Atomic Layer Deposition of Nickel Anchor to Prevent SOEC Degradation

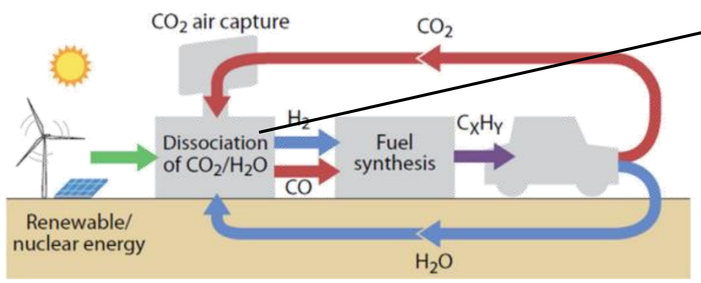
K. Hansen[1], O. Maksimov[1], J. M. Vohs[2], & H. Bhandari[1]

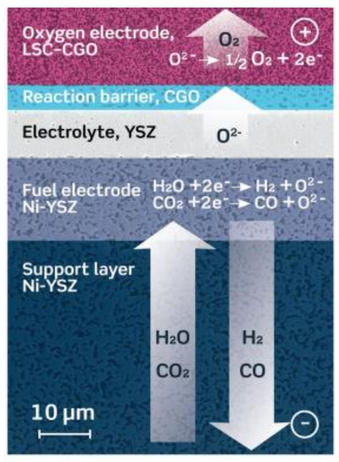
[1]Radiation Monitoring Devices, Watertown, MA 02472

[2]University of Pennsylvania, Philadelphia, PA 19104

Motivation

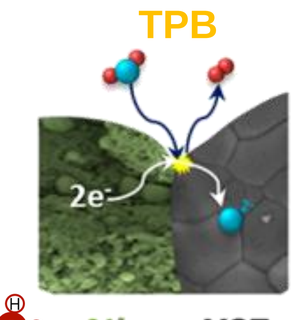
Solid oxide electrolysis cells (SOECs) are of interest for the direct electrochemical conversion of steam to hydrogen gas- a chemical fuel for sustainable closed-loop recycling of renewable energy[1,2]

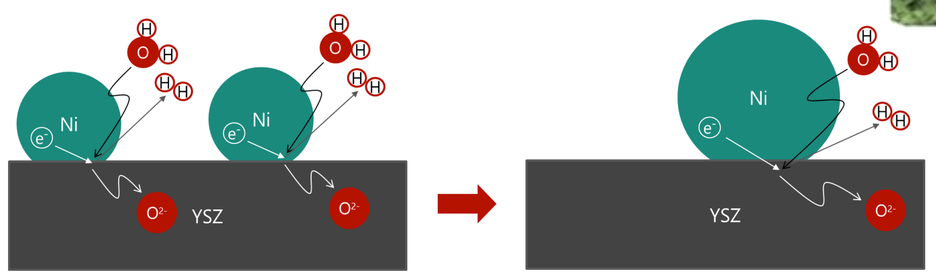




- A significant barrier to commercial viability of SOECs is the degradation of hydrogen electrodes during electrolysis

- Electrolysis occurs where Yttria-stabilized Zirconia (YSZ) and Nickel (Ni) come in contact with steam, also known as *Triple Phase Boundary (TPB)*[3,4]
- However, Ni migrates and agglomerates reducing the density of TPBs





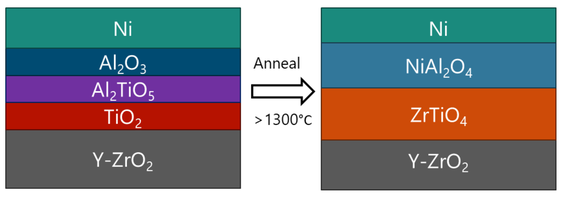
❖ Outlook: Develop robust electrode structure preventing Ni migration

❖ Challenge: Binding Ni in complex microstructure while preserving TPB

Innovative Solution

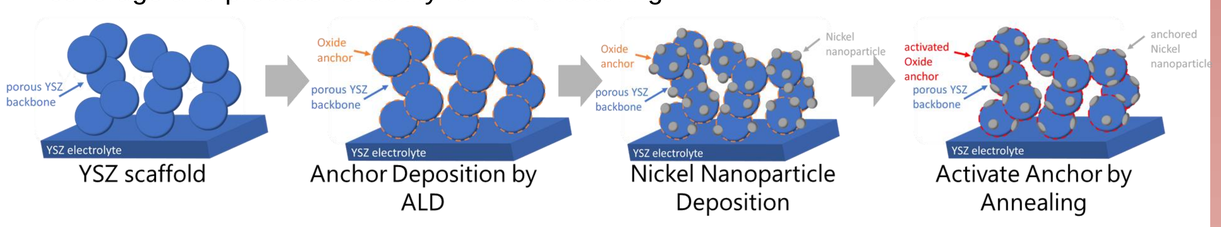
Conformal ALD coating of "Nickel anchor" compatible with SOEC manufacturing

