Advanced Manufacturing of Solid Oxide Electrodes Using ALD

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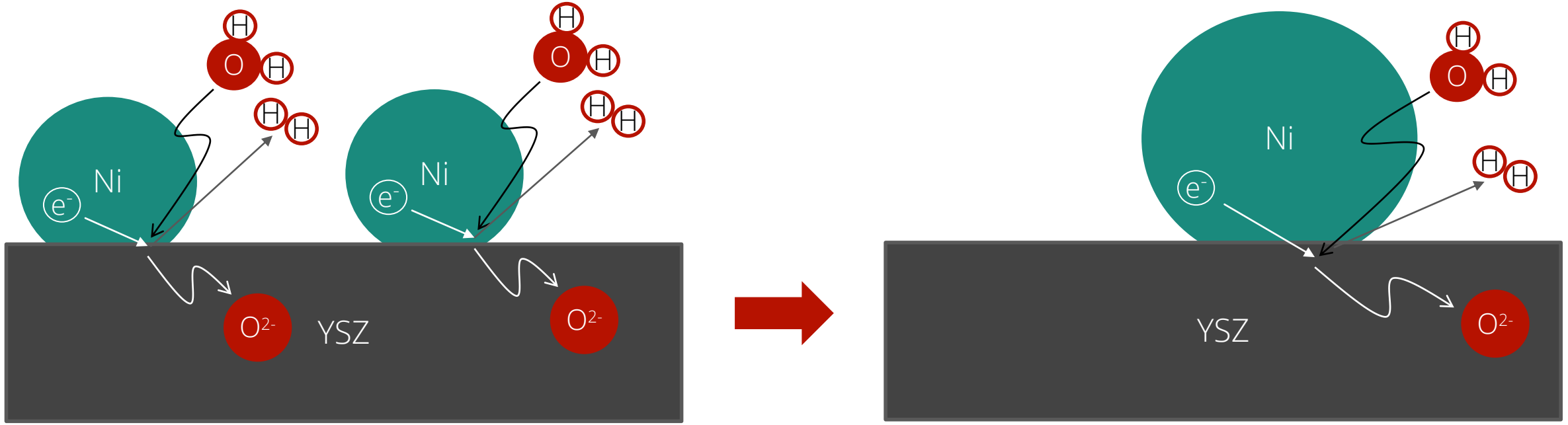
U.S. DOE Office of Fossil Energy and Carbon Management
DOE SBIR Grant #: DE-SC0022769

RMD Inc. and UPenn
Collaborator: Prof. John Vohs – UPenn

SOEC Electrode Degradation – Nickel Migration



- As Nickel migrates and agglomerates, density of TPBs is reduced

What's Been Done to Prevent Degradation

- Add H_2 gas to feed to prevent Ni oxidation
- Increasing surface area/density of active TPBs with additional catalysts via infiltration, ALD, PLD

- ❖ Outlook: Develop robust electrode structure preventing Ni migration
- ❖ Challenge: Binding Ni in complex microstructure while preserving TPB
- ❖ Solution: Conformal ALD coating of chemical anchor compatible with SOEC manufacturing

Timeline

Phase I Base Period

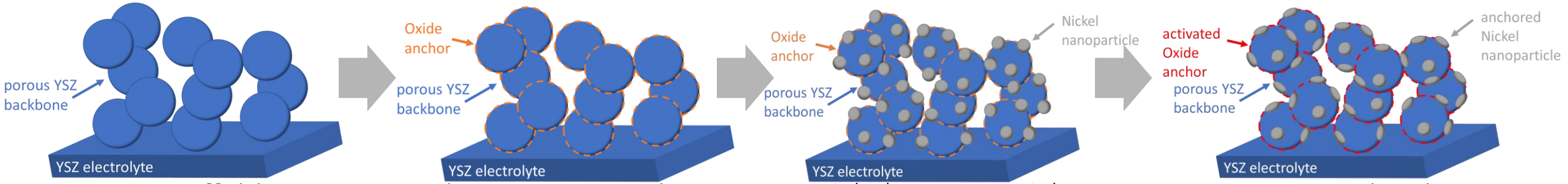
POP: 06/27/22 – 03/27/23

Duration: 39 weeks

Goal:

1. Demonstrate the technical feasibility for the growth of the proposed anchor films via ALD in YSZ scaffolds provided for us by our collaborator, UPenn
2. Evaluate and validate the performance of ALD-coated fuel electrode by performing representative electrolysis testing and evaluating the extent of nickel migration

