# A Bifunctional Ceramic Fuel Cell Energy System

## An Update on Reversible Air-electrodes Development

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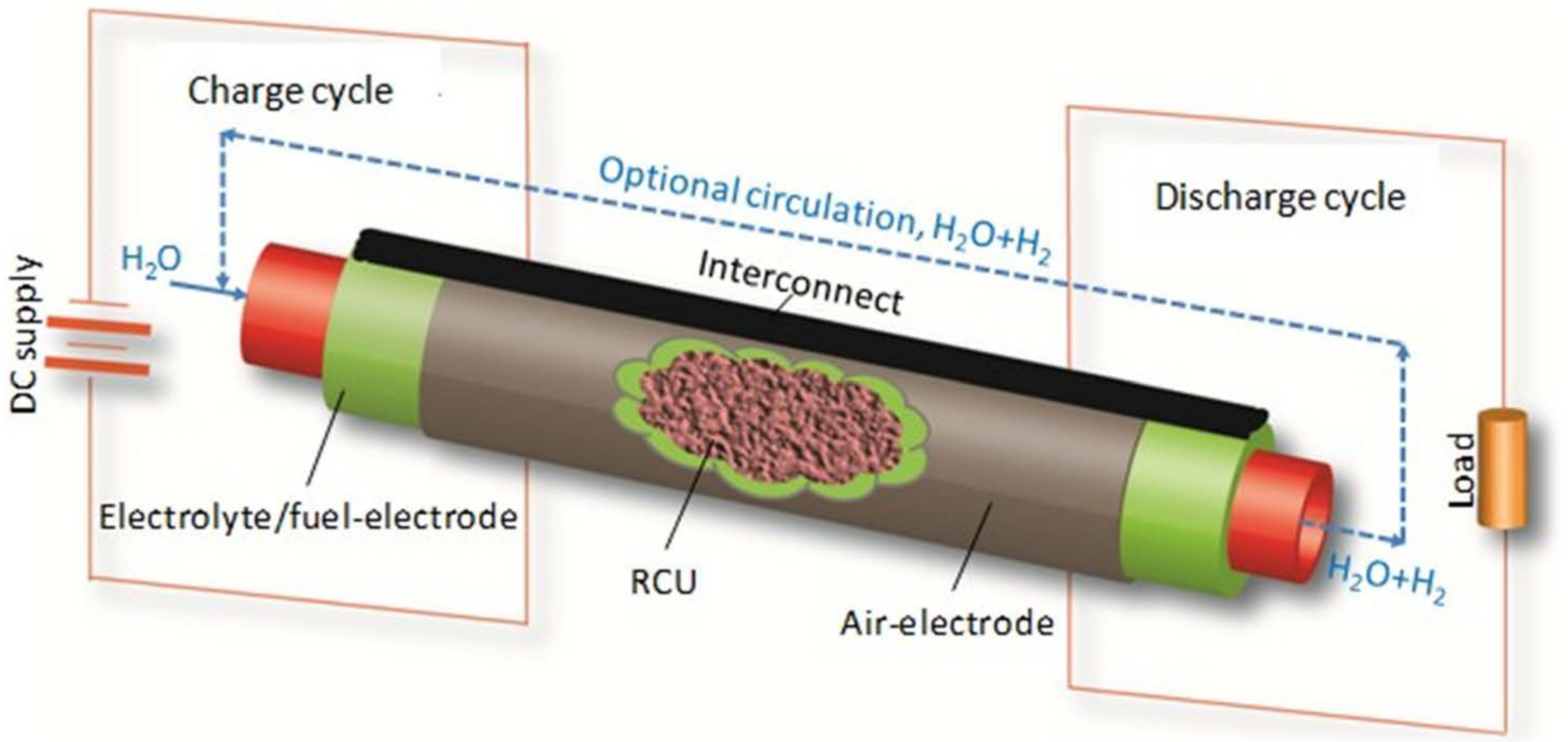
Award#: DE-AR-0000492

# About this REBELS Project

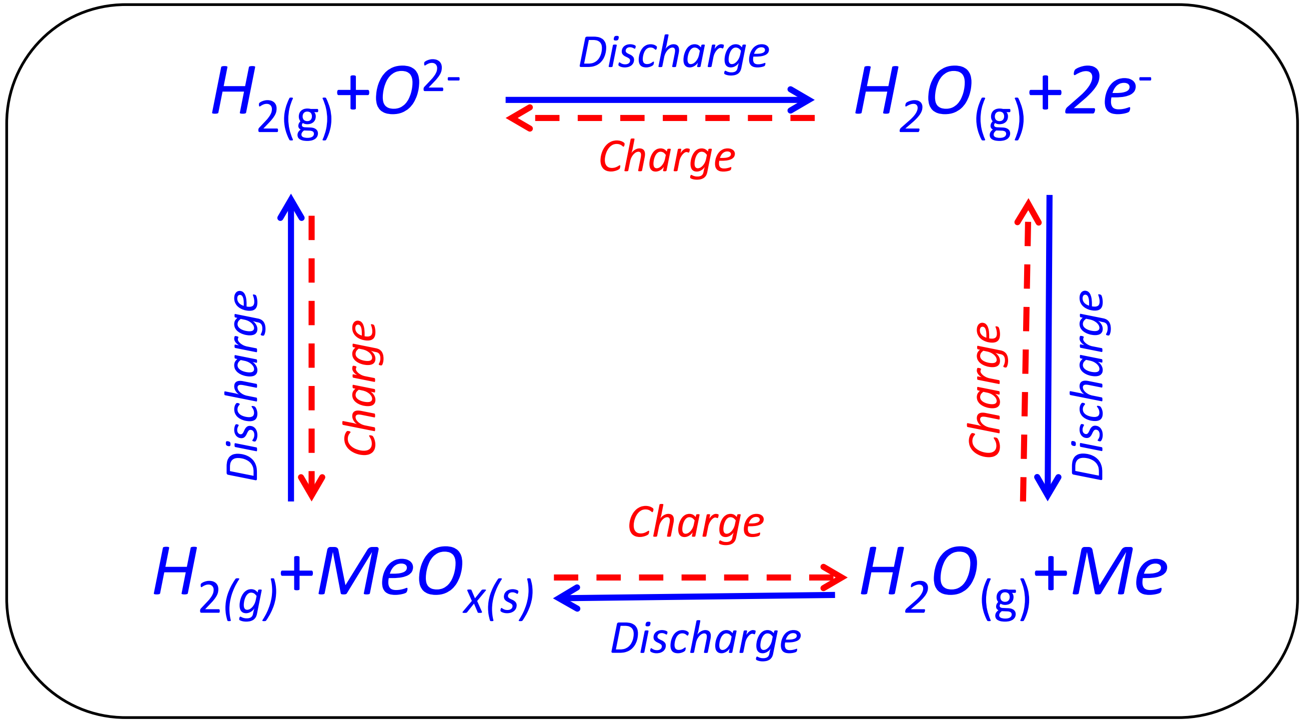
- Demonstration of power generation and energy storage functionality of the new fuel-cell/battery hybrid system at bench-scale
- Development of reversible IT-air-electrodes
- Development of IT-electrolytes
- Development of Fe-based energy storage materials
- Development of computational models

