Nanoscale X-Ray Computed Tomography (nano-CT) Methods for Evaluating Platinum-Based Fuel Cell Degradation

Laboratory for Transport Phenomena in Energy Systems

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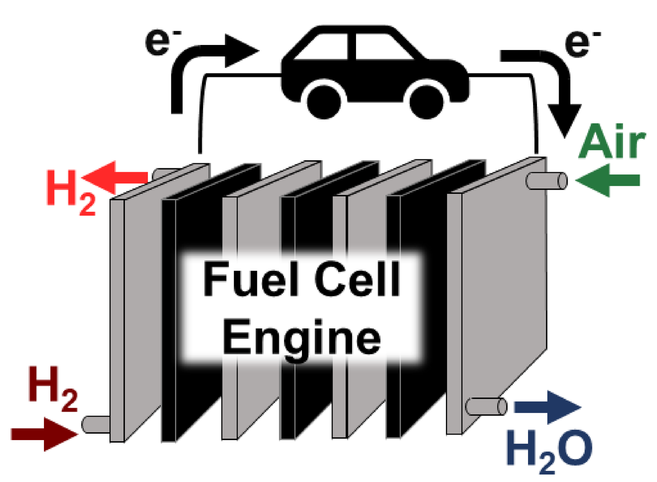
Motivation

Polymer electrolyte membrane (PEM) fuel cells are a promising renewable energy conversion technology for the transportation industry. They operate by converting the chemical potential energy of hydrogen and oxygen to heat and electricity with water as the only product. The electricity generated can then be used to power a vehicle, such as the Chevy Colorado, shown below.