Novel Oxide Anchor to Prevent Nickel Migration in Ni-YSZ Fuel Electrode

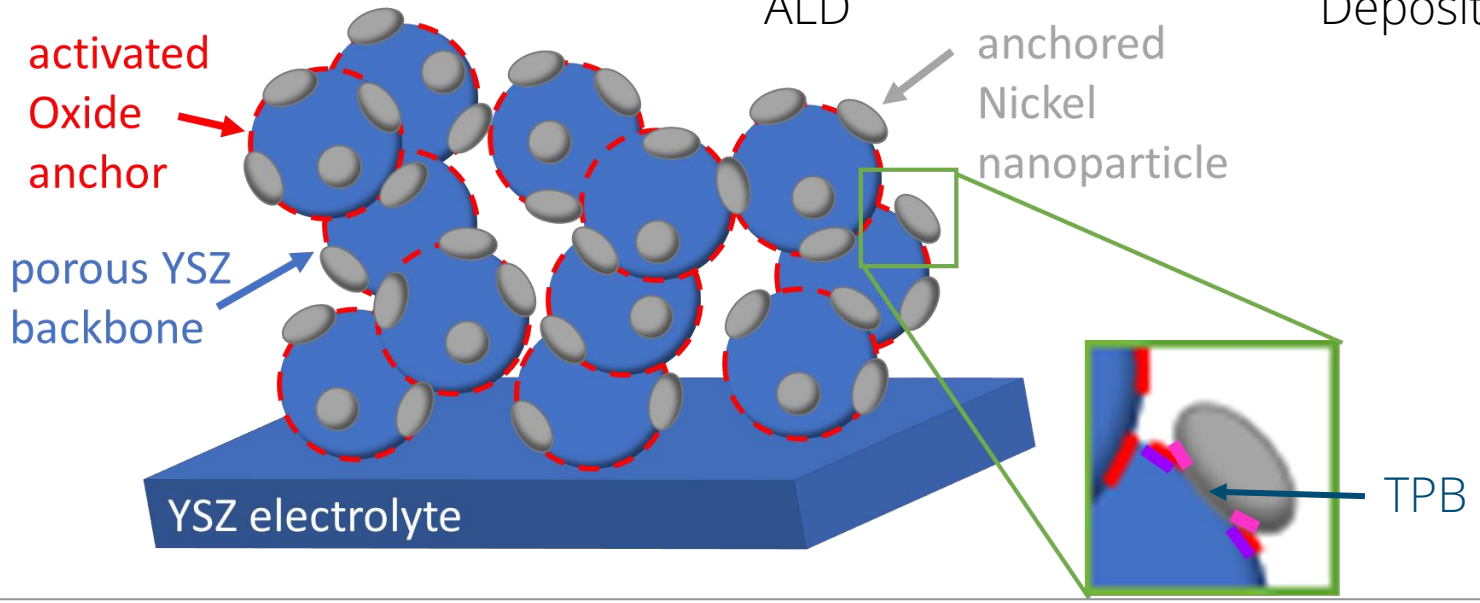


YSZ scaffold

Anchor Deposition by ALD

Nickel Nanoparticle Deposition

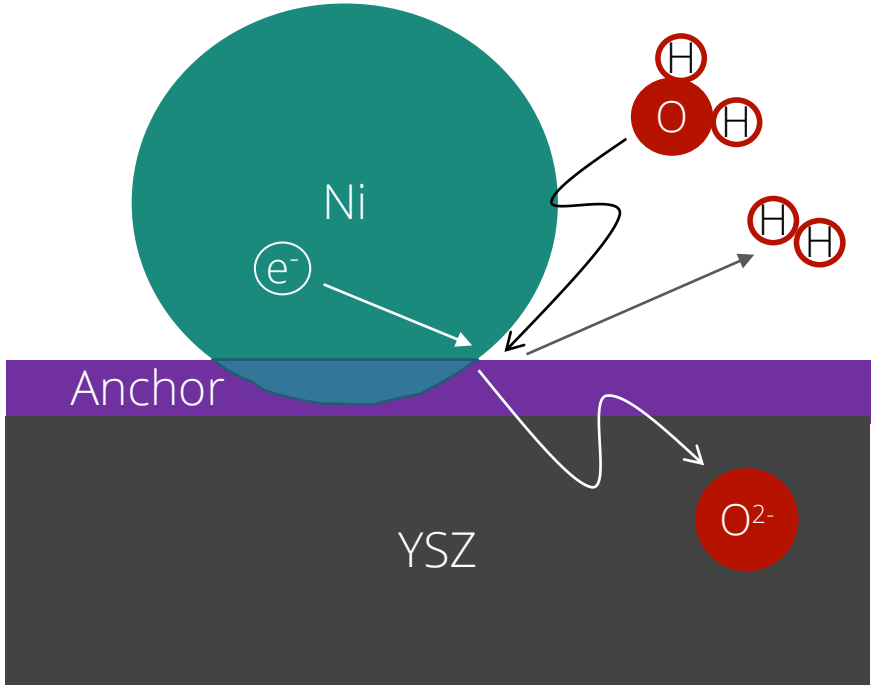
Activate Anchor by Annealing



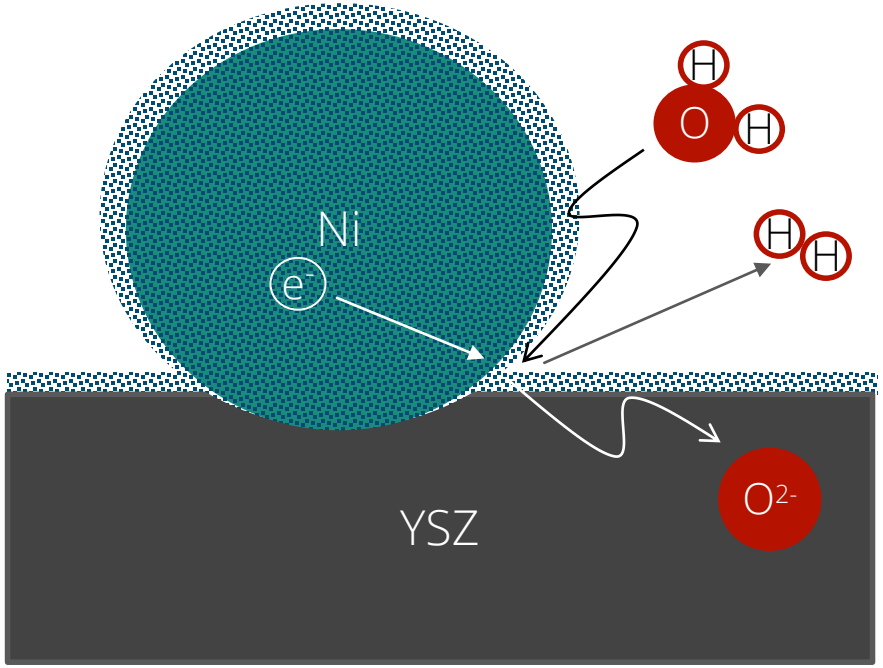
ALD enables anchor to deposit conformally on YSZ scaffold

Advantage of Anchoring

- Prevents Ni migration and agglomeration while preserving Ni for TPBs
- Minimized risk of blocking TPB