# The Battery Configuration




***Energy Environ. Sci.***, *2011, 4, 4942–4946*

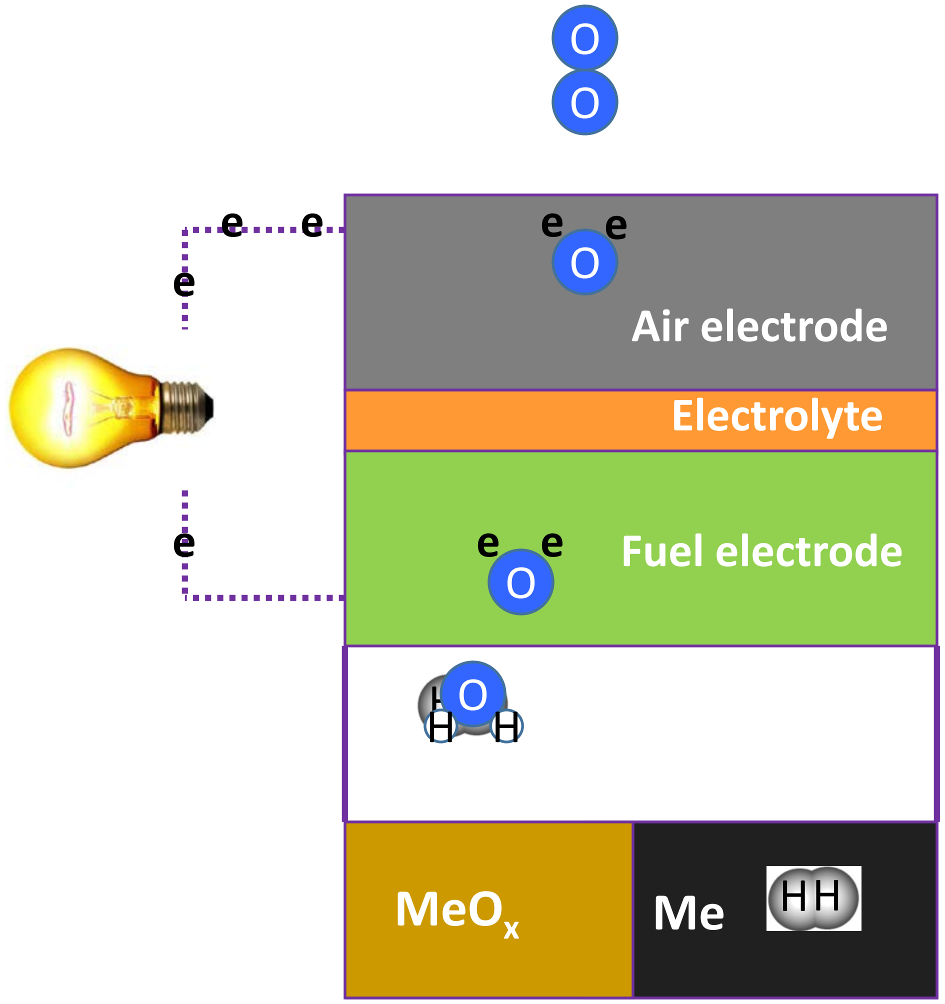
# The New Battery Chemistry



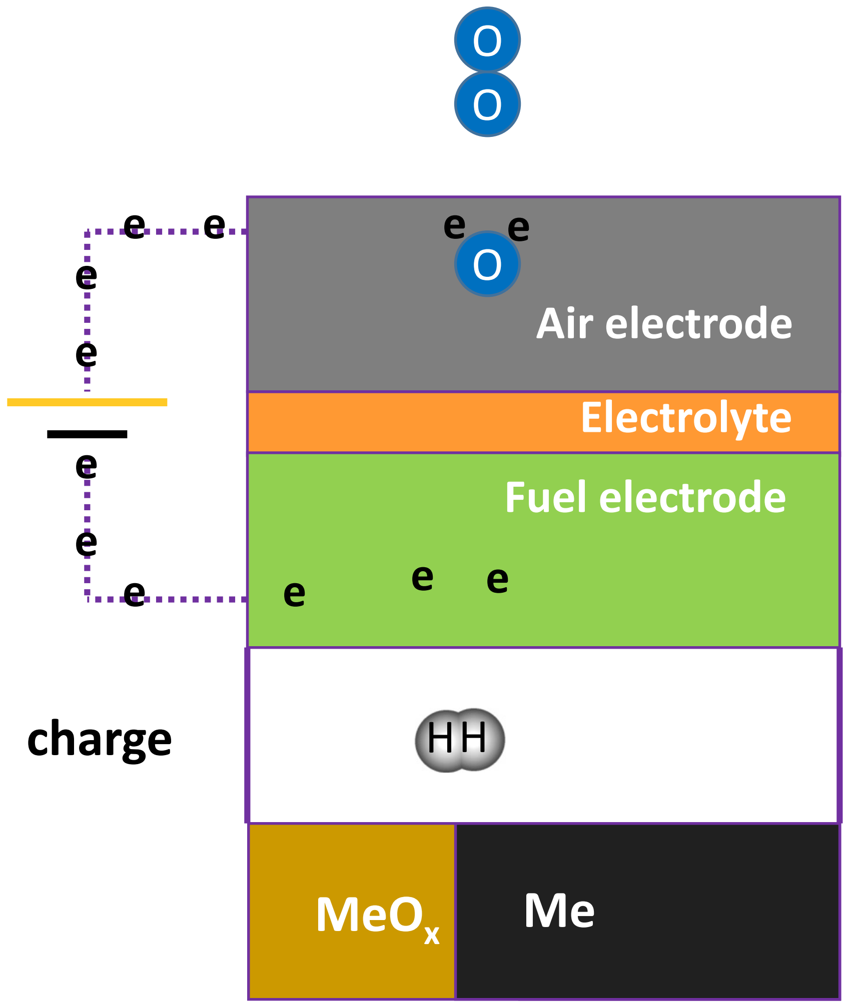

**Overall Reaction:** $$Me+\frac{x}{2}O_2 \underset{Charge}{\overset{Discharge}{\rightleftarrows}} MeO_x$$

**<u>S</u>olid <u>O</u>xide <u>M</u>etal <u>A</u>ir <u>R</u>edox <u>B</u>attery (SOMARB)**

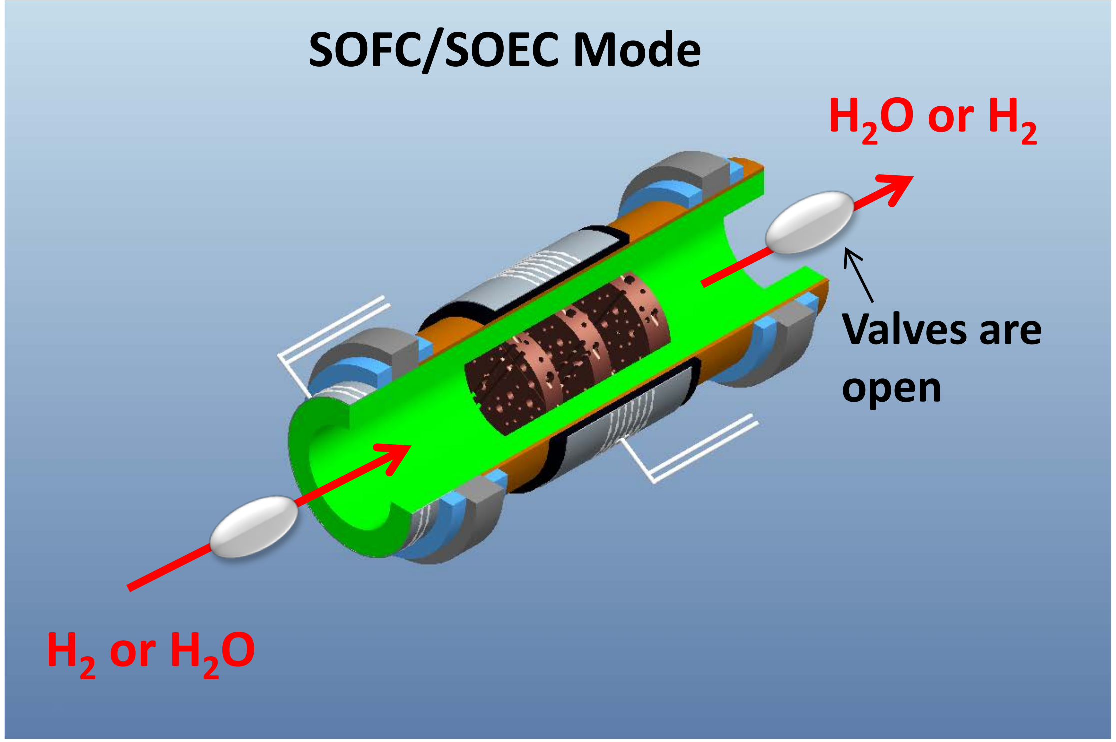
# Working Principle: Discharging

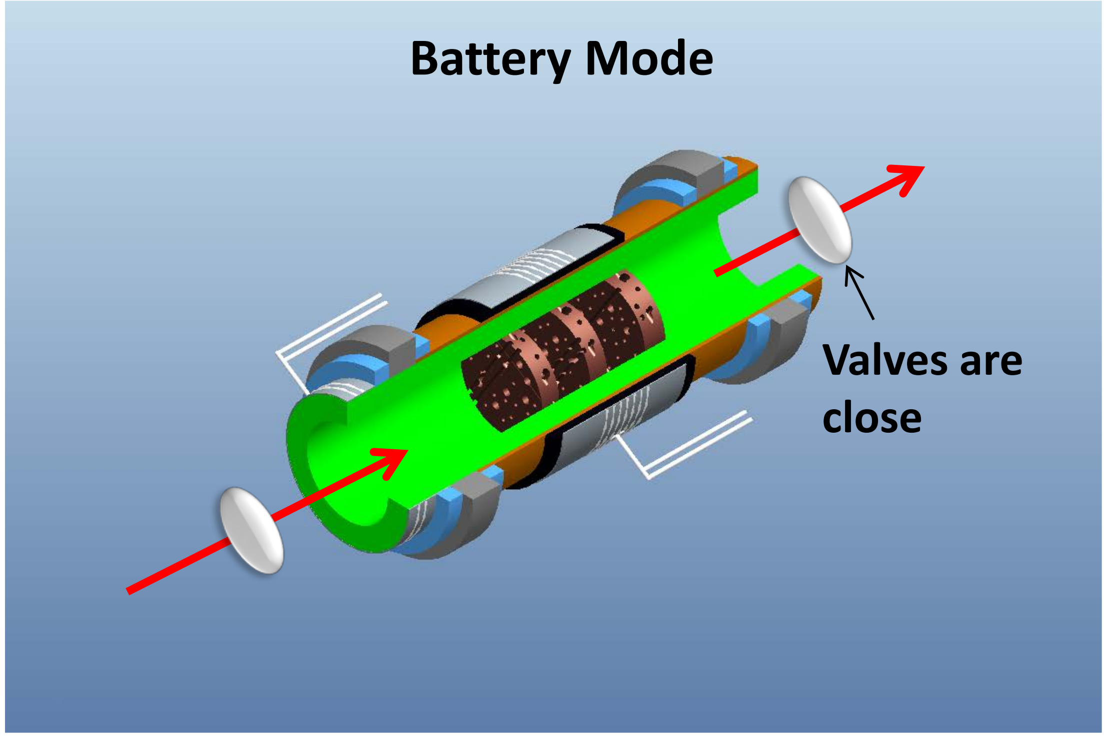


# Working Principle: Charging

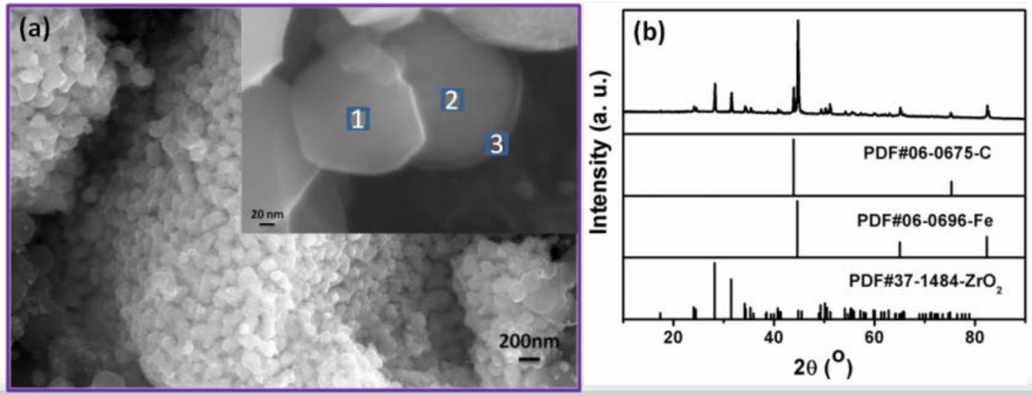


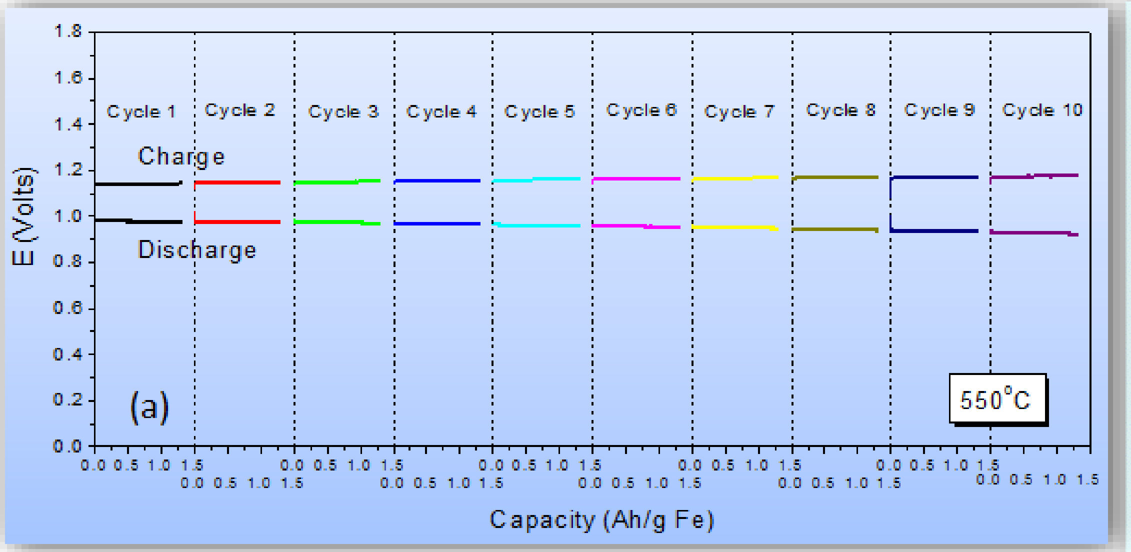
# Easy Switching between Fuel Cell and Battery Mode

