Cation Migration and LSCF/SDC Decomposition Related to Long-Term Operation Mode as Revealed by Electron Microscopy

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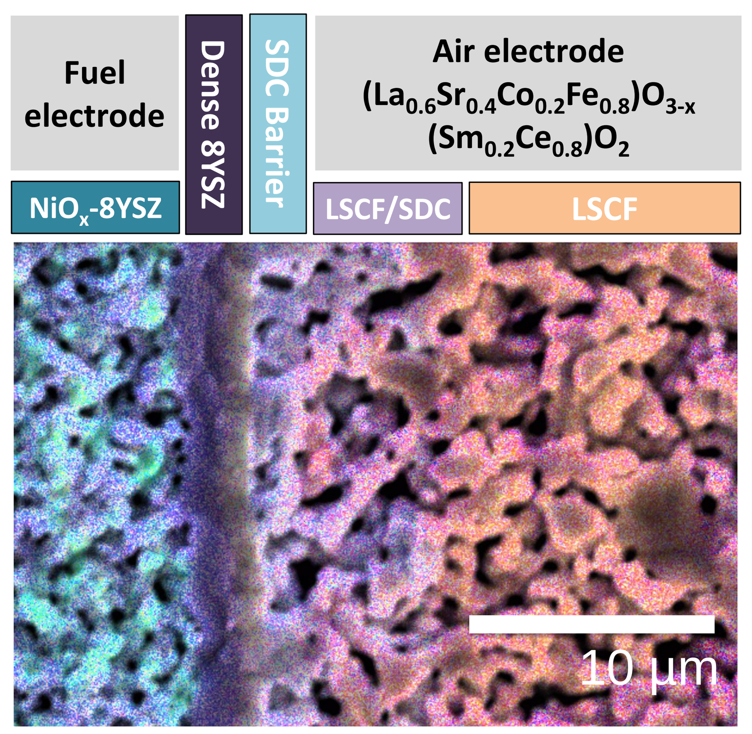
Abstract: Solid Oxide Cell Performance Degradation

Commercial solid oxide cells (SOCs) exhibit performance degradation for various operation modes: fuel cell, electrolysis, and reversible. Cation migration is a well-established mechanism related to performance degradation, so "barrier" layers are often employed to mitigate this migration and retain the desired composition for electrode particles.

Motivation: SDC Barrier Influence on Cation Migration

Utilize energy dispersive spectroscopy (EDS) in electron microscopes to track cation migration and particle decomposition in air electrodes as a function of long-term (>1,000 hr) operating conditions for commercial cells incorporating a Sm-doped ceria barrier (SDC) layer.



Cross-section SEM/EDS image of electrode/electrolyte interfaces for anode-supported commercial SOFC button cell (Nexceris).