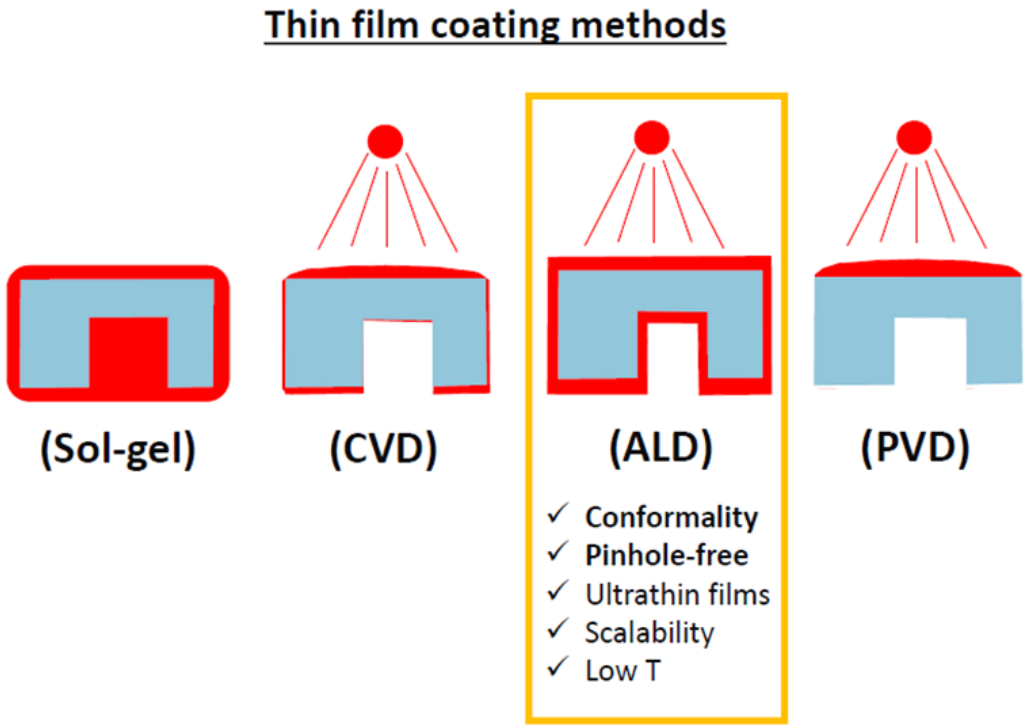


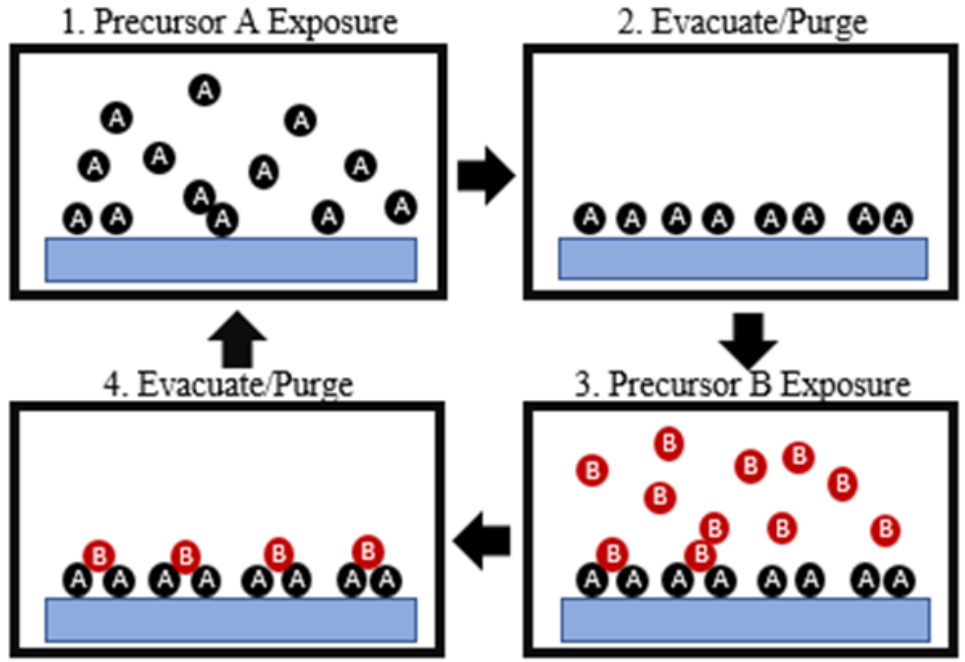
Anchor

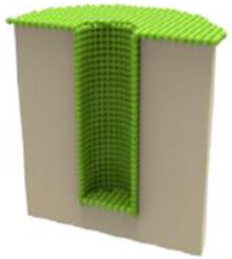


Porous overcoat

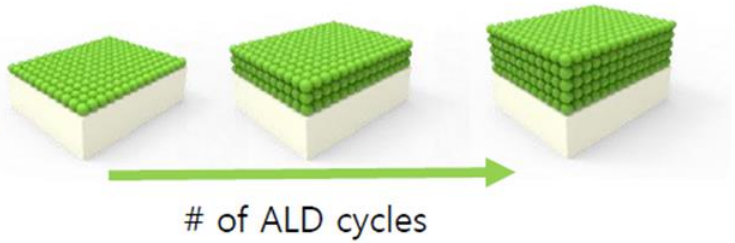
Atomic Layer Deposition (ALD)



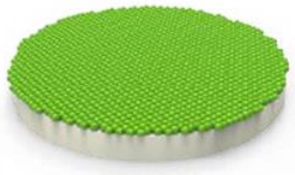




Good conformality

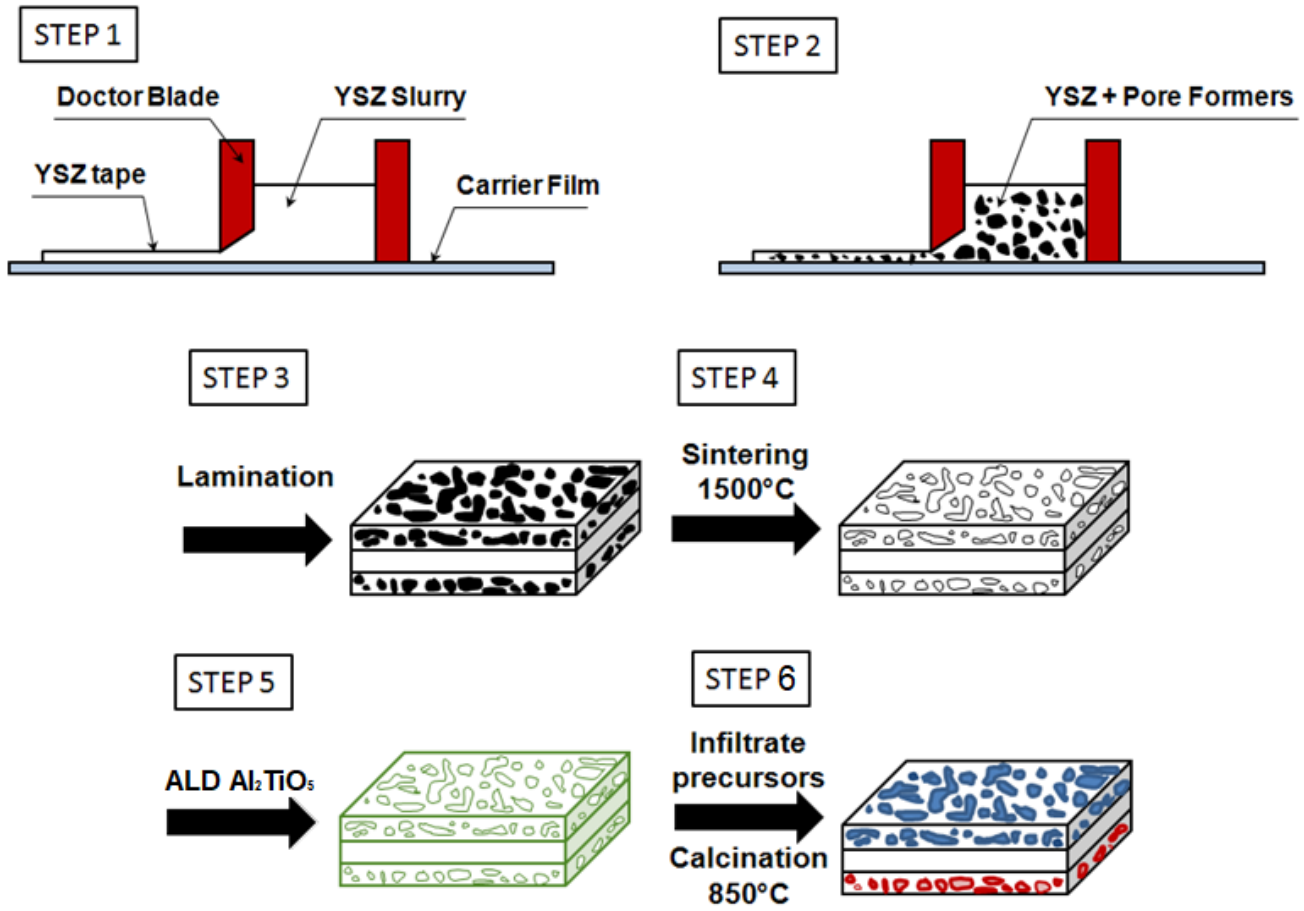


Thickness control



Good uniformity

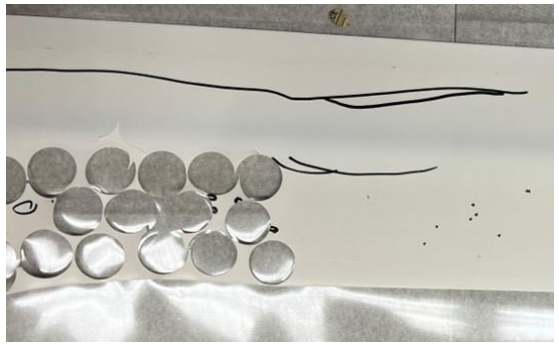
Approach



- Cells fabricated via tape casting
- Anchor coating will be deposited by ALD into the cell scaffold
- Wet infiltration to add the active components
- Calcination anneal will activate anchor