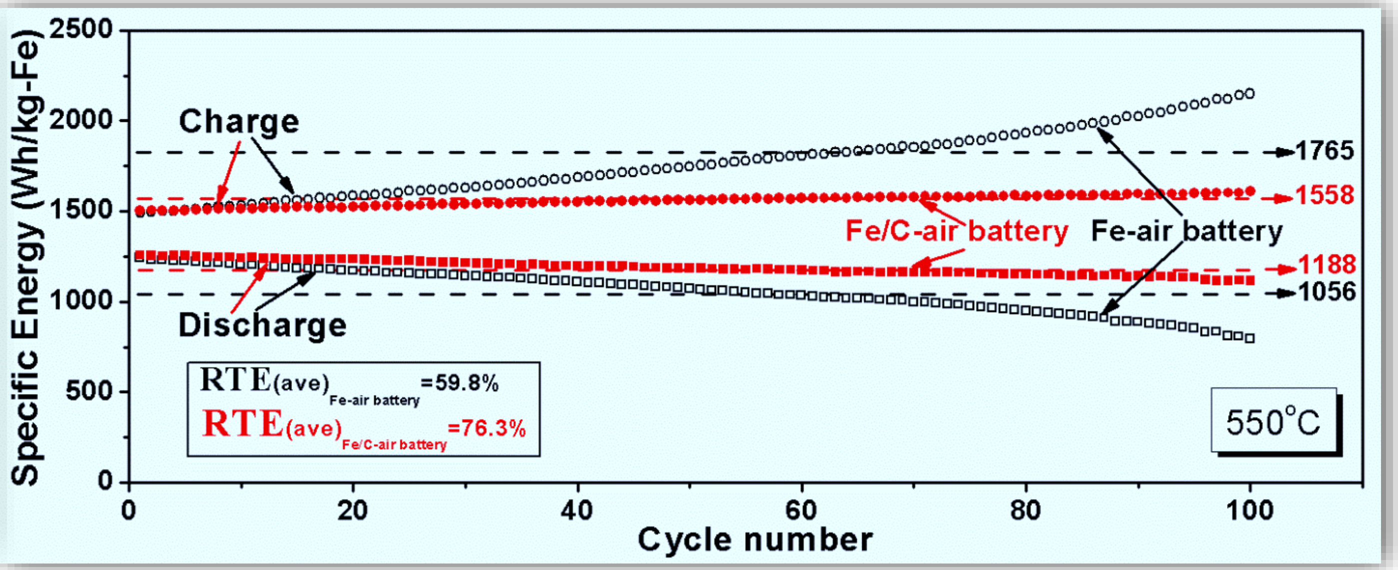


# A Typical Performance of the SOMARB Battery




*Chem. Comm.*, 2014, **50**, 623.

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# Distinguished Advantages

- All ceramic components
- Transfer of two electrons by $O^{2-}$
- Only gaseous $O_2$ involved in ORR and OER
- Energy storage with high-capacity chemical redox bed
- Energy cycling at high rates
- Independent power and energy
- Adaptable to new metal-air chemistries
- Scalable, sustainable & safe

# A Reversible Air-electrode of Choice: $SrCoO_{3-\delta}$

Important Features:

- Highly oxygen catalytically active at IT range
- Unstable at elevated temperatures: losing oxygen to decompose into $Sr_2Co_2O_5$:

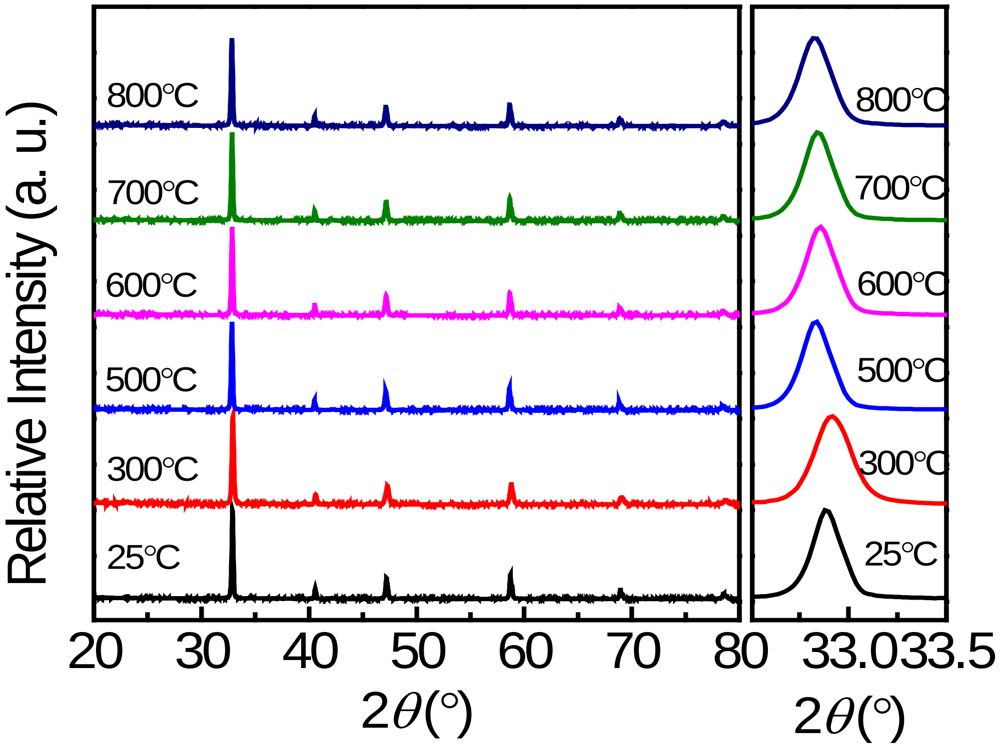
$$SrCoO_{3-\delta} = SrCoO_{2.5} + (0.5-\delta)/2O_2$$

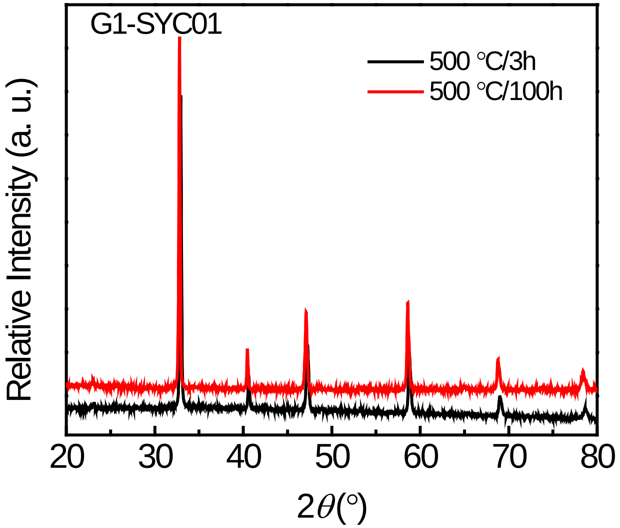
Making $SrCoO_{3-\delta}$ stable:

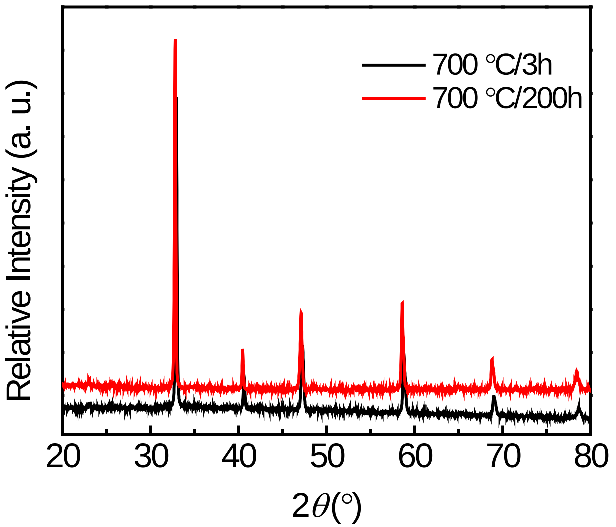
- Phase stabilization by A- and B-site donor doping
- Morphological stabilization of nanostructures by atomic layer deposition

# Phase Thermal Stability – SYC Series

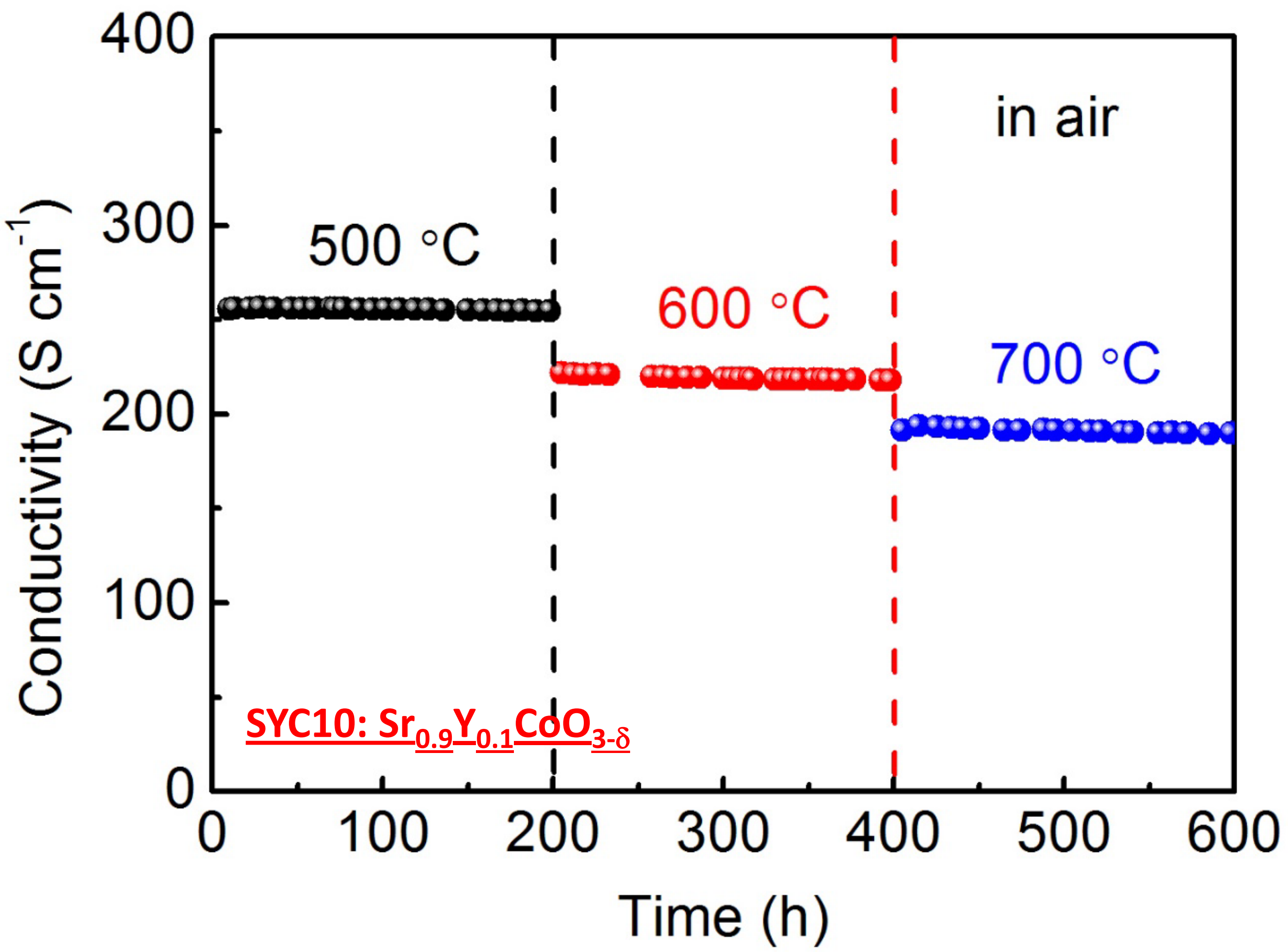
**SYC10: $Sr_{0.9}Y_{0.1}CoO_{3-\delta}$**