4 operations in this study

As-made: OCV 120 hrs

SOFC mode: 1,657 hrs

SOEC mode: 1,437 hrs

r-SOC mode: 1,000 hrs

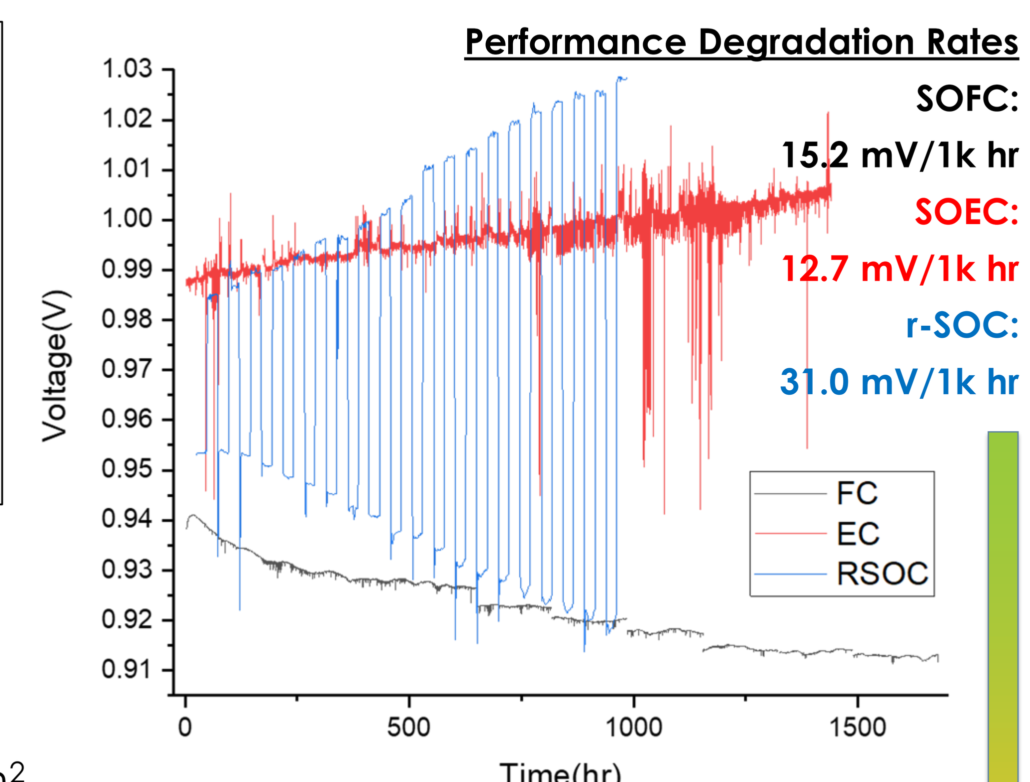
Operation parameters

Temperature: 850 °C

Current Density: 0.5 A/cm^2

Fuel cell mode: 100% H_2

Electrolysis mode: 50% steam/50% H_2

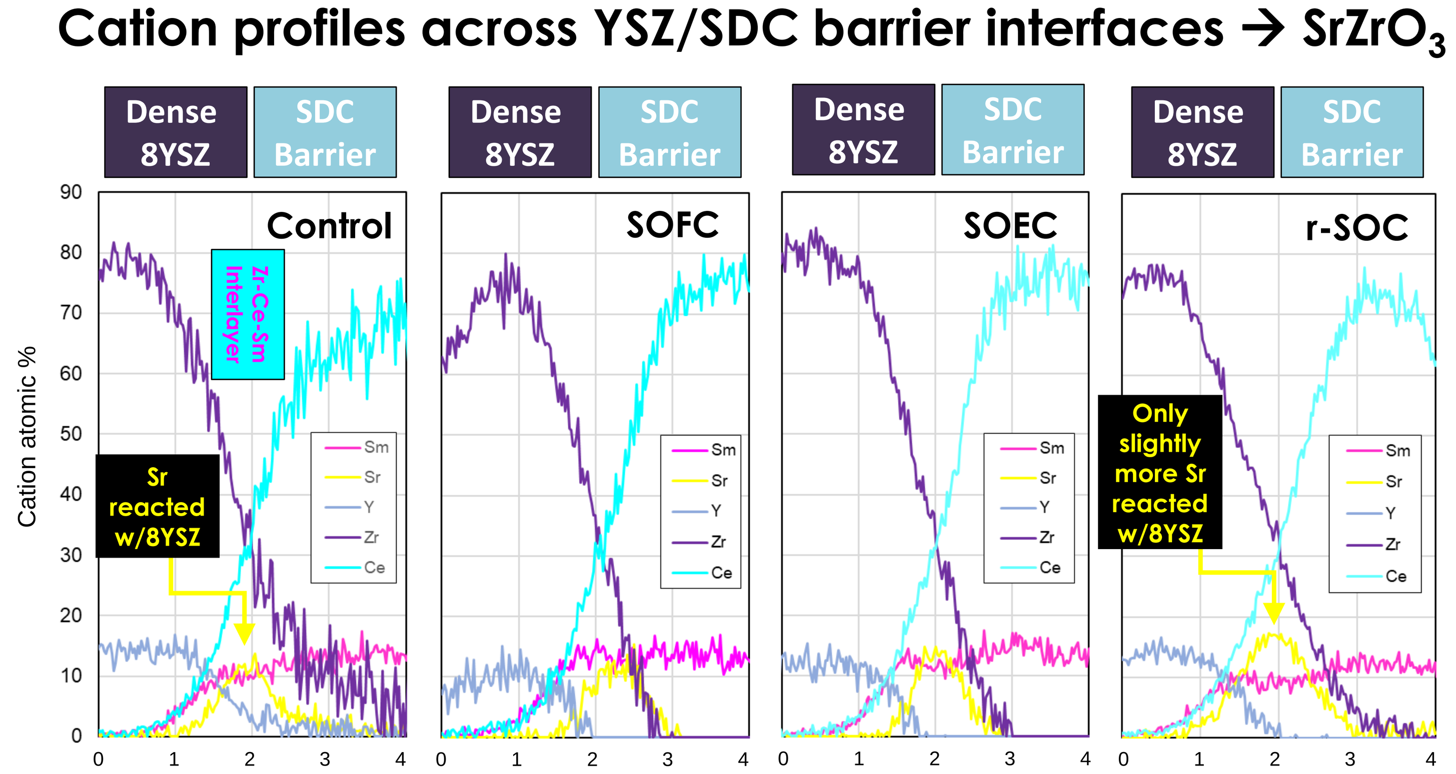