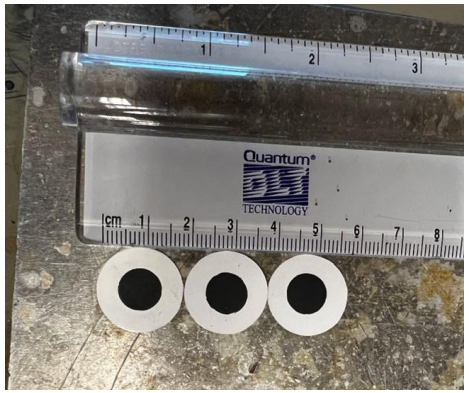
Cell Fabrication – Tape Casting

- Cells are fabricated using tape casting with a slurry containing YSZ or YSZ plus graphite pore formers

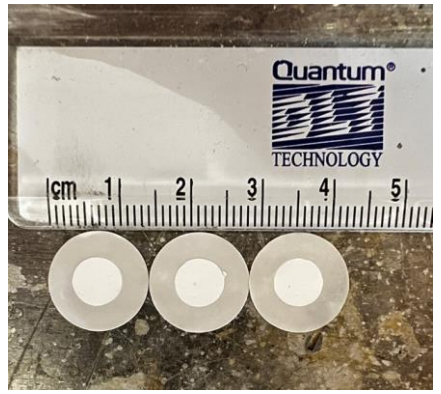


YSZ tape used for making dense electrolyte layer

YSZ tape with graphite pore former used for making electrode layers