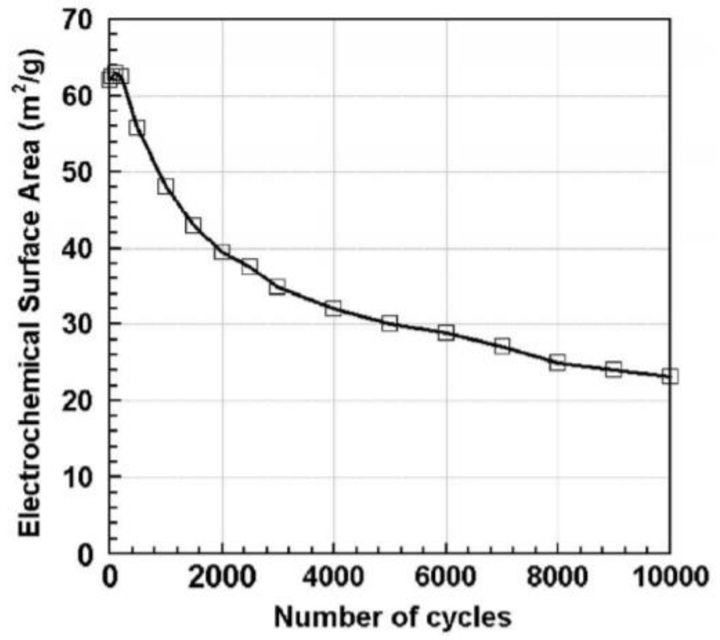


PEM Fuel Cell Engine Schematic

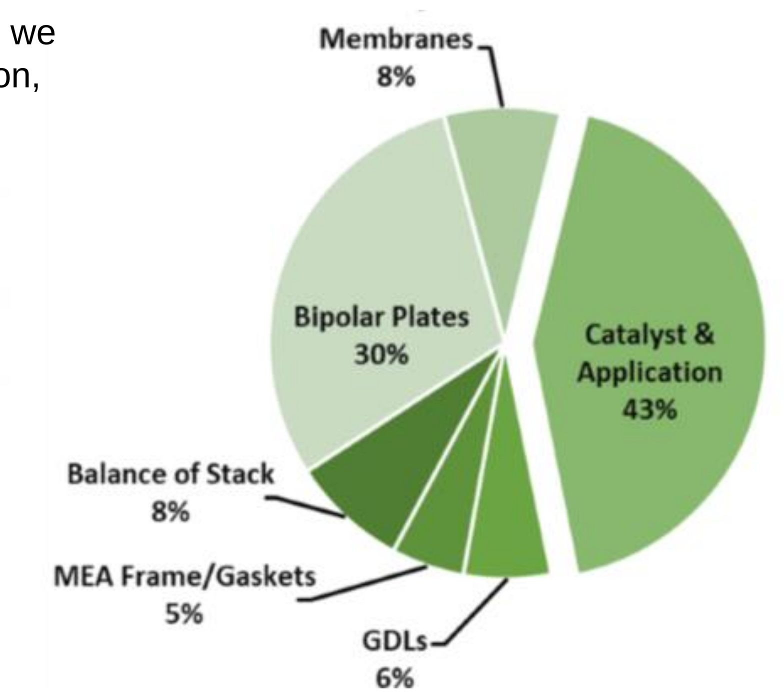
PEM Fuel Cell Chevrolet Colorado[1]

While PEM fuel cell technology is well suited to address the need for renewable energy conversion technologies for long-range, high-power transportation applications, the technology is currently too expensive for widespread adoption. The high cost of this technology is largely due to the cost of the platinum used for the catalyst[2].

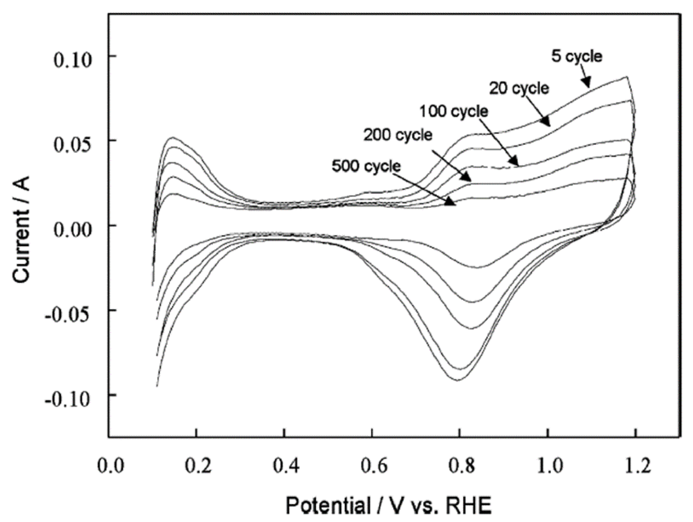
To reduce the cost of PEM fuel cell technology, we need to address issues with catalyst degradation, which has been shown to be significant[3,4].



ECSA Loss (Catalyst Loss) During Voltage Cycling[3]



Fuel Cell Cost Breakdown by Component, Estimated at Production Volume of 500k Units.



ECSA Loss (Catalyst Loss) During Voltage Cycling[4]

The purpose of this work was to explore the effects of different types of carbon supports, as well as the effect of different platinum-based catalysts on the extent of catalyst degradation. In this analysis, 4 different samples were tested:

1. Platinum catalyst on vulcan carbon support, non-cycled
2. Platinum catalyst on vulcan carbon support, cycled 30,000 times using an accelerated stress test
3. Platinum cobalt catalyst on high surface area carbon, non-cycled
4. Platinum cobalt catalyst on high surface area carbon, cycled 30,000 times using an accelerated stress test