- Anchoring prevents Ni migration and agglomeration while minimizing risk of blocking TPB
- Recent research suggests that applying *Aluminum Titanate (ALT)* in the Ni-YSZ composites can anchor the Ni catalyst and prevent agglomeration[5]

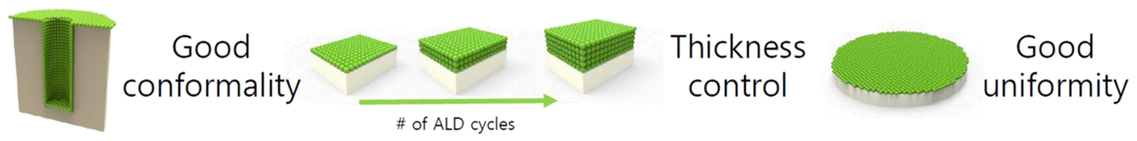


850°C $Al_2TiO_5 \rightarrow Al_2O_3 + TiO_2$
1100°C $Al_2O_3 + NiO \rightarrow NiAl_2O_4$
1300°C $TiO_2 + ZrO_2 \rightarrow ZrTiO_4$

- While this has been demonstrated via a solution infiltration method, there is a need for an alternate conformal coating technique for ALT with improved thickness precision, step coverage and process reliability for manufacturing

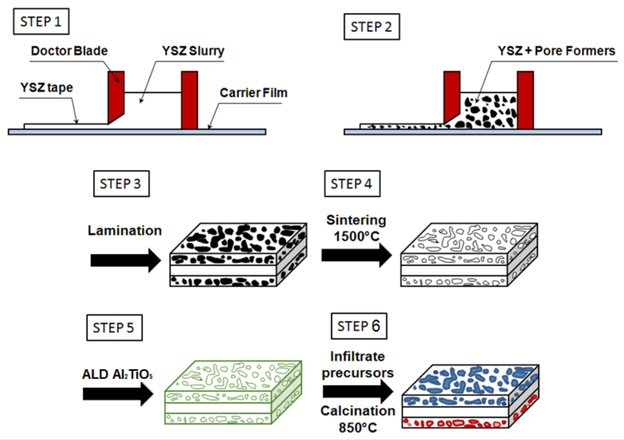


- Atomic layer deposition (ALD) is a conformal coating technique driven by surface chemistry that relies on controlled vapor infiltration in porous substrates to grow thin films with a nm-scale thickness control[6]



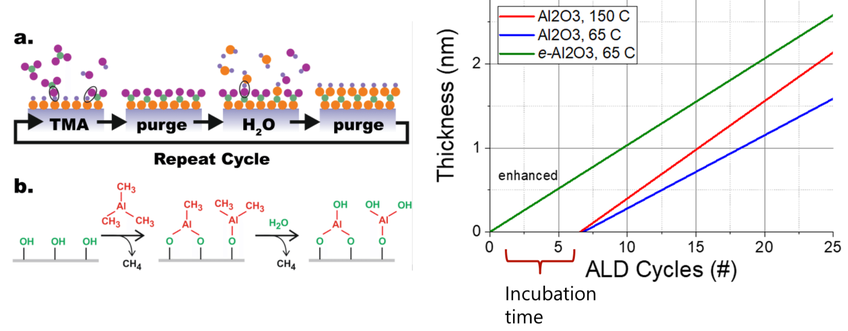
Approach

- Cells fabricated via tape casting
- ALT anchor will be deposited by ALD into the cell scaffold
  - ➢ precise control of the thickness and porosity of the ALT layer is critical
- Wet infiltration to add the active components
- Calcination anneal will activate anchor

