Development of High-Performance Metal-Supported Solid Oxide Electrolysis Cells (MS-SOECs) and Innovative Diagnostic Methodologies
FE0032110

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Project Objectives

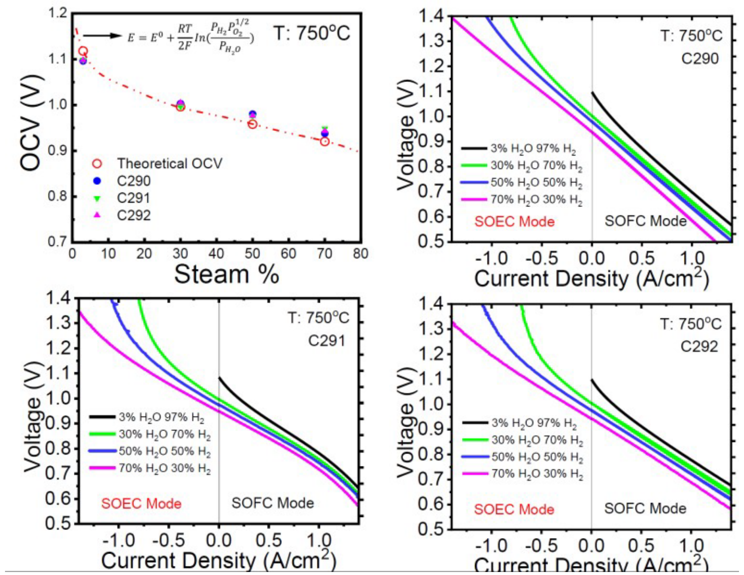
- To fabricate metal-supported solid oxide electrolysis cells (MS-SOECs) to improve the electrolysis performance and while maintaining the mechanical strength for the cells,
- To perform baseline cell testing and develop accelerated test protocols, and
- To perform theoretical and post analyses and employ machine learning to study the dependence of electrochemical performance on microstructural details

Effect of H_2O Concentration on the SOEC Performance

The research examines three reversible solid oxide cells (RSOCs), specifically focusing on the effects of steam concentration during operation.

The cells use a PGCO interlayer and a PNO oxygen electrode.

Effect of H_2O Concentration on the SOEC Performance



- The cells demonstrate good initial performance (OCV values match expectations).
- SOFC mode: Consistent performance is observed across different steam concentrations when the cells are operating as fuel cells (SOFC mode).
- Electrolysis mode: At high power demands in electrolyzer mode, performance is limited by concentration polarization (not enough water reactant available at a flow rate of 250 sccm).
- Solution: Increasing the steam concentration enhances performance, leading to a significant boost in current density (above 1.25 A/cm2 with 70% steam). This suggests better steam delivery to the reaction sites is key.

Finding: The results highlight the importance of steam concentration for optimizing the performance of these RSOCs in electrolysis mode.