Sponsor

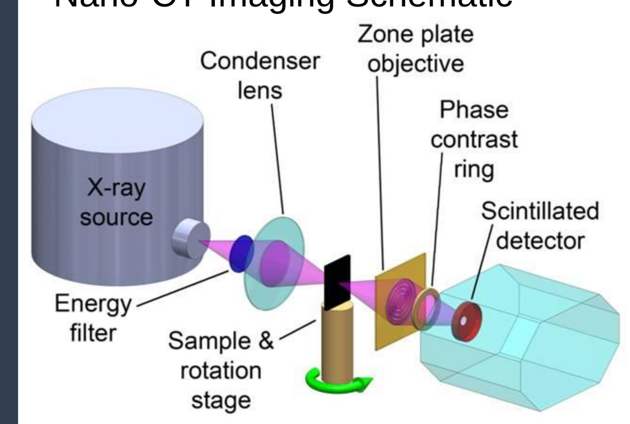
U.S. DEPARTMENT OF ENERGY

Collaborators

GM, 3M, Cornell University, Drexel University, NREL National Renewable Energy Laboratory

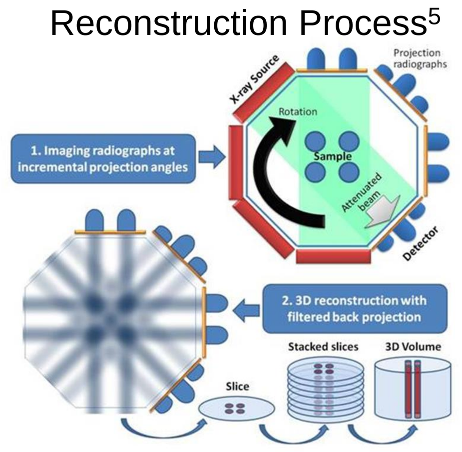
Methods

Nano-CT Imaging Schematic[5]

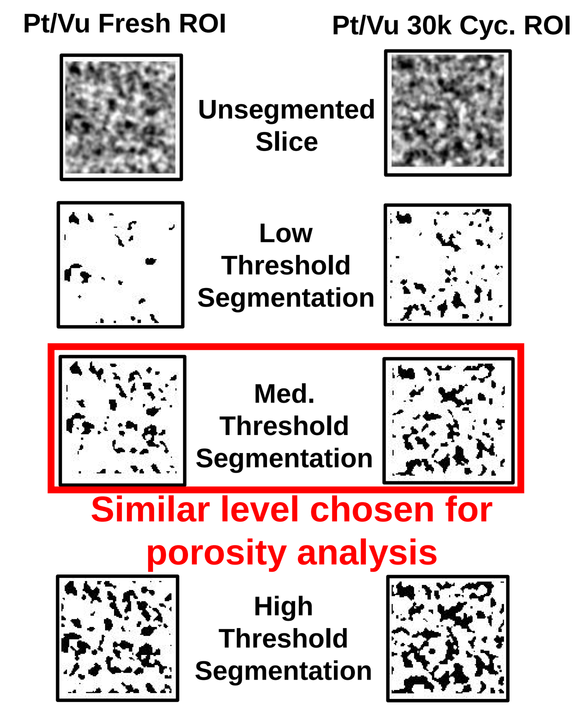


4 MEA samples (Pt/Vu-Fresh, Pt/Vu-cycled, PtCo/HSC-Fresh, and PtCo/HSC-cycled) were imaged in large field of view (LFOV) phase contrast (PC) and absorption contrast (ABS) modes and reconstructed using proprietary software by Zeiss.

Nano-CT Reconstruction Process[5]