Cell voltage over time (above) for the three operation conditions.

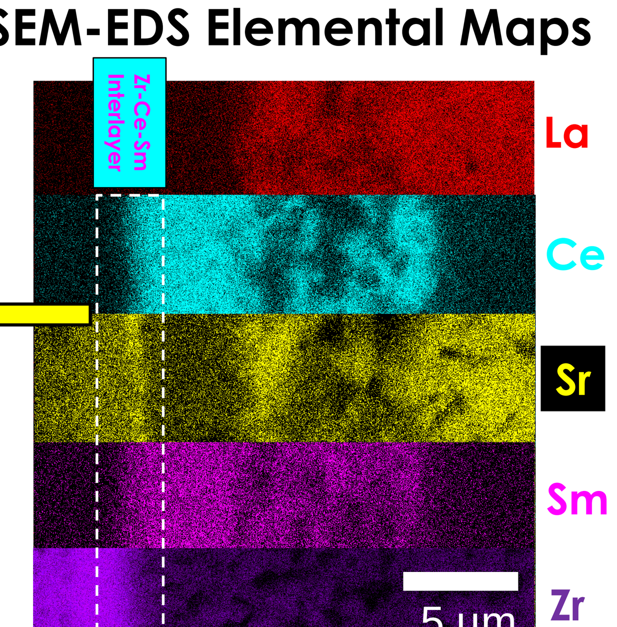
Scanning Electron Microscopy (SEM) - EDS

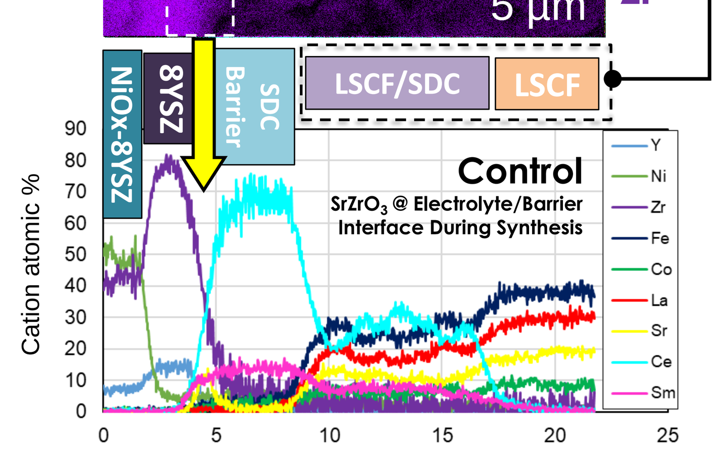
Q600 SEM @ Carnegie Mellon Univ., 20 keV, 1,024 pixel, 5 µs dwell time, drift-corrected, 2,500x magnification mapping

