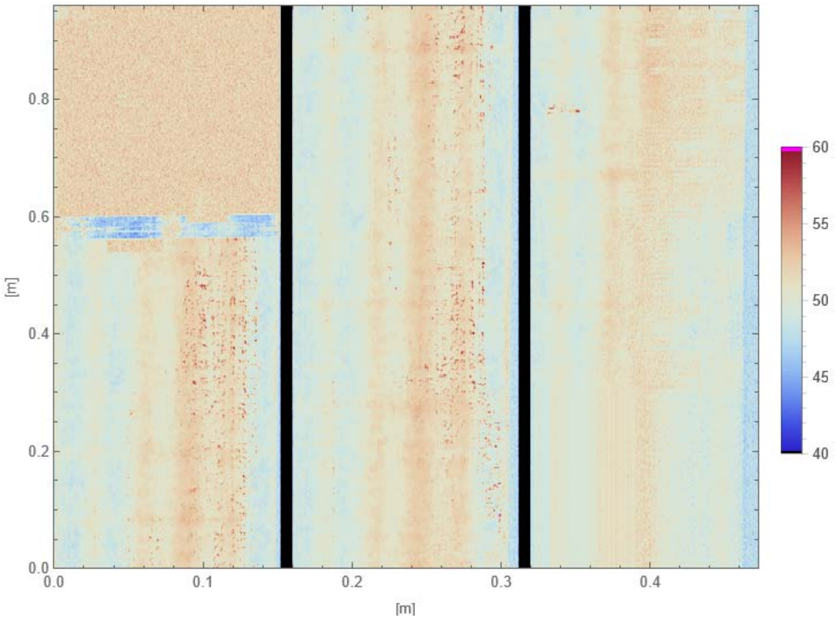


Figure 11. NRE 212 Layer 2(Nafion) Thickness Map

Conclusions and Future Work

MEA with opaque coating: **transmission imaging**

- Initial bench-top static experiment proves the concepts of performing transmission imaging of highly absorbing MEAs .
- The transmission imaging in a moving roll-to-roll environment showed a strong transmission signal, demonstrating a potentially viable pathway for real-time, in-line, high-throughput dynamic optical transmission imaging for uniformity/defects testing of the opaque MEAs and their components.

- Future Work:

- Light uniformity correction
- Expand width of the FOV
- Develop system for 50ft/min
- Synchronize web-line motion with camera/flashlight to obtain good repeatability with identical phase of each run

Conclusions and Future Work

Transparent membranes: **reflectance hyperspectral imaging**

- Initial static experiment proves the concepts of performing reflectance hyperspectral imaging of transparent membranes.
- The hyperspectral imaging in a moving roll-to-roll environment showed clear fringes, demonstrating a potentially viable pathway for real-time, in-line, high-throughput dynamic optical imaging for membrane thickness monitoring in mass production.

- Future Work:
  - Increase the thickness detection accuracy for multi-layer membranes
  - Increase the thickness detection accuracy at the border of two adjacent materials
  - Add the function of the relative position detection of each layer
  - Tune the system to accommodate higher web-line speed
  - Synchronize the web-line motion with the image acquisition

Thank you!

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