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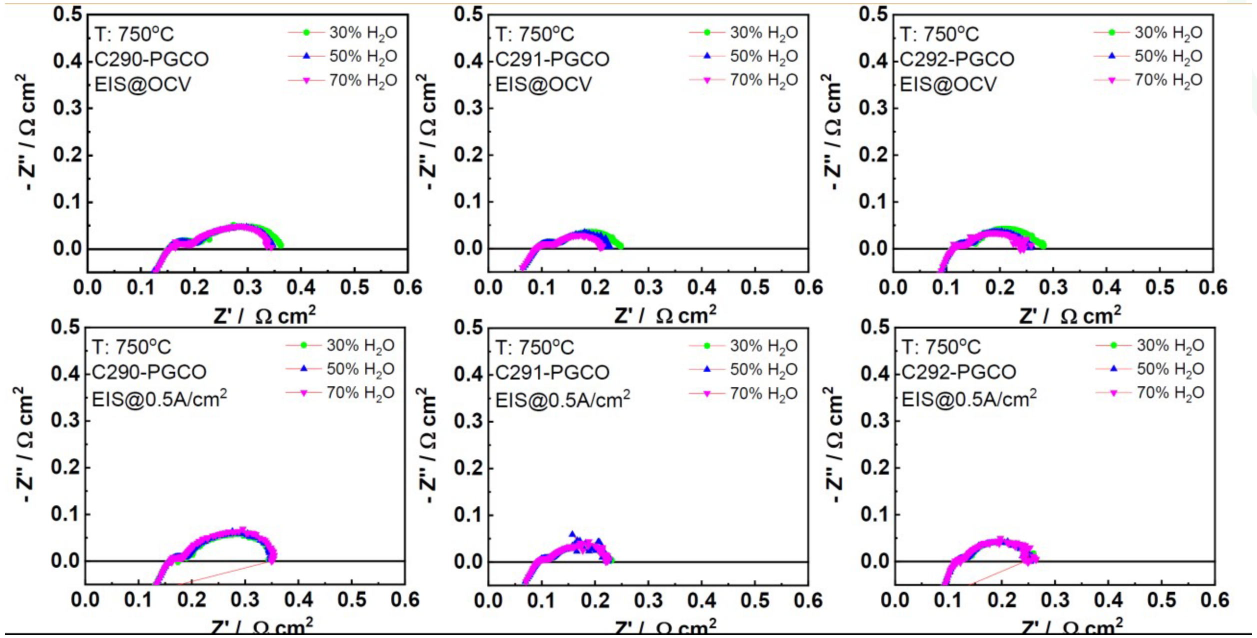
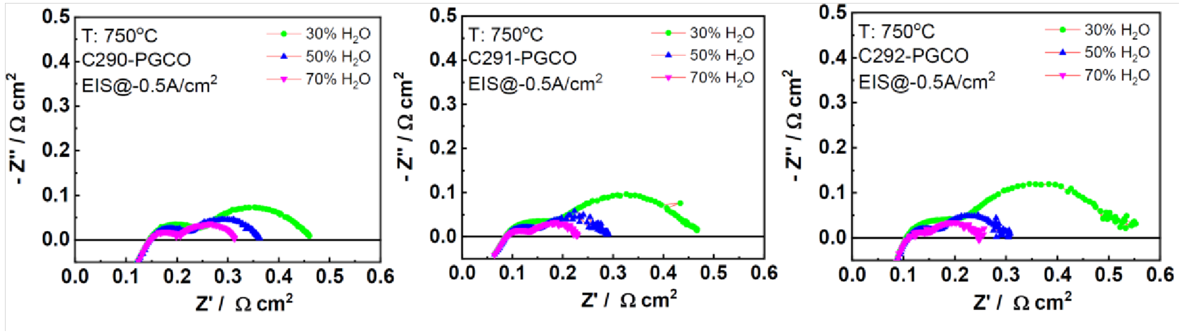


- Impedance studies reveal C291 and C292 with a good ohmic resistance (~0.1 Ω cm^2).
- Fuel cell mode impedances remain consistent with H_2O concentration, agreeing with parallel IV curves for I>0.
- Electrode polarization resistances decrease with increasing steam concentration.
- Under OCV, the electrode resistance (~0.13 Ω cm^2, including both oxygen electrode and fuel electrode contributions) is comparable to the ohmic resistance of 0.1 Ω cm^2, highlighting the potential benefits of further reducing the ohmic resistance for electrolysis current.

Effect of H_2O Concentration on the SOEC Performance



- A significant low-frequency arch is observed during electrolysis.
- Increasing steam concentration in the fuel electrode can markedly reduce this arch.
- The electrolysis EIS tested under 70% H_2O shows good agreement with the EIS at OCV.
- To suppress the low-frequency resistance effectively, a high steam% or improved steam diffusion pathway is recommended.