Cation profiles across YSZ/SDC barrier interfaces → $SrZrO_3$

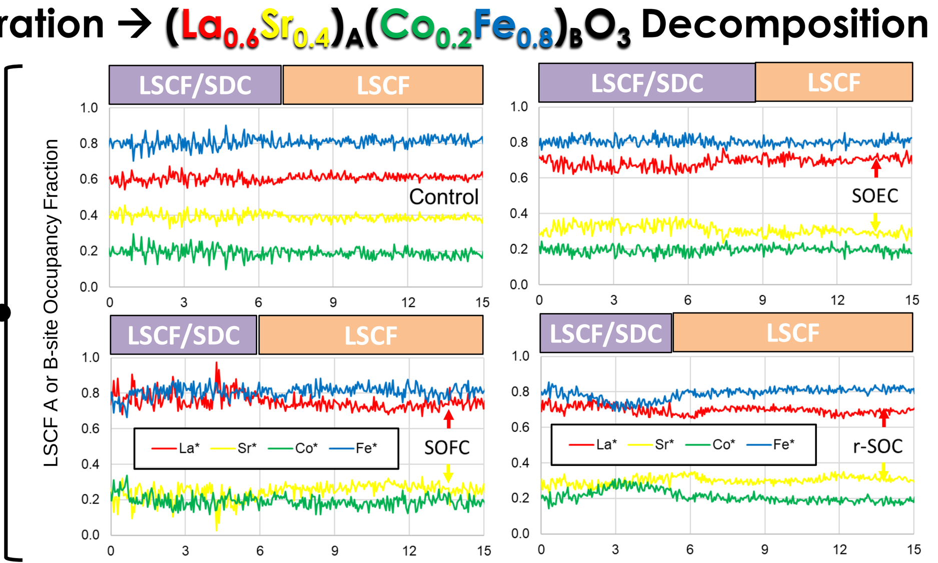


SEM-EDS Elemental Maps

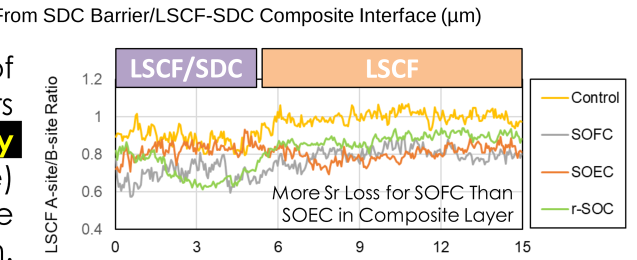




Operation → $(La_{0.6}Sr_{0.4})_A(Co_{0.2}Fe_{0.8})_BO_3$ Decomposition



SEM-EDS profiles of barrier/composite layers indicate **Sr loss by evaporation** (above) leading to increased A-site deficiency w/operation.



Scanning Transmission Electron Microscopy (STEM) - EDS

Thermo-Fisher Themis 200 G3 STEM w/Super-X EDS @ Carnegie Mellon Univ.
200 keV, 1,024 x 1,024 pixel maps, 10 µs dwell time, 100 frames/acquisition