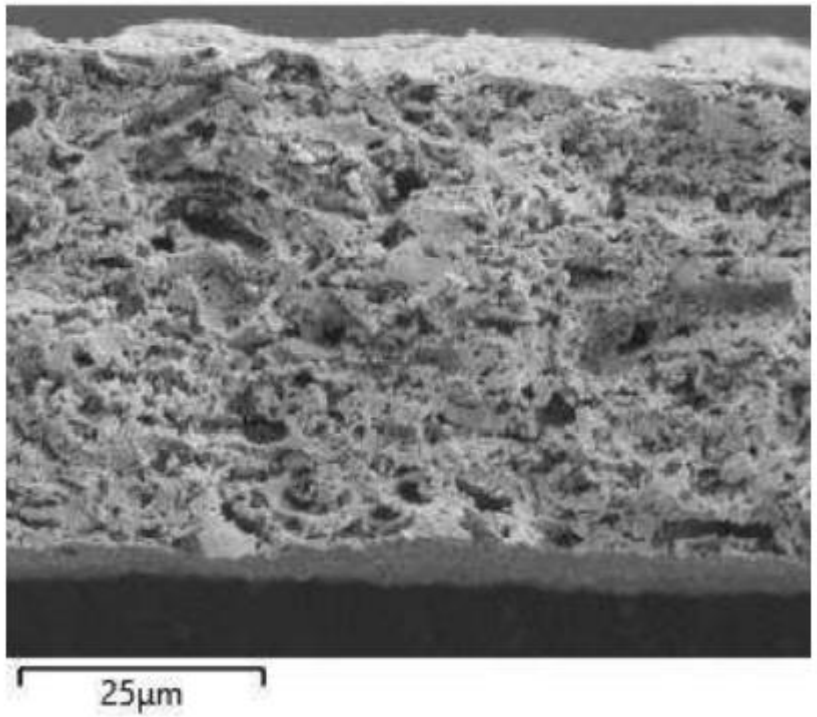


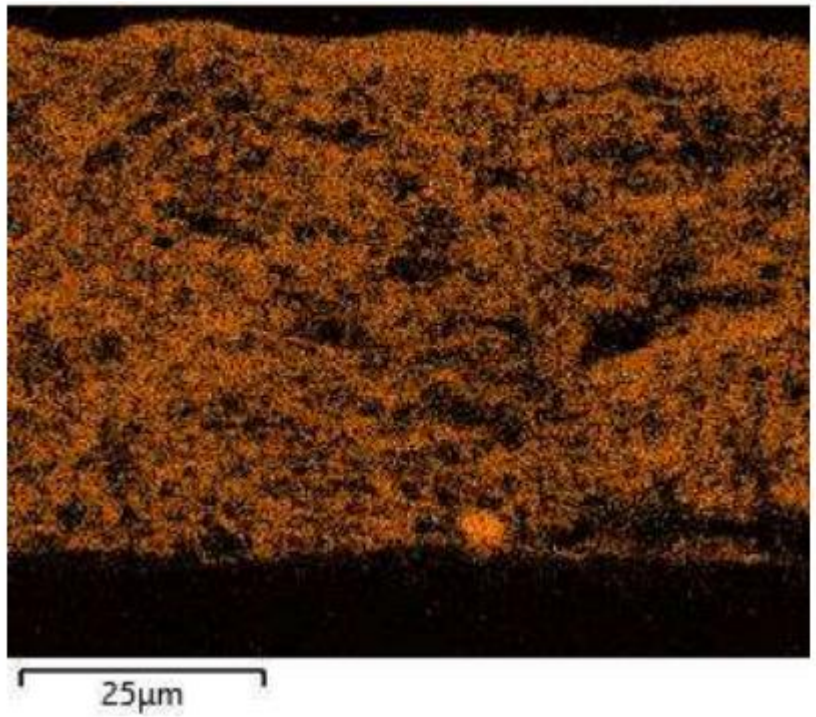
Cells before sintering

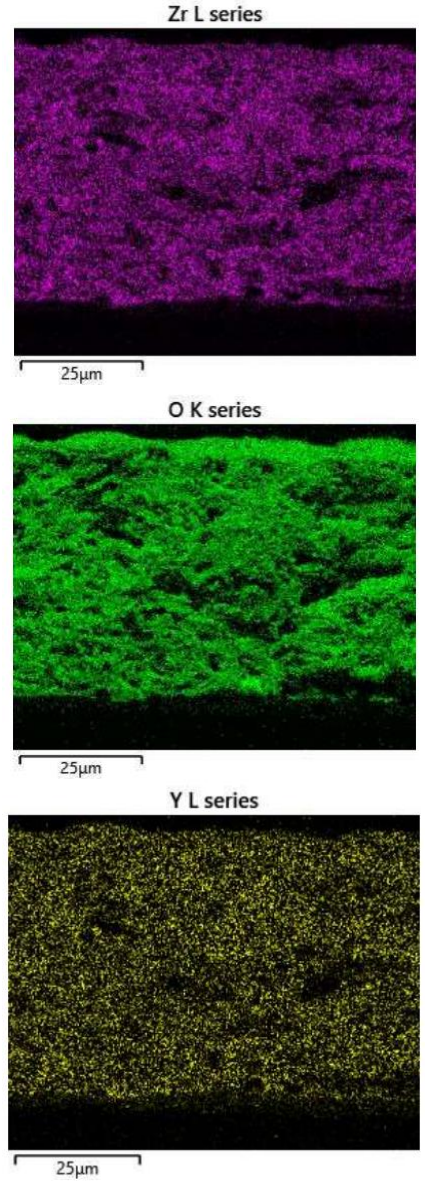


Cells after sintering 1500ºC

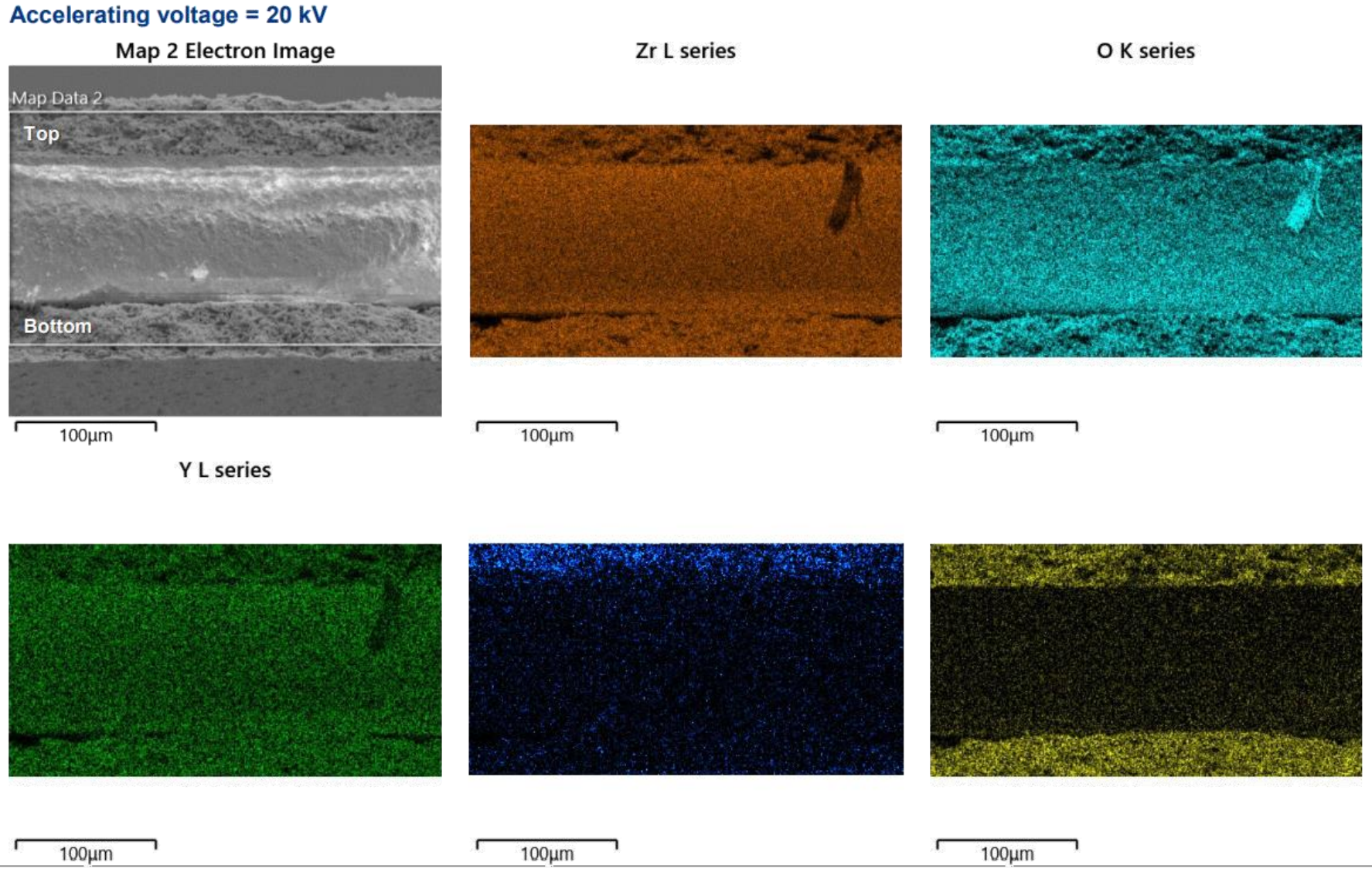
Anchor coated YSZ



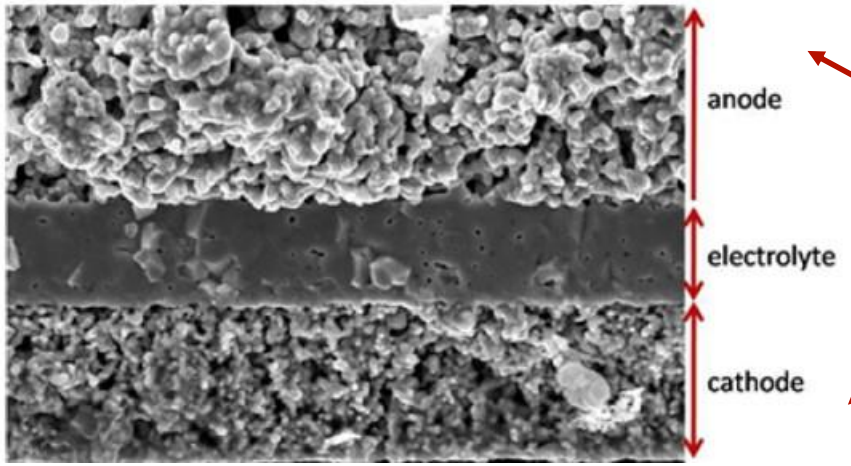




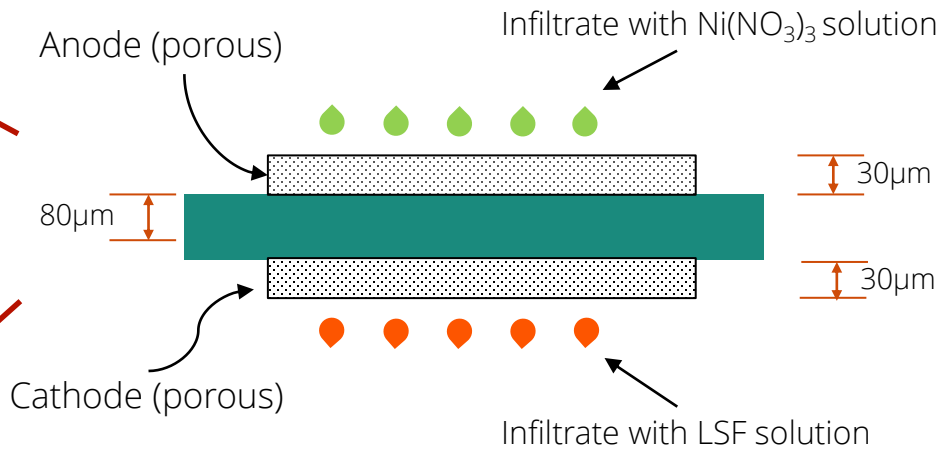
Elemental Mapping of Anchor in Button Cell