Effect of Cyclic Voltage on the SOEC Performance

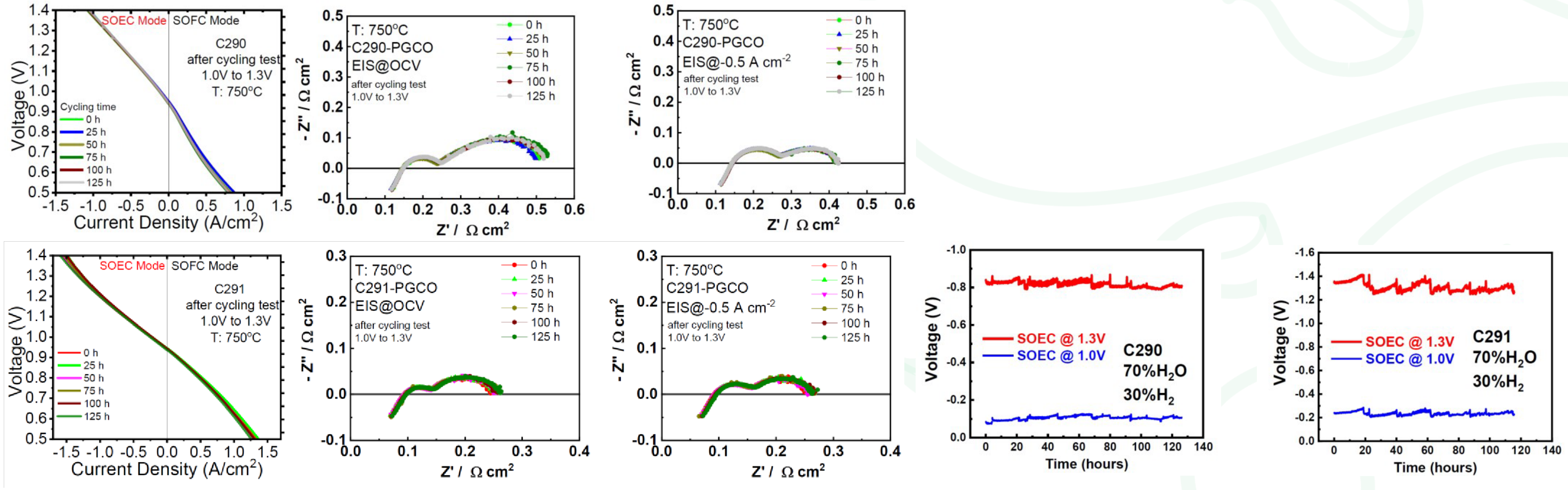
Main Test

- We tested two cells (C290 and C291) to evaluate their durability under switching conditions.

Cycling Details

- We cycled the voltage between 1.0V and 1.3V every 10 seconds in a humid hydrogen environment (70% H2O).

Effect of Cyclic Voltage on the SOEC Performance



Effect of Cyclic Voltage on the SOEC Performance

Results

- Minor fluctuations in voltage over time were observed, likely from refilling the water supply.
- Crucially, over 125 hours of this cycling, we saw almost no deterioration in these key performance indicators:
  - Electrolysis current density (how much hydrogen is produced)
  - Ohmic resistance (internal resistance of the cell)
  - Polarization resistance (resistance related to the electrochemical reaction itself)
  - IV curve (the overall relationship between current and voltage)

Finding

We demonstrate that these cells had remarkable stability and durability, maintaining their performance even under the stress of rapidly changing operating conditions.