Porosity analysis using phase contrast mode

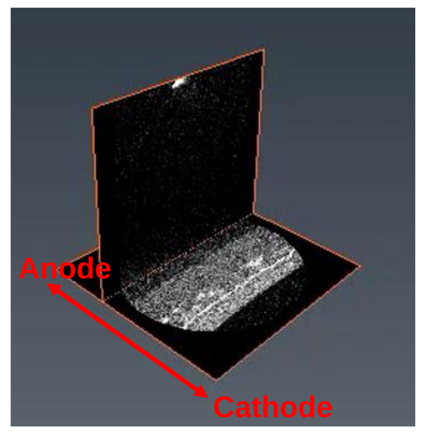


Note: Black = pore, white = solid

Platinum dissolution analysis using absorption contrast mode

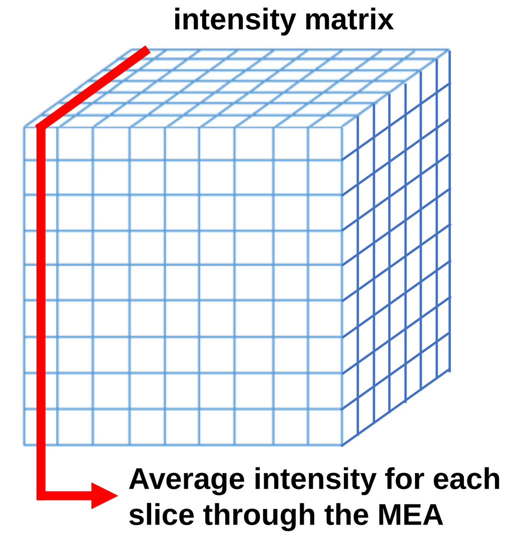
Normalization of intensity data:

$$I_{norm} = \frac{I - I_{air,avg}}{I_{mem,avg} - I_{air,avg}}$$



Absorption Contrast Slice View

3-D normalized pixel intensity matrix

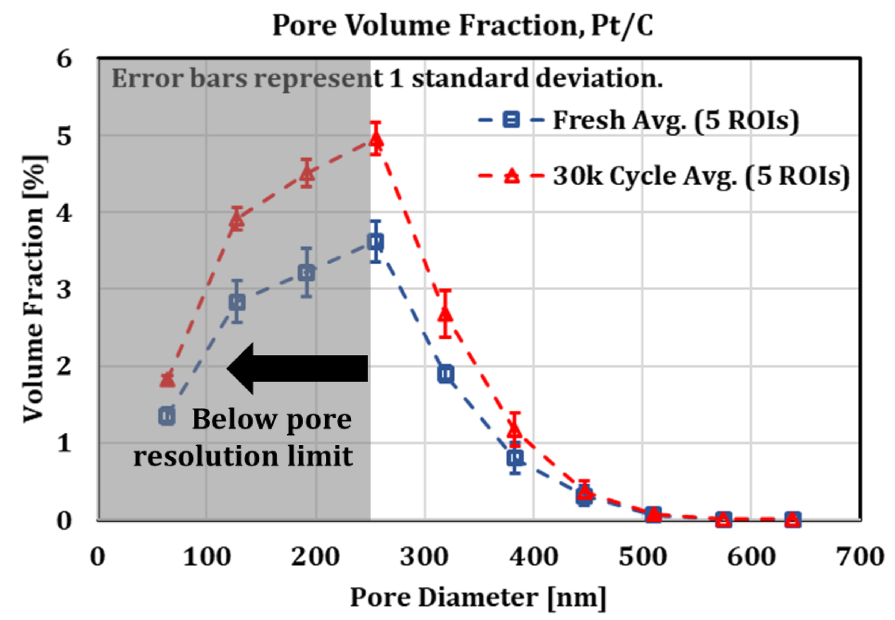


Average intensity for each slice through the MEA

Porosity Results

Pore percentage & pore size distribution for platinum on vulcan carbon samples

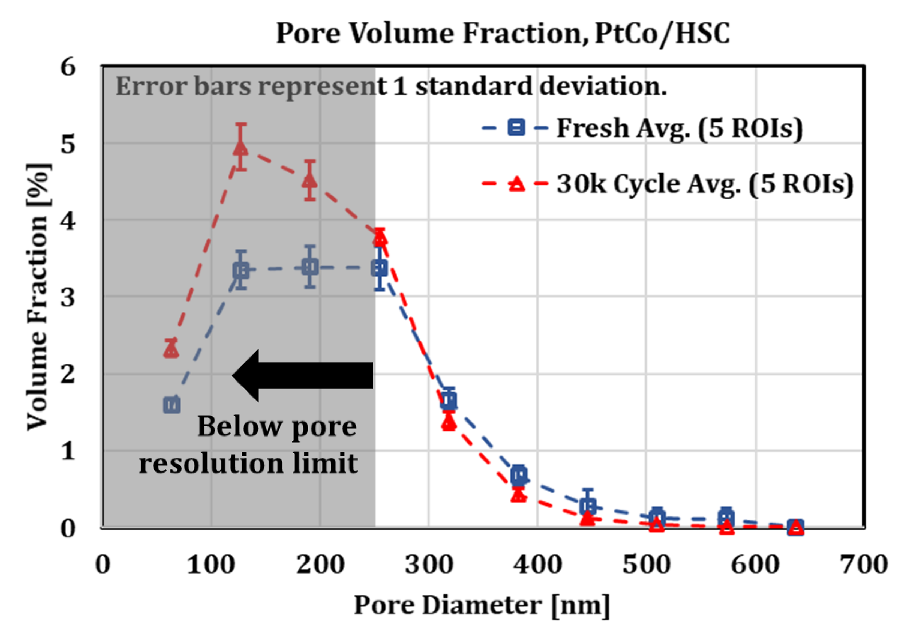
ROI	Pt/C Fresh [%]	Pt/C 30k Cycles [%]
1	6.7	9.7
2	6.7	8.9
3	6.9	8.1
4	5.9	9.5
5	7.3	10.1
AVG	6.7	9.3



A small increase in pore diameter was seen between the fresh and cycled samples for platinum on vulcan carbon, indicating a small amount of carbon degradation.

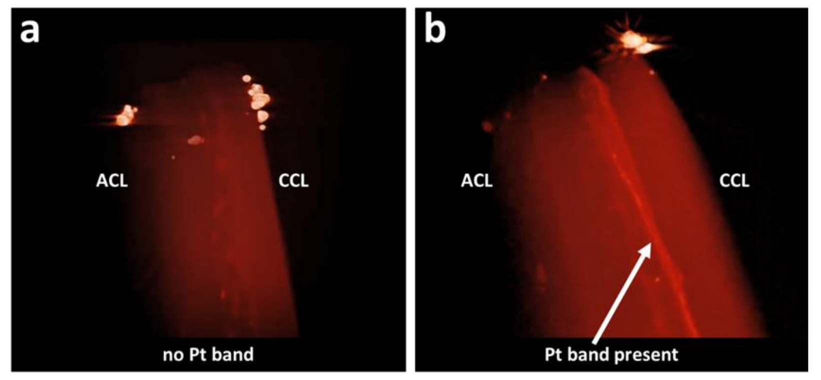
Pore percentage & pore size distribution for platinum cobalt on high surface area carbon (HSC) samples

ROI	PtCo/HSC Fresh [%]	PtCo/HSC 30k Cycles [%]
1	6.6	5.9
2	7.8	5.6
3	6.0	5.8
4	5.5	5.4
5	5.2	6.1
AVG	6.2	5.8

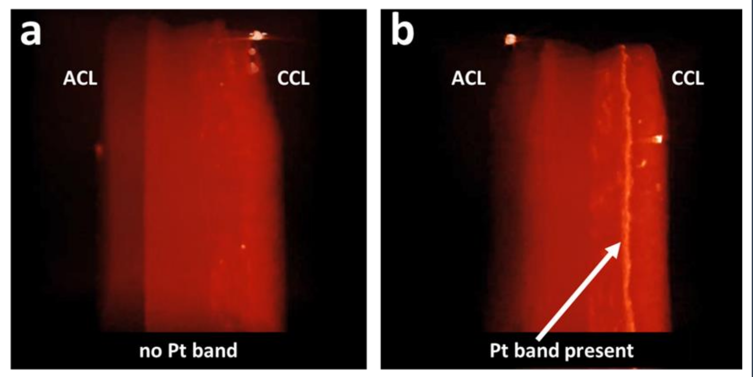


No significant pore diameter increase was seen between the fresh and cycled samples for platinum cobalt on high surface area carbon.