Cell Fabrication: Electrode Infiltration – Post ALD



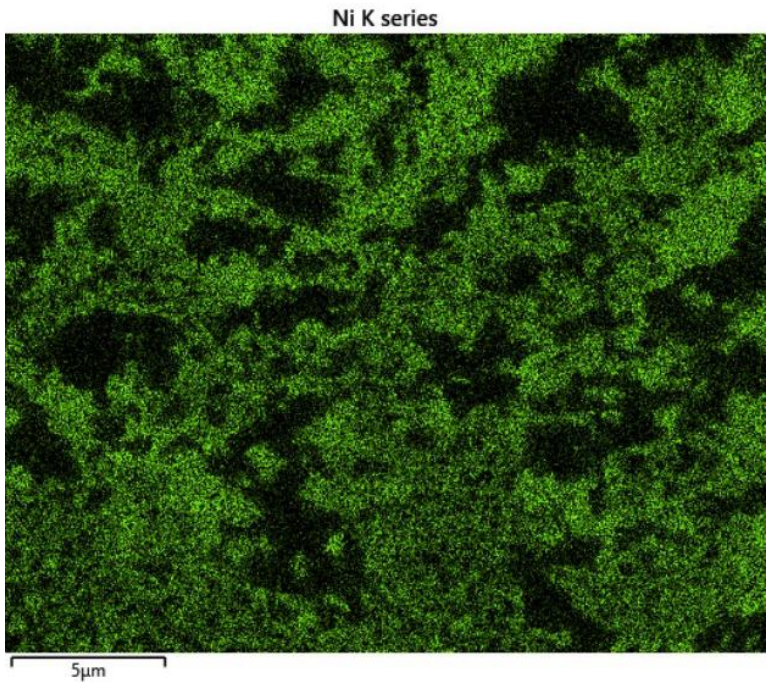
Cross-section micrograph showing a typical cell structure



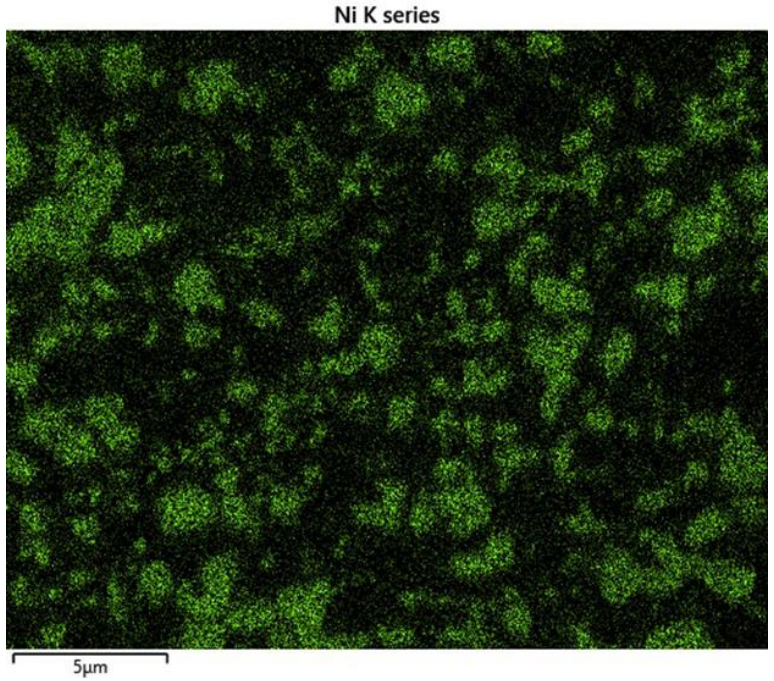
Anode infiltrated with $Ni(NO_3)_3$ solution and heated to 1300 °C

Cathode infiltrated with LSF solution followed by drying.