Effect of Cyclic Operation on the SOEC Performance

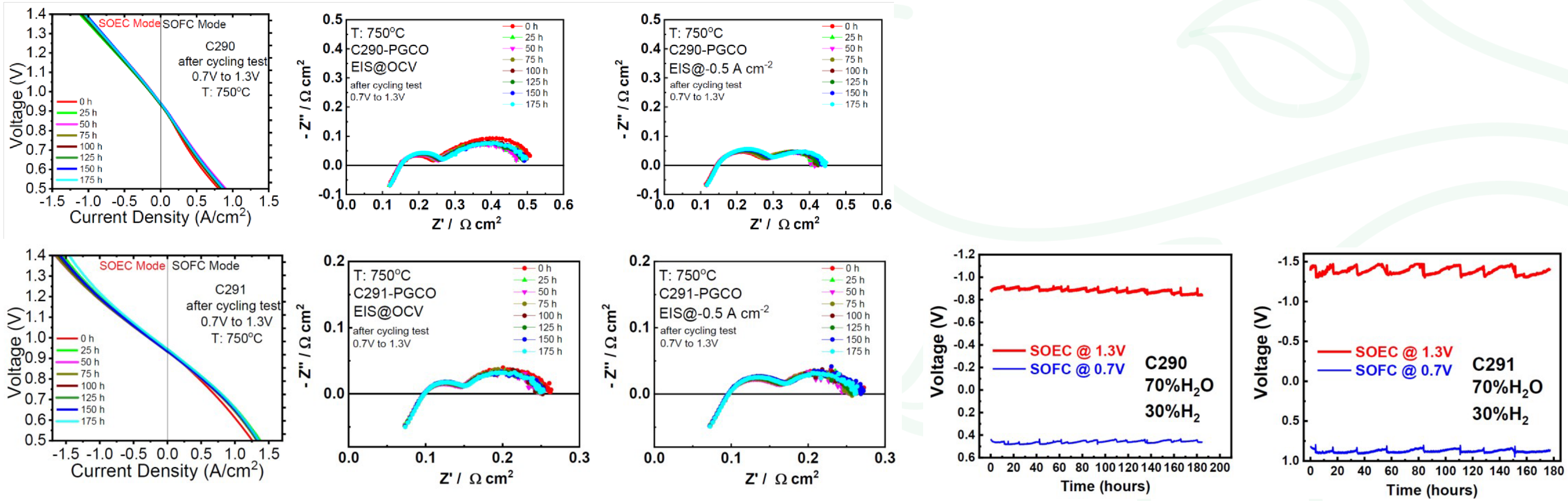
Main Test

- We conducted a long-term cycling test on the cells by repeatedly switched the cells between fuel cell mode (SOFC) and electrolysis mode (SOEC)
- This was done to evaluate the durability of the cells under real-world conditions of changing operation.

Cycling Details

- The cells were cycled between 0.7V (SOFC mode) and 1.3V (SOEC mode) every 10 seconds.
- This test ran for 175 hours, resulting in 31,500 repeated changes between the operation modes.

Effect of Cyclic Operation on the SOEC Performance



Effect of Cyclic Operation on the SOEC Performance

Results

- Both the impedance (a measure of resistance to current flow) and the electrolysis current remained stable throughout the test.
- This stability suggests that the materials and design of the electrodes are strong enough to withstand the repeated stress of changing operating modes.

Finding

We demonstrate that these cells are robust and perform consistently in both SOFC and SOEC modes. This makes them promising candidates for energy systems that need to seamlessly switch between energy generation and energy storage.

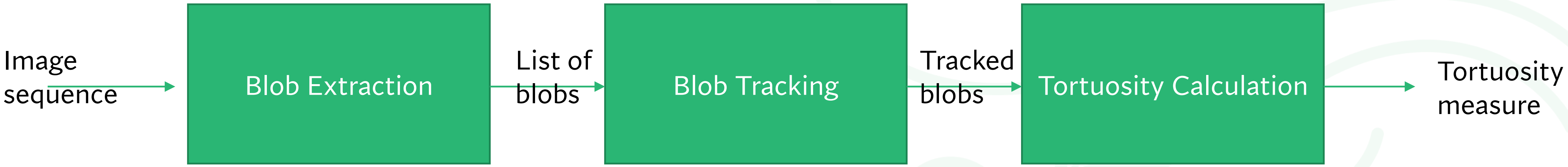
Theoretical Understanding of Effects of Operating Modes on the Performance Durability of Solid Oxide Cells