Platinum Dissolution Results



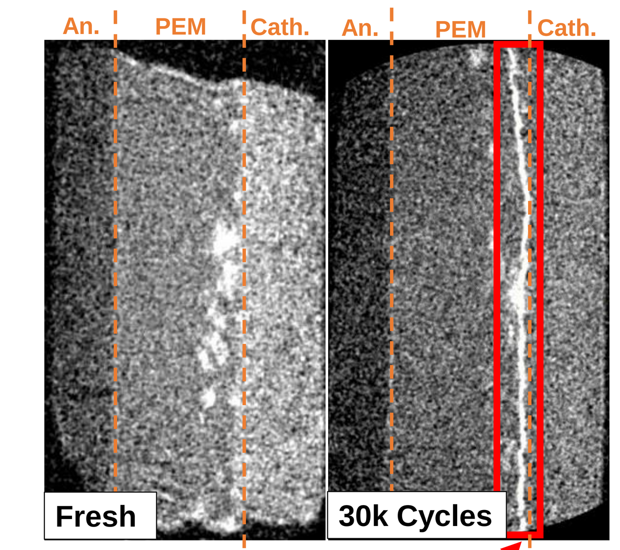
Reconstructed absorption contrast volume of Pt/Vu a) fresh b) 30k cycled



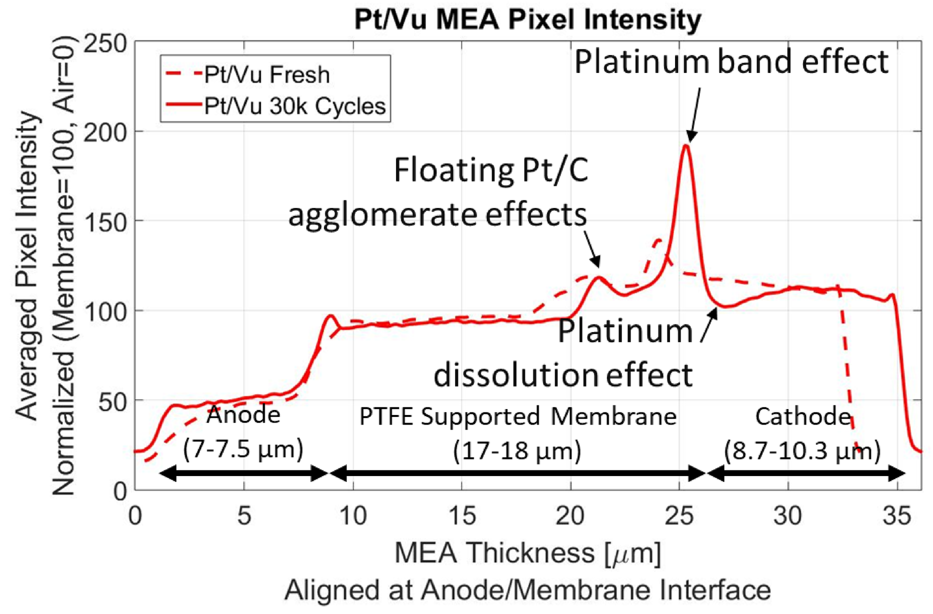
Reconstructed absorption contrast volume of PtCo/HSC a) fresh b) 30k cycled

Preliminary imaging results indicated the formation of a "band" of platinum near the interface of the cathode catalyst layer (CCL) and the proton exchange membrane (PEM).