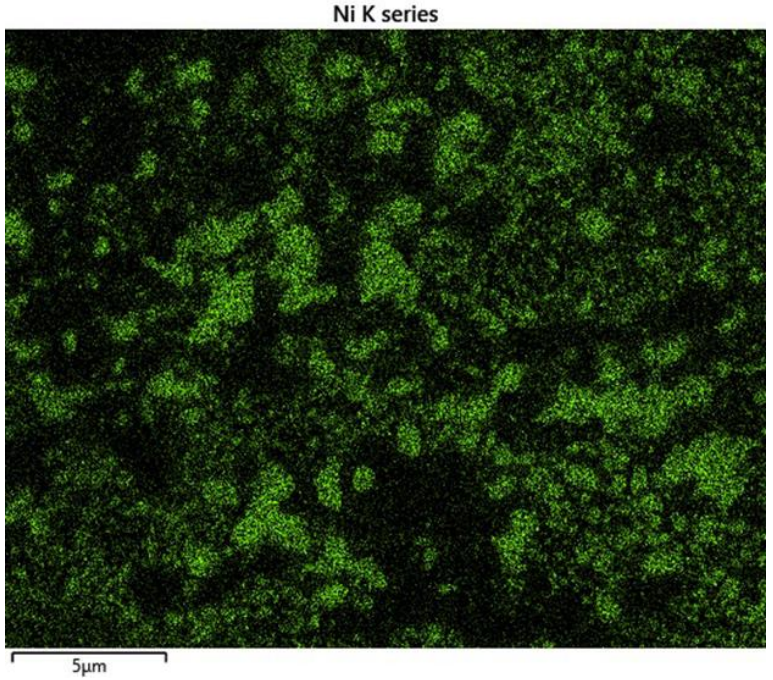
SEM EDS – Ni Mapping



Pristine, untested

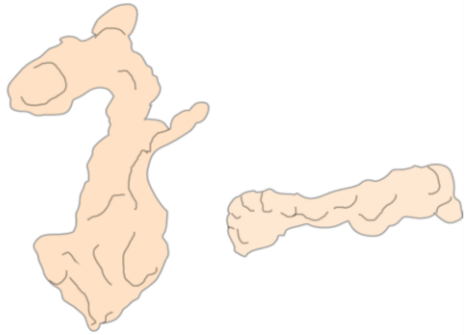


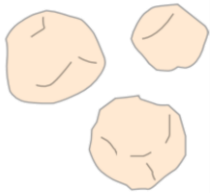
Pristine, tested

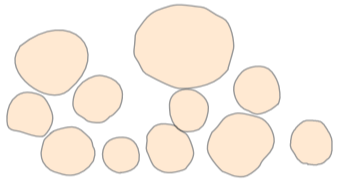


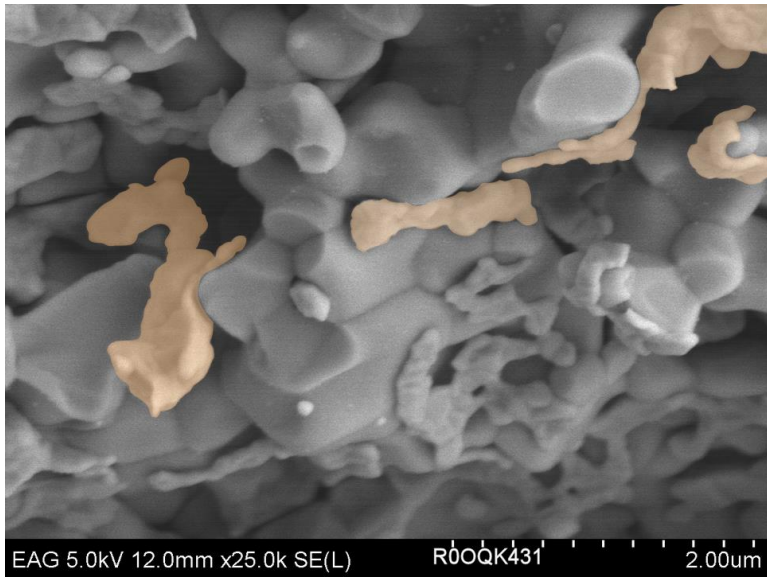
ALD coated, tested

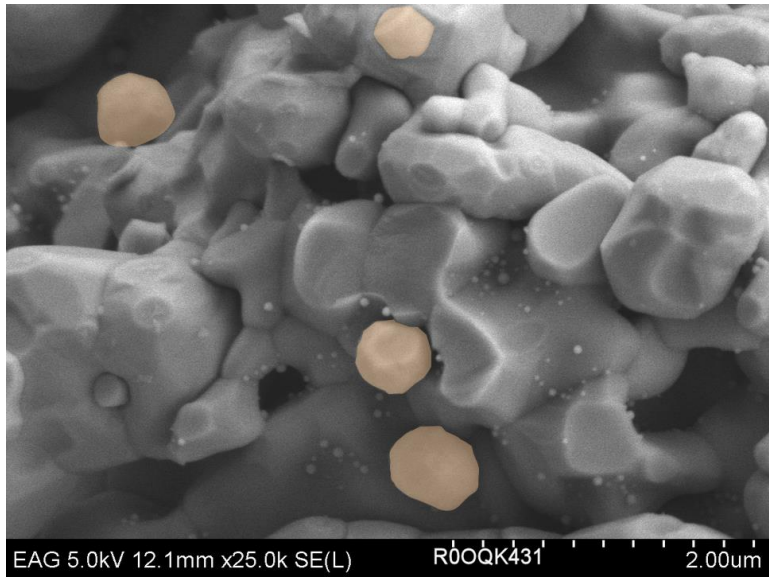
SEM Cross-Section

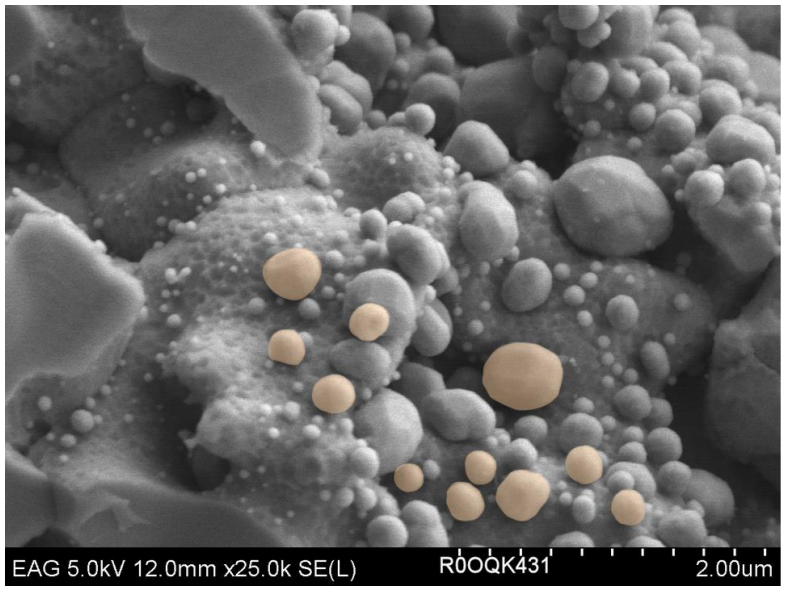










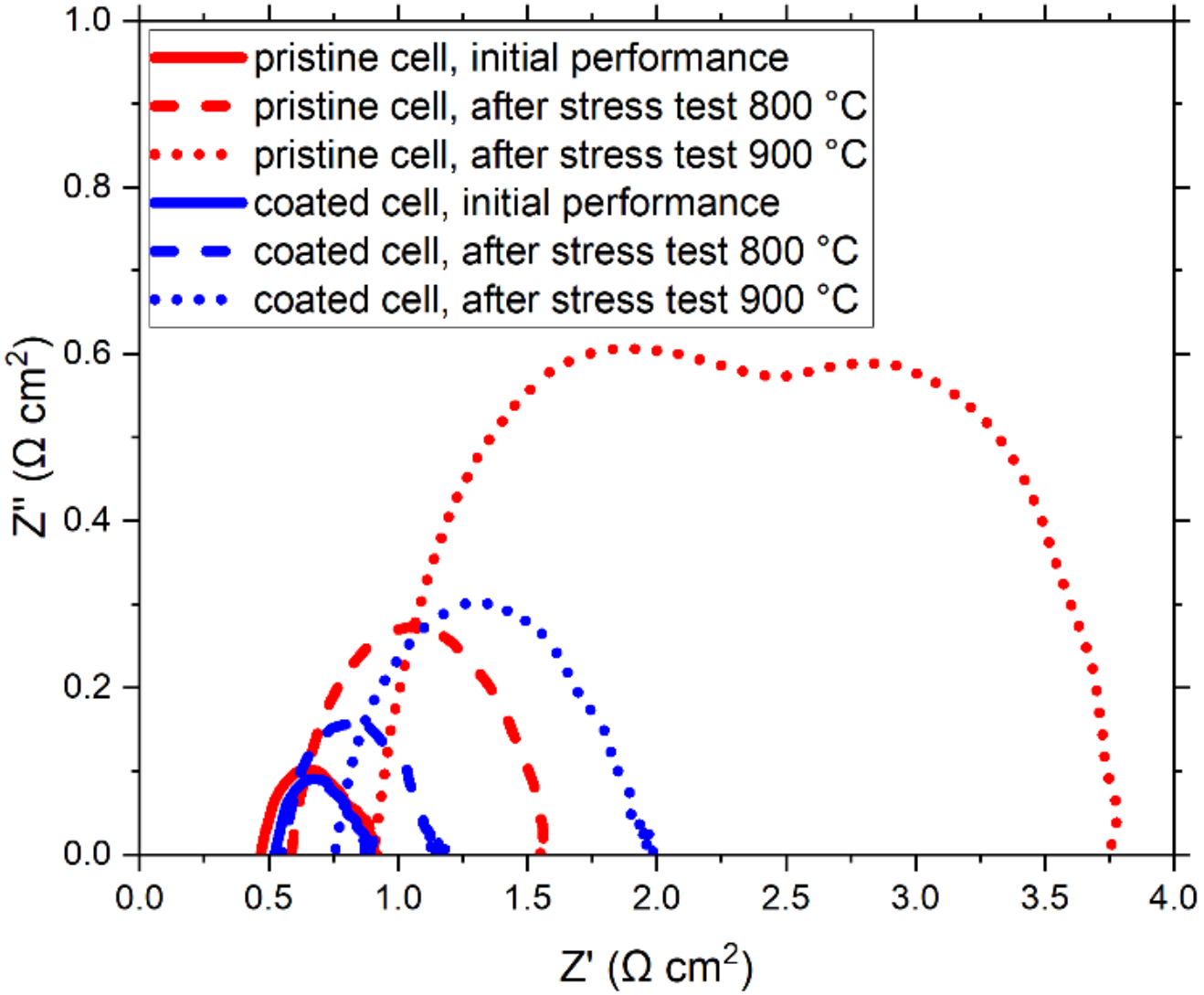


Pristine, untested

Pristine, tested

ALD coated, tested

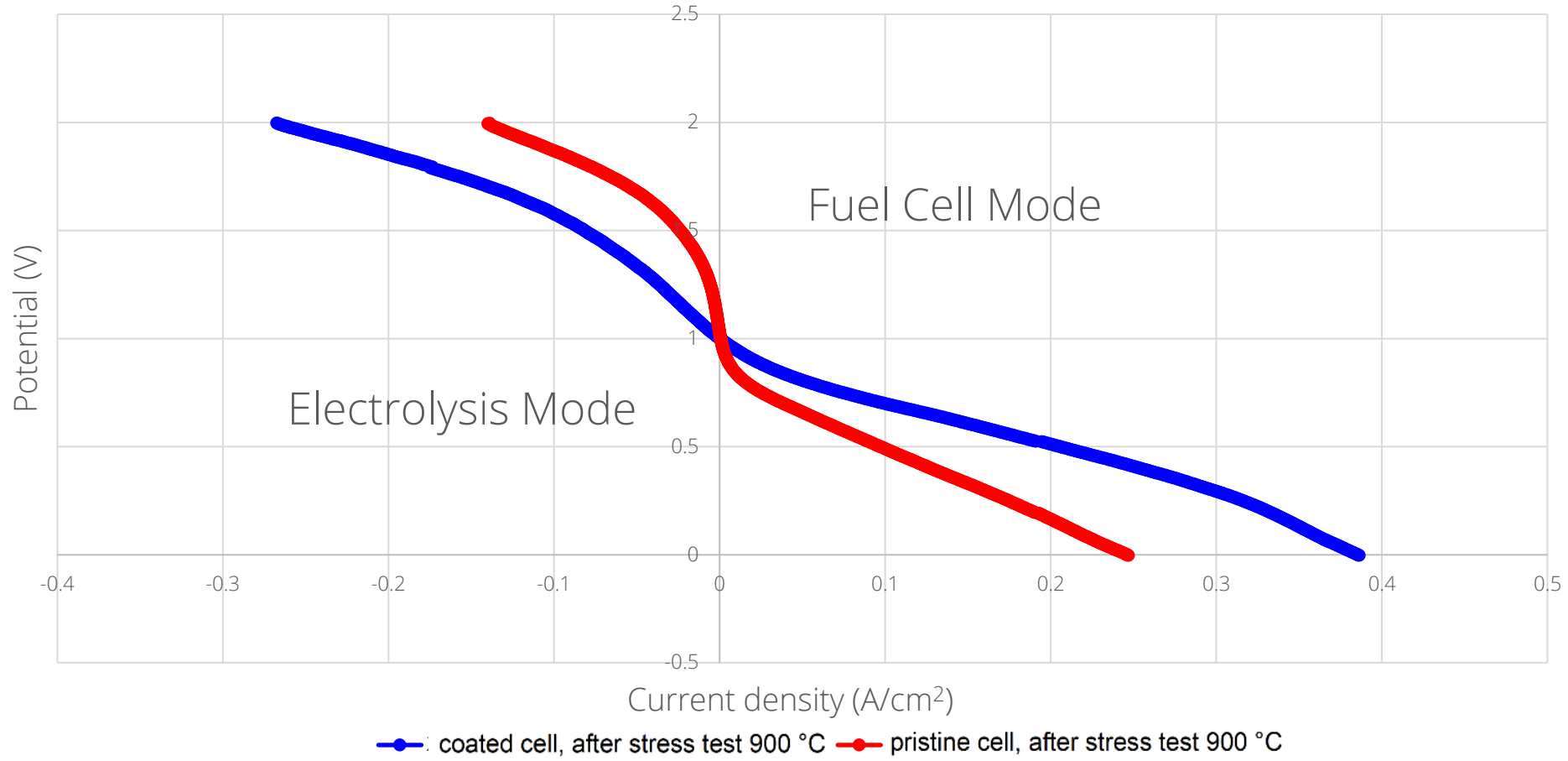
Electrochemical Impedence Spectra Comparison



Success!

Cells were tested in fuel-cell mode using humidified H_2 (3% H_2O)

I-V Curve Comparison



Collected with cell exposed to humidified H_2 (3% H_2O)

Phase I Summary

- We successfully developed an ALD process for depositing the proprietary anchor coating conformally on high aspect ratio surfaces

- We successfully demonstrated that a thin anchor coating deposited by ALD significantly enhances the thermal stability of Ni in an infiltrated Ni-YSZ electrode button cell

- We met with SOEC manufactures to evaluate scale up
  - There are various SOEC manufacturing processes and ways to introduce ALT-ALD

Planning for Success

- Strategic Collaboration with Dr. John Vohs of UPenn a SOEC expert
- Design a dedicated ALD reactor design for realizing the anchor coating on the SOEC hydrogen electrodes
- Collaborate with SOEC manufacturers in Phase II to bring this technology to their processes
- Open to a direct and/or licensing business model
- RMD has a growing portfolio with ALD technologies
  - Microelectronic Semiconductor Coatings
  - Photonic Integrated Circuits Coatings
  - Gas Barrier Coatings
  - RF Window Coatings
  - X-ray and Neutron Supermirror Coatings

ALD Batch Processing, PICOSUN P-1000
https://www.azom.com/article.aspx?ArticleID=11424

AckInowledgements

- Our Collaborator Dr. John Vohs of UPenn
- The RMD Advanced Thin Film Technologies Team
- Our Project Manager Debalina Dasgupta

Questions?