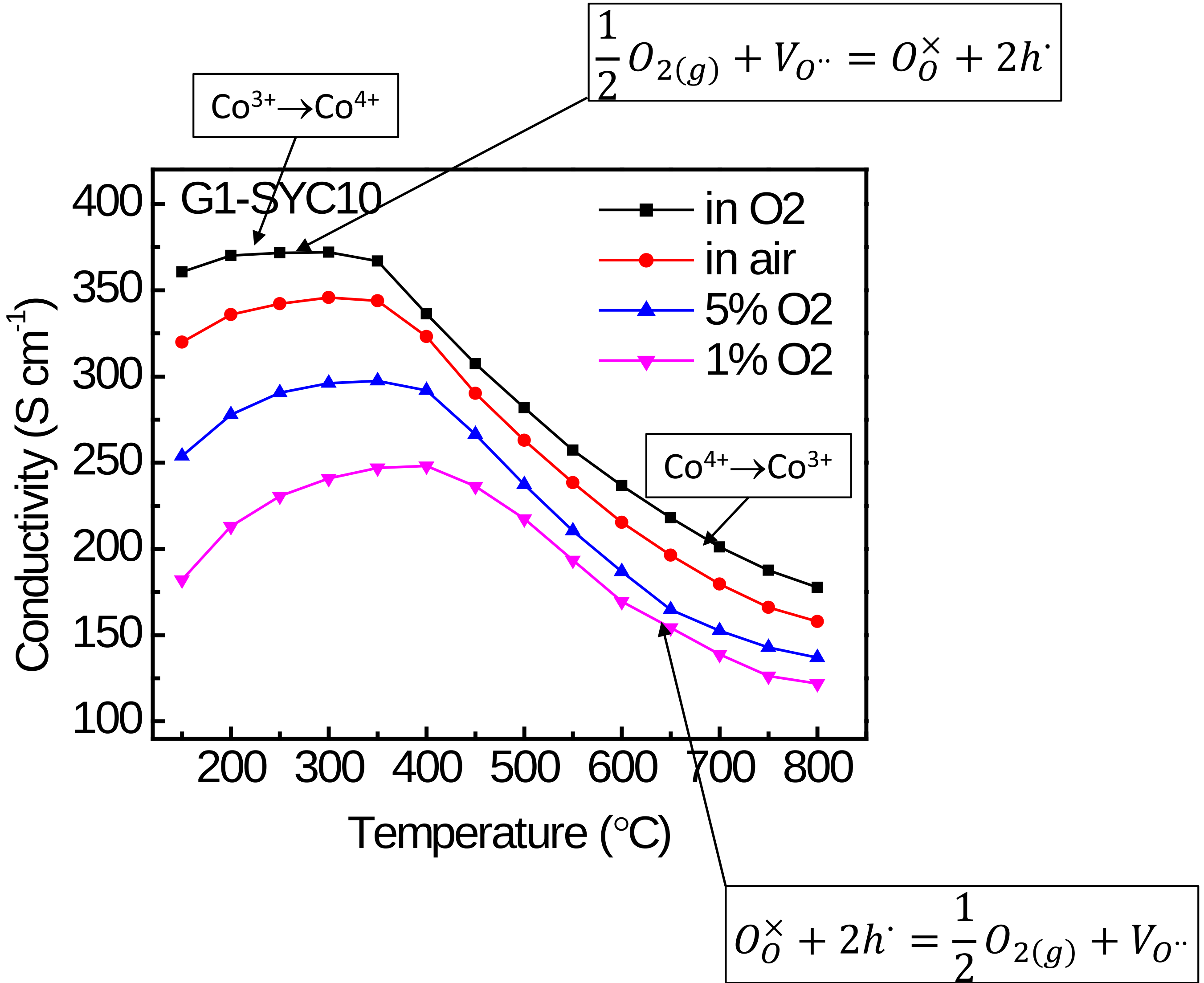



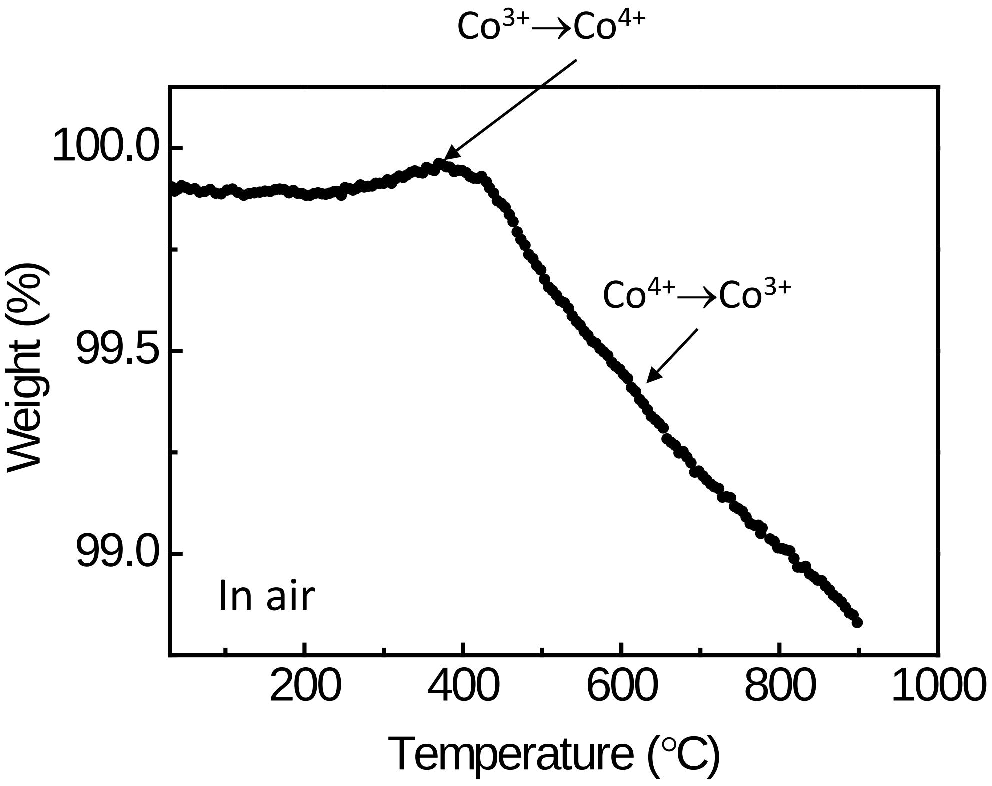
# Conductivity Stability – SYC Series

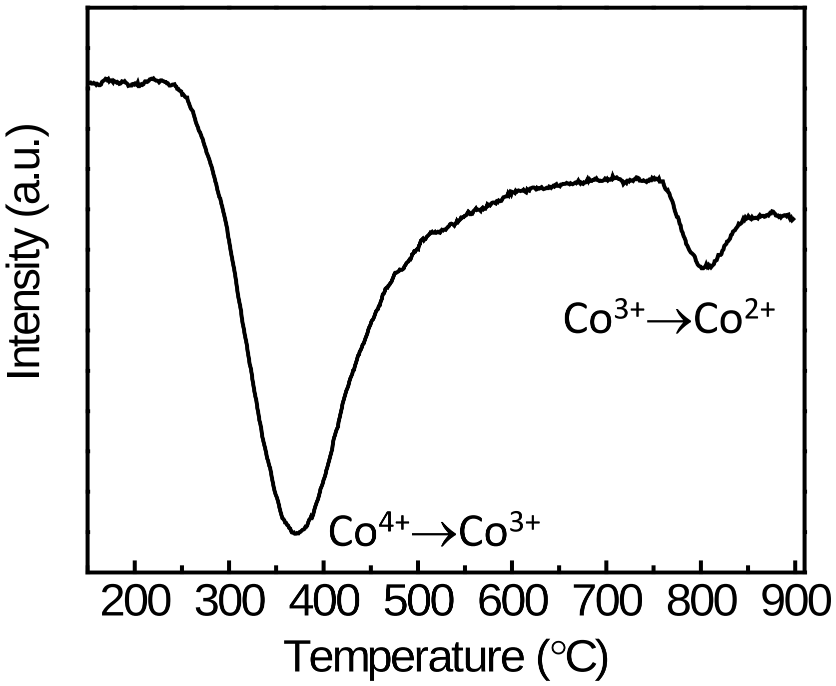


# Conductivity *vs* T – SYC Series



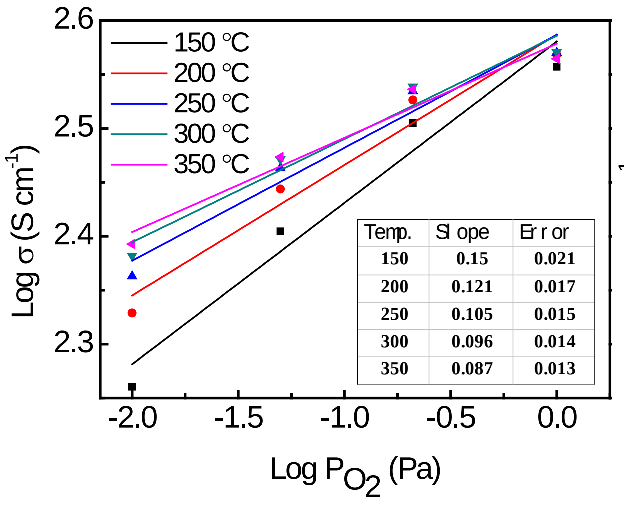
# TGA and TPD: SYC Series

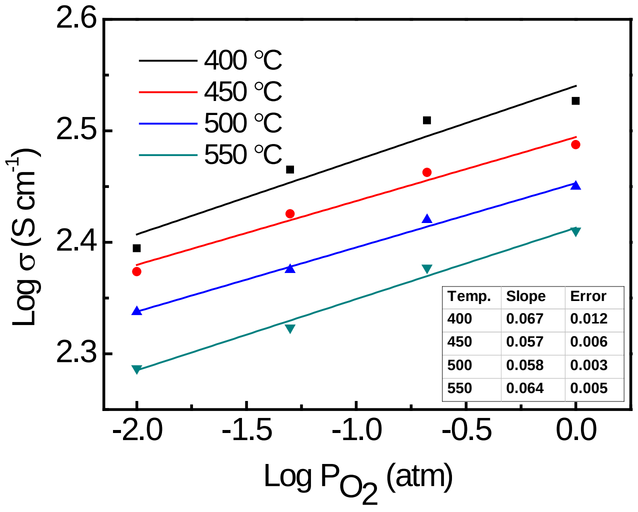


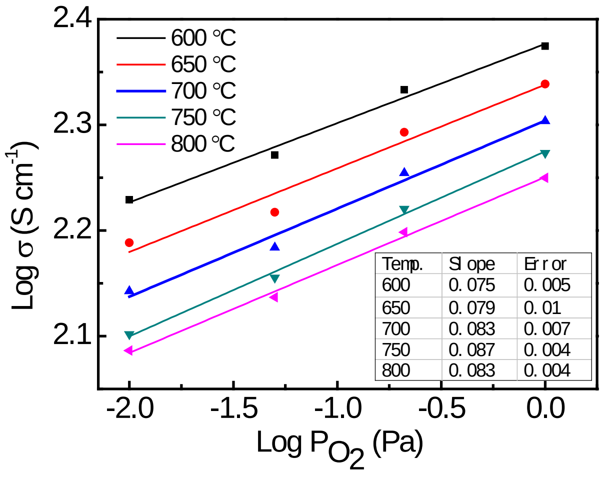