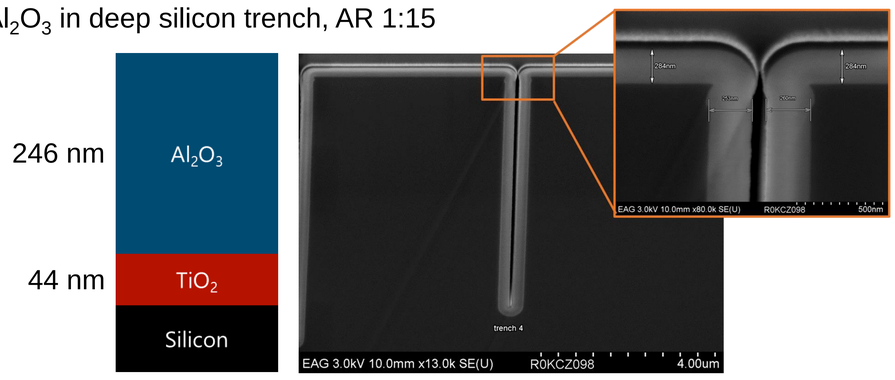


ALD Process Development

- Demonstrate Al_2O_3 growth at high and low temperatures with "incubation time" with non-linear growth to achieve porous films by ALD

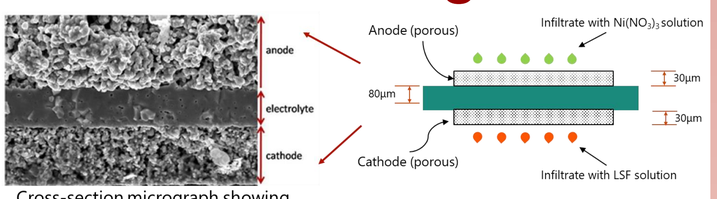


- SEM cross section analysis demonstrates uniform, conformal multilayer coating of TiO_2 and Al_2O_3 in deep silicon trench, AR 1:15

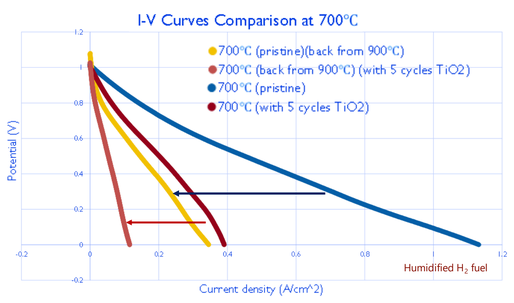


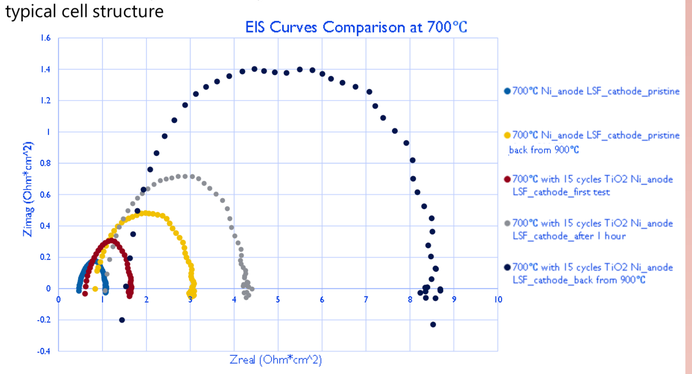
Cell Fabrication and Testing

- YSZ-based button test cells fabricated via slurry tape casting
- Ni added via wet infiltration
- Preliminary results of adding TiO_2 to hydrogen electrode prior to Ni infiltration and effect of TiO_2 interlayer on cathode performance



Cross-section micrograph showing a typical cell structure





Future Work

- Demonstrate the technical feasibility for the growth of the proposed ALT films via ALD in YSZ scaffolds provided for us by our collaborator, UPenn
- Evaluate and validate the performance of ALD-coated fuel electrode by performing representative electrolysis testing and evaluating the extent of nickel migration
- Evaluate and create a plan of process integration for manufacturing scale-up
  - ➢ Design a dedicated ALD reactor design for realizing the ALT 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

Bibliography

1. Hauch, A. et. al. Science. 370, (2020) 6513.
2. Mewafy, B., et. al. ACS Applied Energy Materials. 2, (2019) 7045-7055.
3. Zhang, X.; et. al. J. Ener. Chem. 26, (2017) 839.
4. Zhou, Z. et. al. Materials. 14, (2021) 3139.
5. Law, C. H.; Sofie, S. W. J. Elecrochem. Soc. 158, (2011) B1137.
6. Grillo, Fabio, et al., Catalysis Today. 316, (2018) 51-61.

Contact: Katherine Hansen, khansen@rmdinc.com

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