- Investigate how the choice between galvanostatic (constant current) and potentiostatic (constant voltage) operating modes in Solid Oxide Cells (SOCs) impacts their performance over time, especially when cell components begin to degrade
- Stable Cells: Initially, the operating mode (galvanostatic vs. potentiostatic) does not have a huge impact on performance.
- Degraded Cells: As components degrade, the operating mode becomes much more important for managing degradation and maintaining performance.
- Oxygen Electrode (OE) Degradation:
  - High oxygen pressure (p_{O2}) accelerates degradation? Constant voltage electrolysis helps mitigate this.
  - Low p_{O2} worsens degradation? Constant current electrolysis is preferable.
- Fuel Electrode (FE) Degradation:
  - High p_{O2} leads to issues? Constant current electrolysis is better.
  - Low p_{O2} is problematic? Constant voltage electrolysis helps

Machine vision processing of microstructural images acquired from electron microscopy

We obtained a set of 326 SEM images (Slice id # from 001 to 651 in increments of 2), each of which is 1536 by 1024, 8 bits per pixel. We initiated work to detect and track the pores in this initial set.

Our goal in this phase is to extract the holes, represented by the black image regions (hereinafter referred to as “blobs”), and track them. We can then calculate the tortuosity measure from the sequence of tracked blobs.



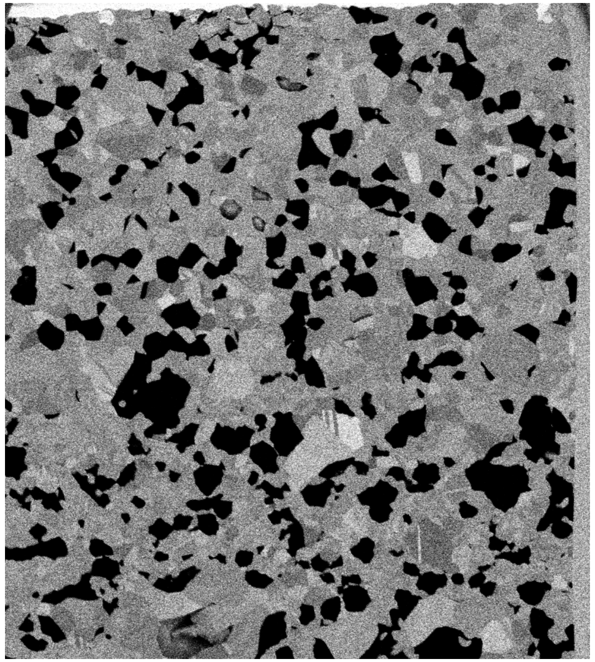
- Segmentation
- Post segmentation clean up

- Tracking based on matching location, shape, size of blobs

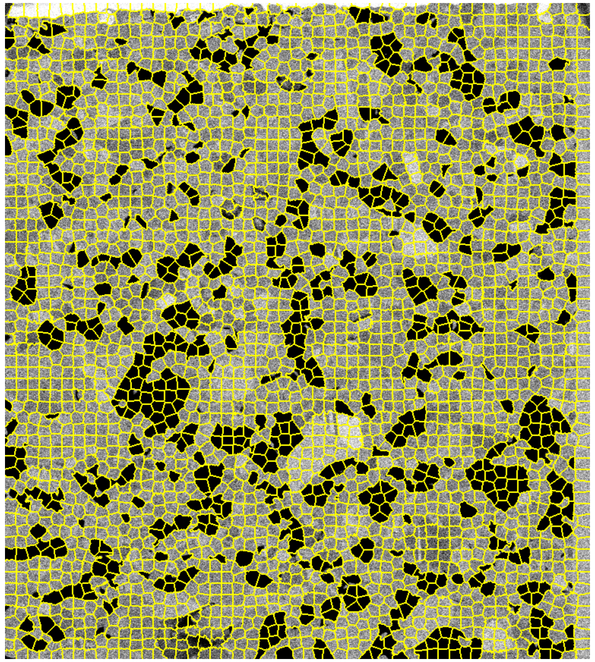
- Based on the length of the path that joins the list of tracked blobs

The extraction and tracking processes are being developed in parallel. The ultimate goal is to use deep learning for extraction of the blobs.
To facilitate the development of the tracking process, we temporarily use a simple thresholding method to extract the blobs.