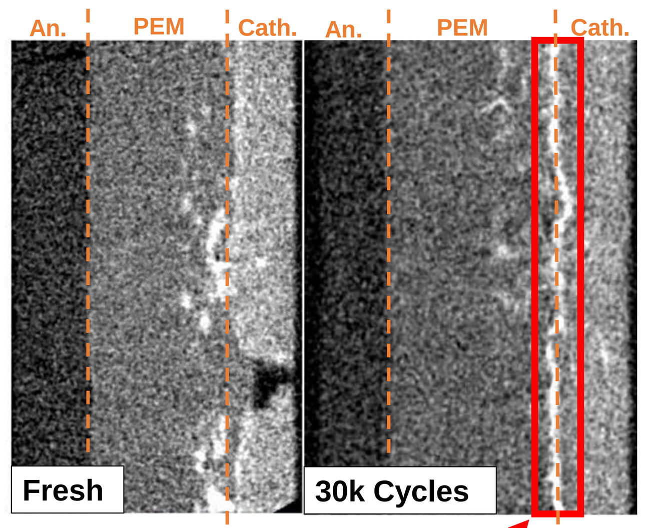
Pt/Vu ABS Slice Views



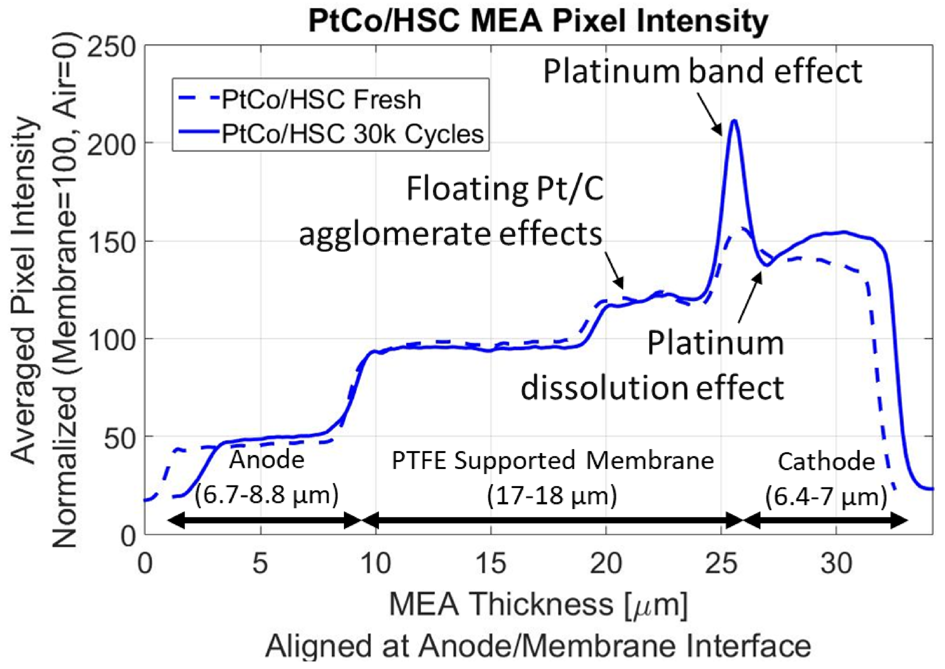
Platinum band



PtCo/HSC ABS Slice Views



Platinum band



Further analysis using averaged pixel intensities indicated a region of platinum dissolution and a corresponding platinum "band" spike near the interface of the cathode and membrane for both types of catalyst and carbon support.

Conclusion

In this work, we utilized a novel method (nano-CT) to view the catalyst degradation effects of voltage cycling on fuel cell cathodes. We successfully determined that:

1. Platinum dissolves from the cathode for platinum and platinum alloy catalysts.
2. Platinum dissolves from the cathode for HSC and Vulcan carbon supports.
3. Platinum migrates to the membrane/cathode interface for HSC and vulcan carbon supports.
4. Vulcan carbon supports degrade more than HSC supports, as shown by the increase in porosity.

References

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