Sample preparation – FEI Nanolab Focused Ion Beam (FIB) @ CMU

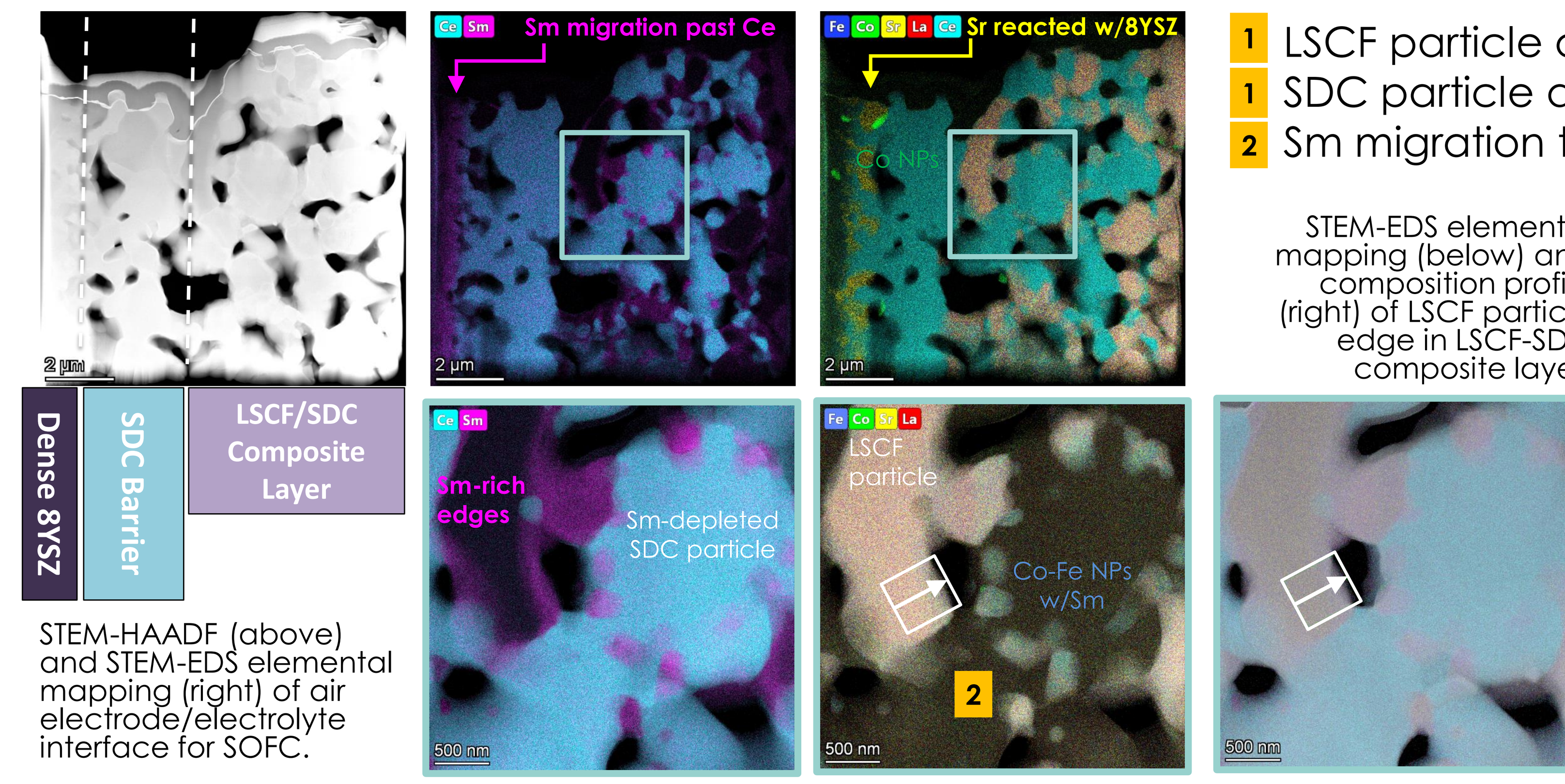
- 30 keV Ga+ beam ion milling, lift-out
- Site-specific analysis: **air electrode/electrolyte interface**