**Oxygen intake and release are reversible**

# Conductivity *vs* $Po_2$ – SYC Series




T<350°C,

$$\frac{1}{2}O_{2(g)} + V_{O^{\cdot\cdot}} = O_O^{\times} + 2h^{\cdot}$$

Higher order of reaction m

T>350°C,

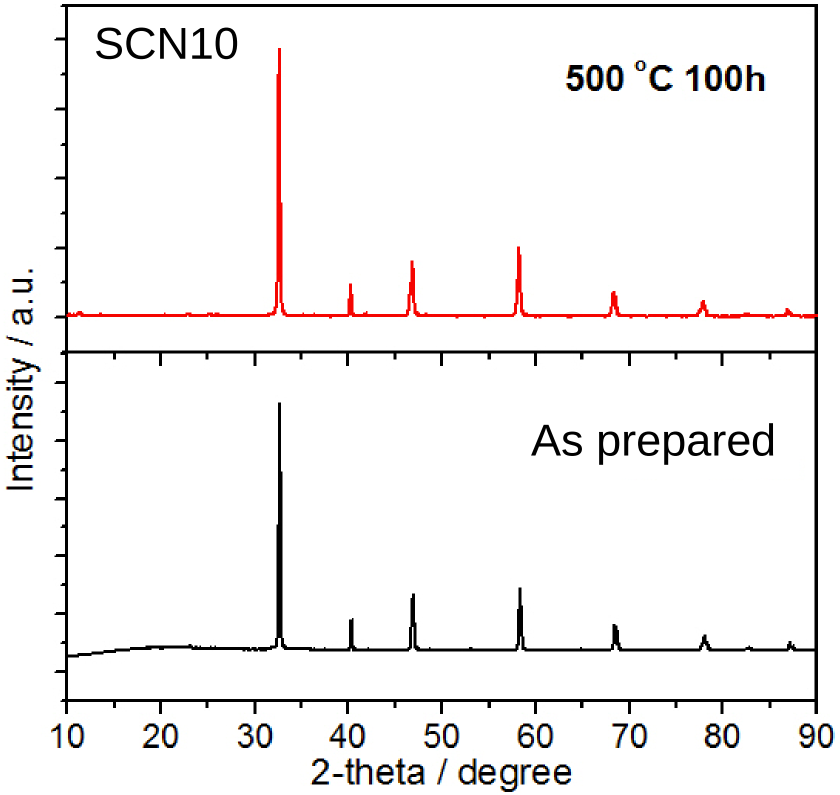
$$O_O^{\times} + 2h^{\cdot} = \frac{1}{2}O_{2(g)} + V_{O^{\cdot\cdot}}$$