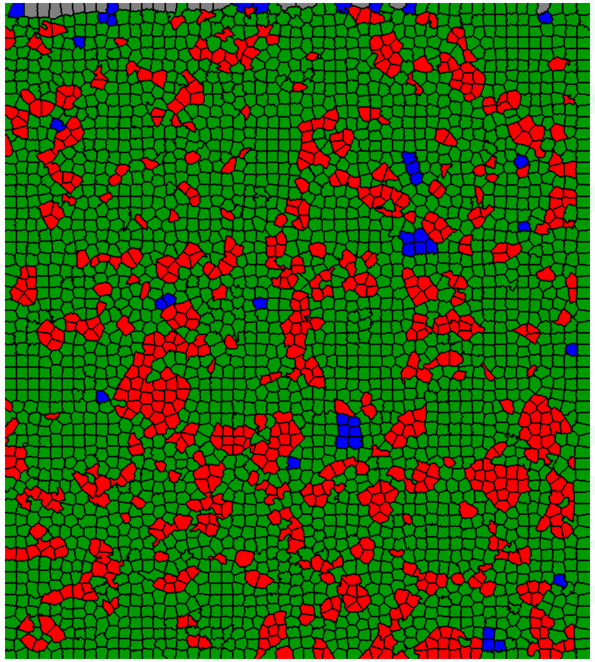
Image Segmentation and Labeling



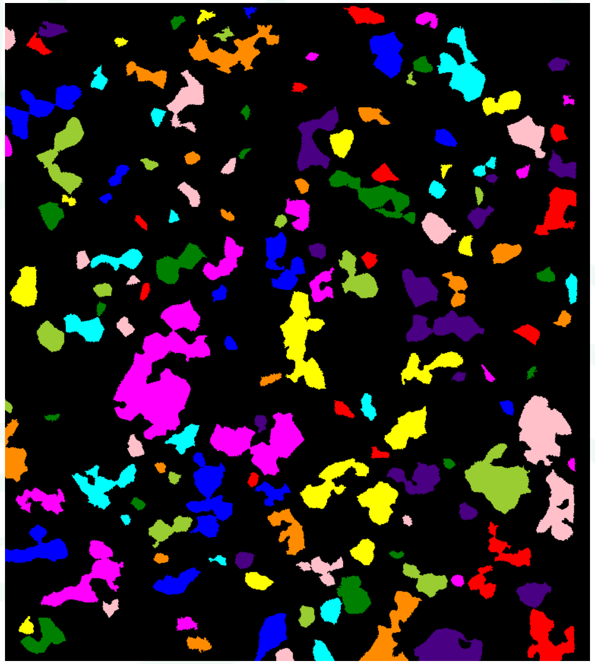
Original



Super Pixels



Classified Super Pixels



Each connected component (“blob”) is assigned a random color for illustration

Progress Thus Far

Cell Performance

- Good Open Circuit Voltage (OCV): Cells function as expected, with OCV aligning with theoretical values.
- SOFC vs. SOEC: Cells perform well as fuel cells (SOFC mode). However, in electrolysis mode (SOEC), concentration polarization occurs at high current densities.
- Steam Concentration Impact: Increasing steam concentration improves SOEC performance up to a specific current density (1.25 A/cm^2 at 70% H_2O).

Impedance Analysis

- Low Ohmic Resistance: Cells labeled C291 and C292 exhibit good ohmic resistance (~0.1 Ω cm^2).
- Electrode Polarization Dependence: Electrode resistances decrease with higher steam concentration.
- Room for Improvement: Reducing ohmic resistance could further improve SOEC performance.

Other Observations

- Cycling Stability: Cells C290 and C292 showed no performance degradation during cycling tests.
- Low-Frequency Impedance Changes: Increasing steam concentration in the fuel electrode reduces impedance issues seen at low frequencies during electrolysis.

For more information

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