SOFC: 1,657 hours operation

1 LSCF particle decomposition: La/Sr depletion at particle edges

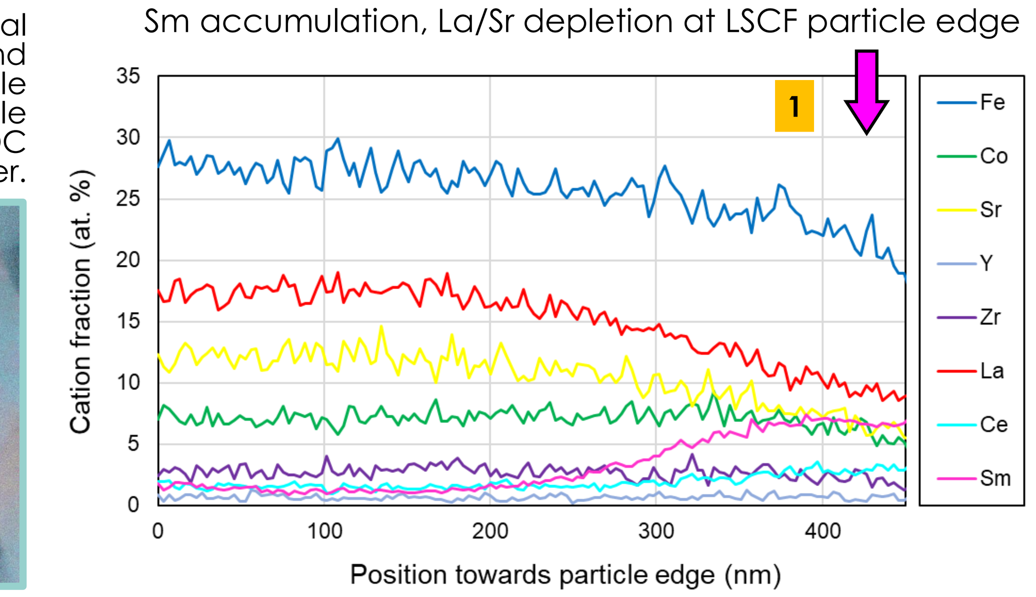
1 SDC particle decomposition: Sm accumulation at LSCF edges

2 Sm migration to Co-Fe-O nanoparticles (NPs) contacting SDC



STEM-HAADF (above) and STEM-EDS elemental mapping (right) of air electrode/electrolyte interface for SOFC.

STEM-EDS elemental mapping (below) and composition profile (right) of LSCF particle edge in LSCF-SDC composite layer.

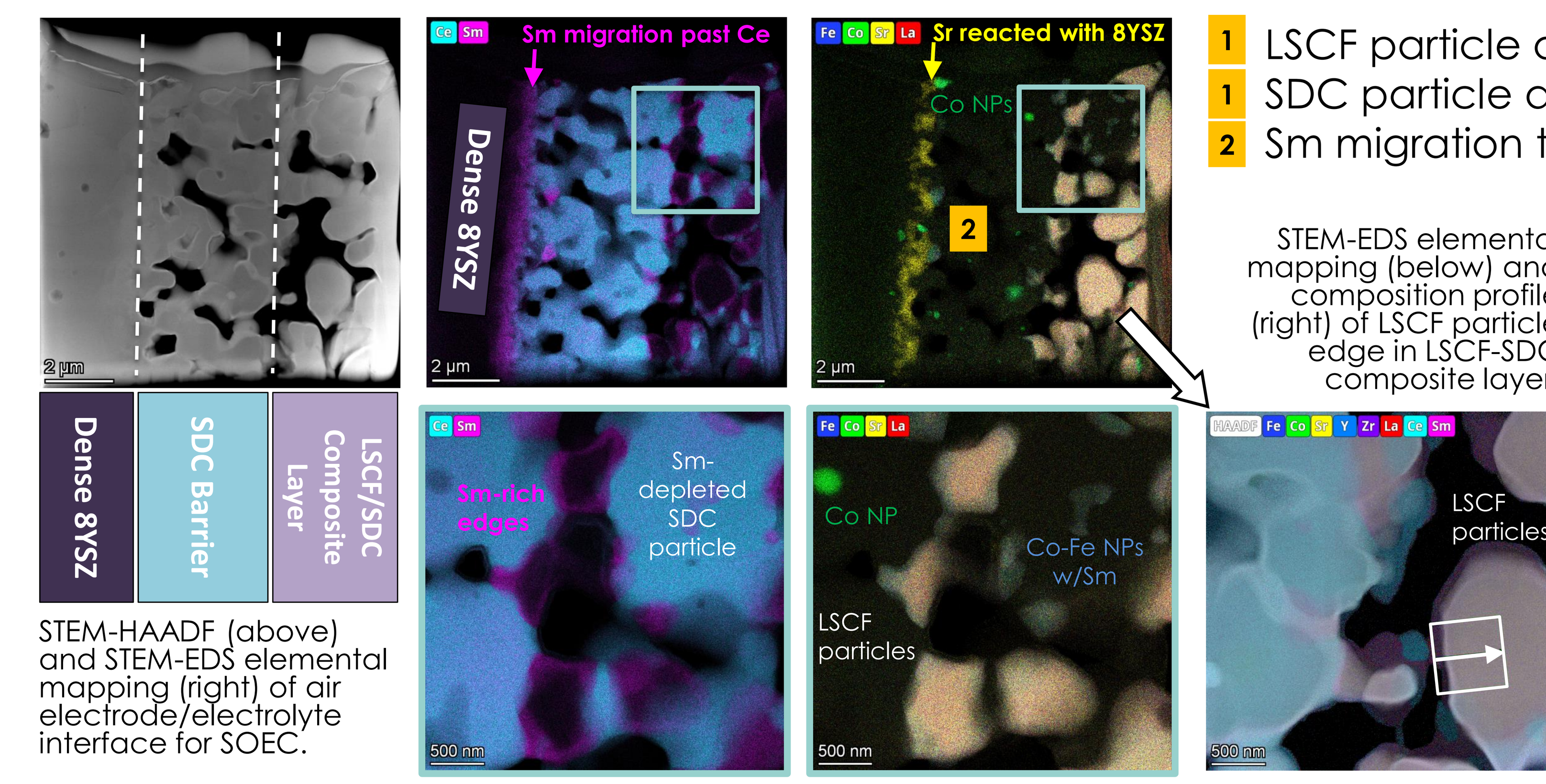


SOEC: 1,437 hours operation

1 LSCF particle decomposition: La/Sr depletion at edges

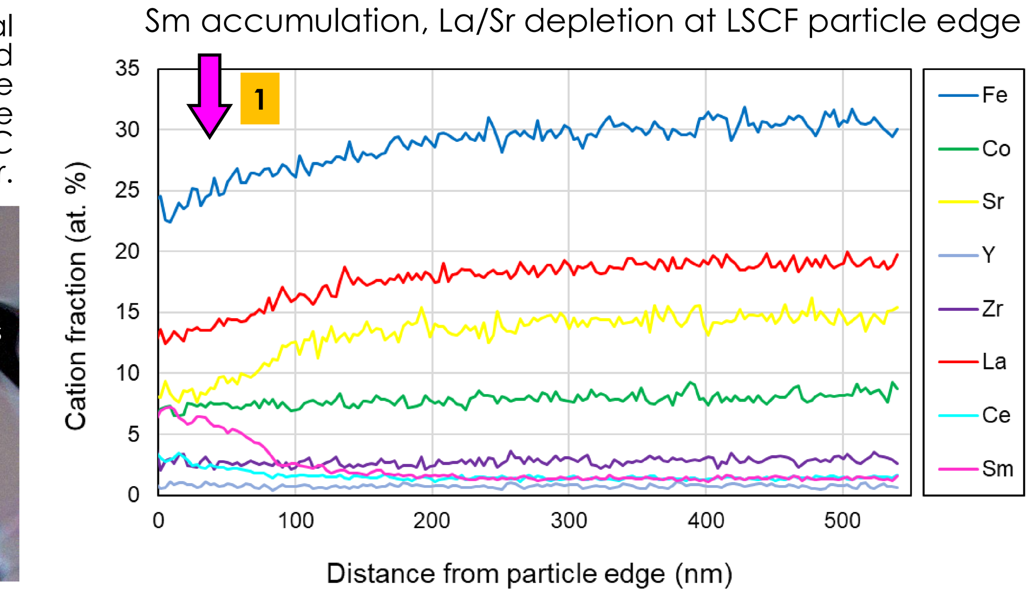
1 SDC particle decomposition: Sm accumulation at LSCF edges

2 Sm migration to Co-Fe-O nanoparticles (NPs) contacting SDC



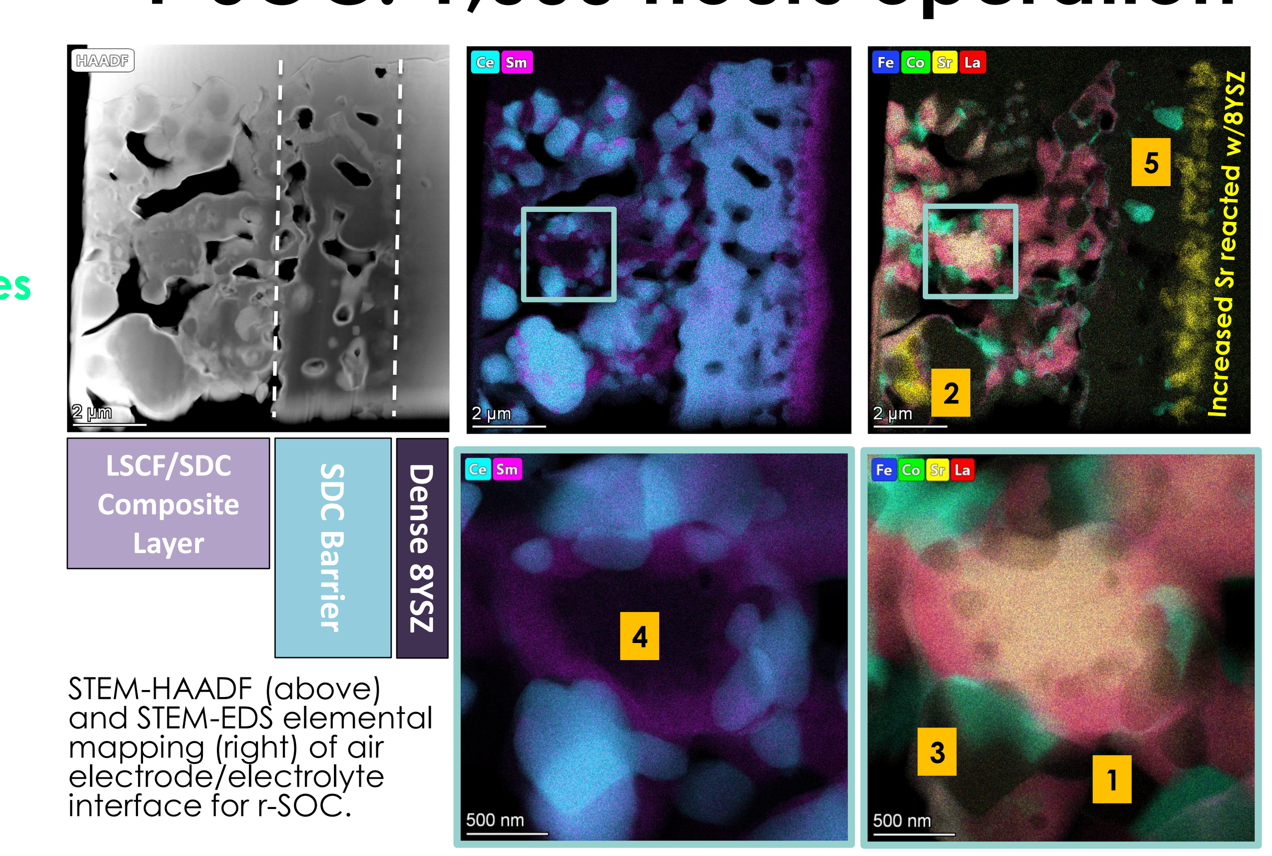
STEM-HAADF (above) and STEM-EDS elemental mapping (right) of air electrode/electrolyte interface for SOEC.

STEM-EDS elemental mapping (below) and composition profile (right) of LSCF particle edge in LSCF-SDC composite layer.



r-SOC: 1,000 hours operation

- LSCF particle decomposition into:
  1 La-Fe-oxides
  2 Sr-rich oxides
  3 Fe-rich Co-Fe-oxides (no Sm)
- SDC particle decomposition: Sm migration to La-Fe-oxides in composite layer 4
- No Sm migration to Co-Fe-O particles in contact with SDC inside barrier layer 5



STEM-HAADF (above) and STEM-EDS elemental mapping (right) of air electrode/electrolyte interface for r-SOC.