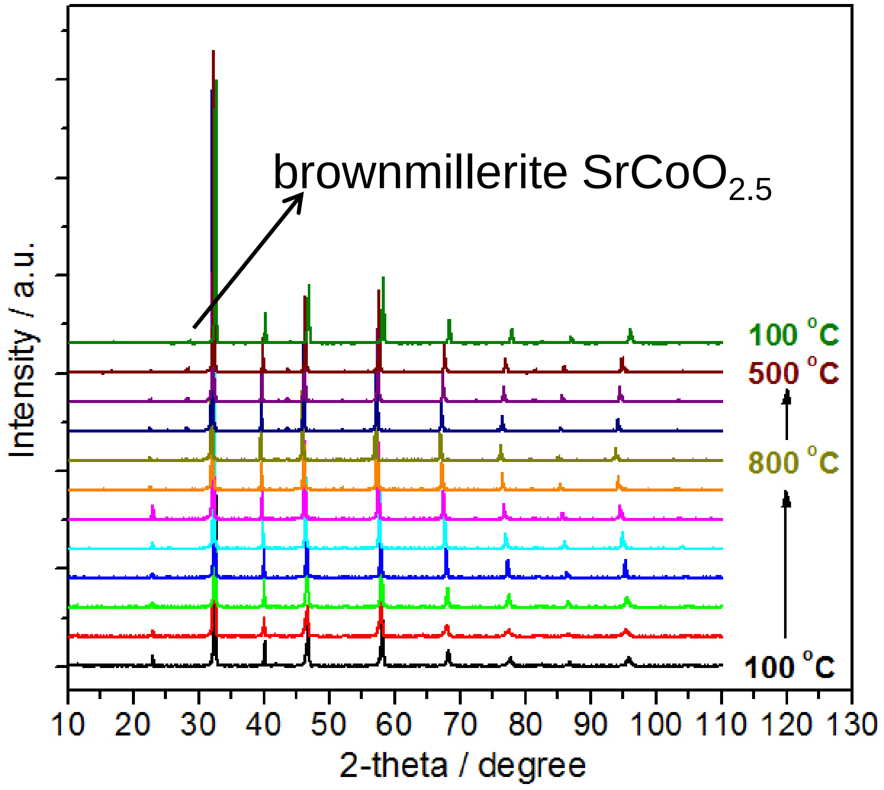
Lower order of reaction m

Charge neutrality: x + 2δ + p = n

# Phase Thermal Stability – SCN Series

**SCN10: $SrCo_{0.9}Nb_{0.1}O_{3-\delta}$**



# Conductivity Stability – SCN Series

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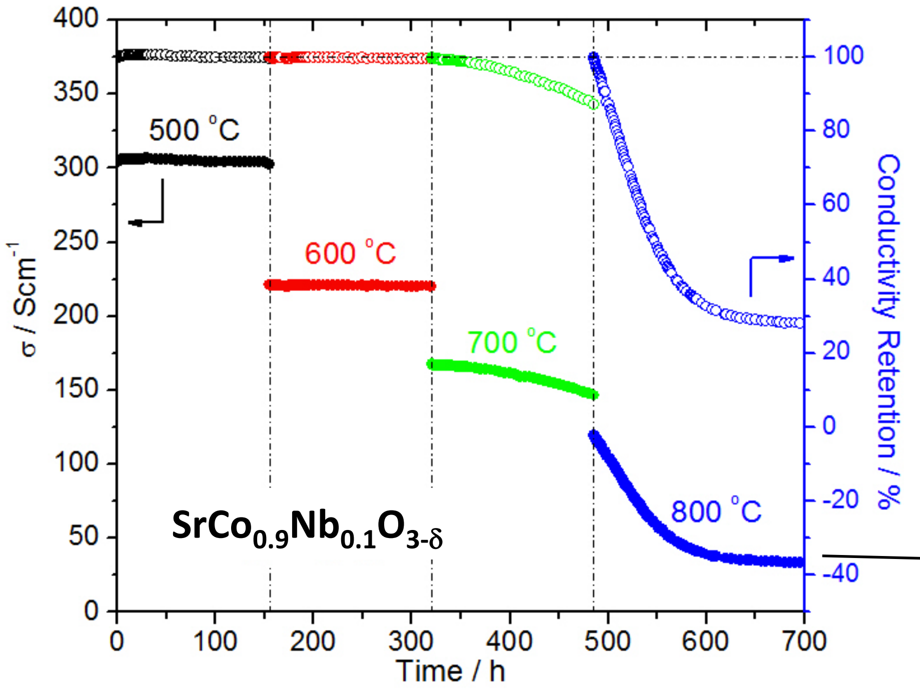
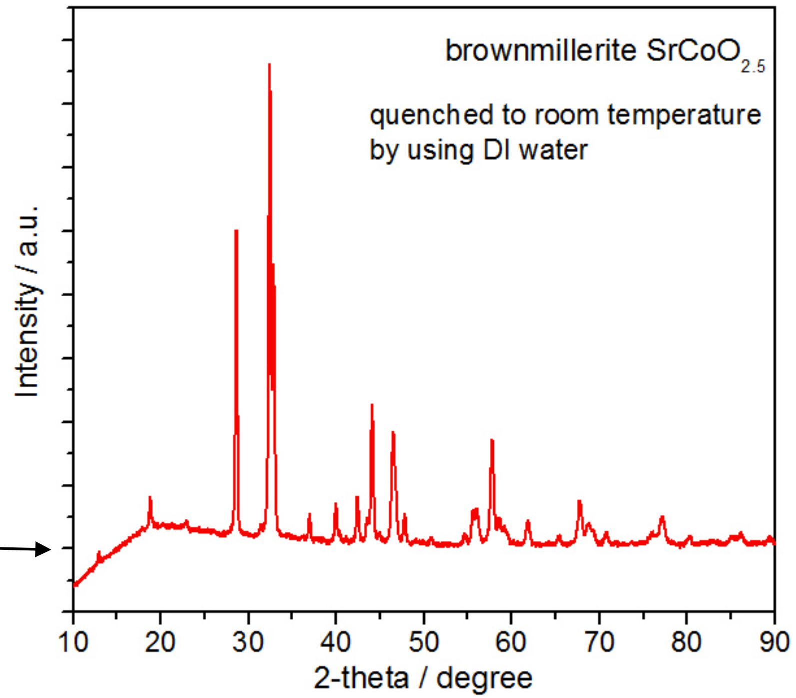
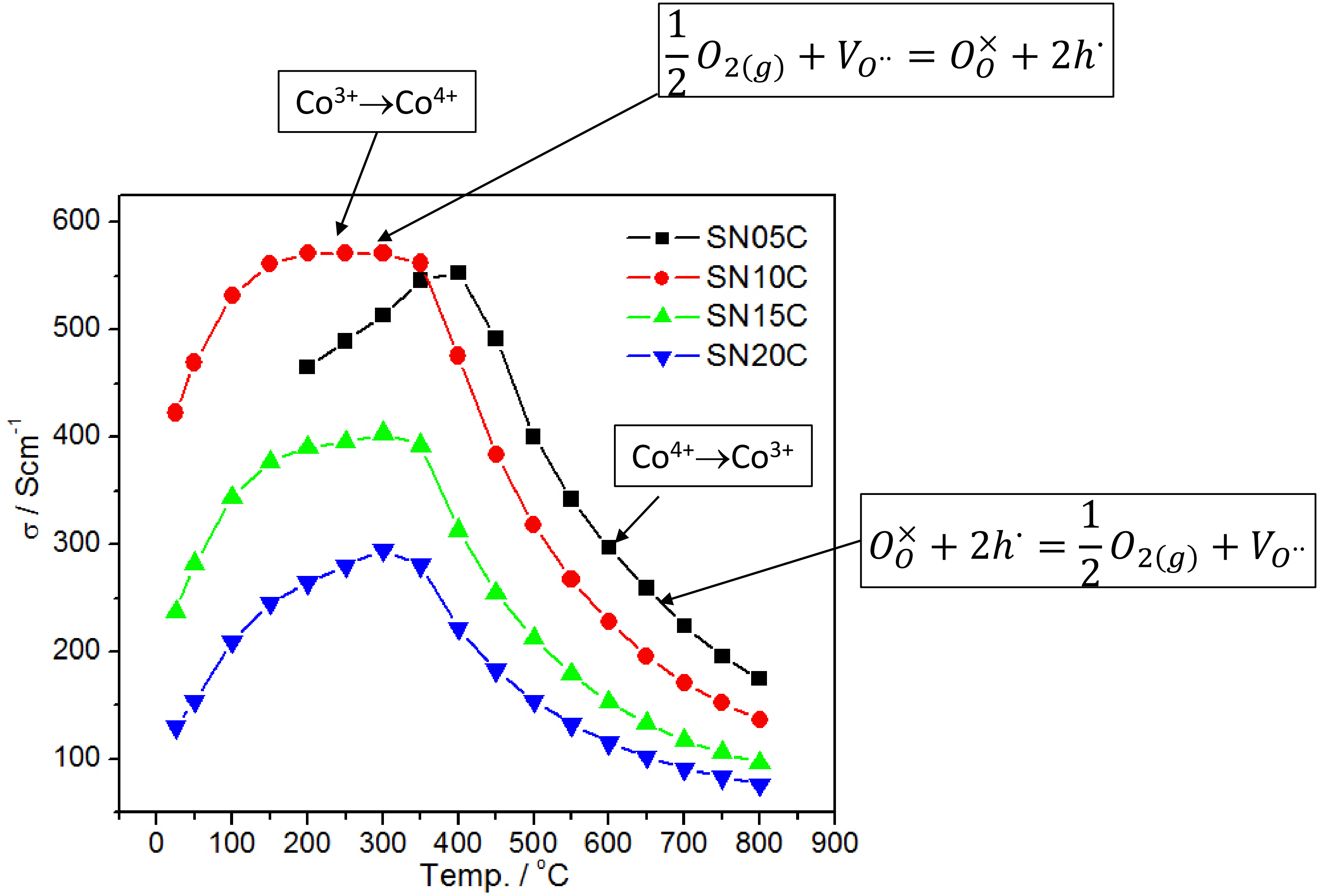
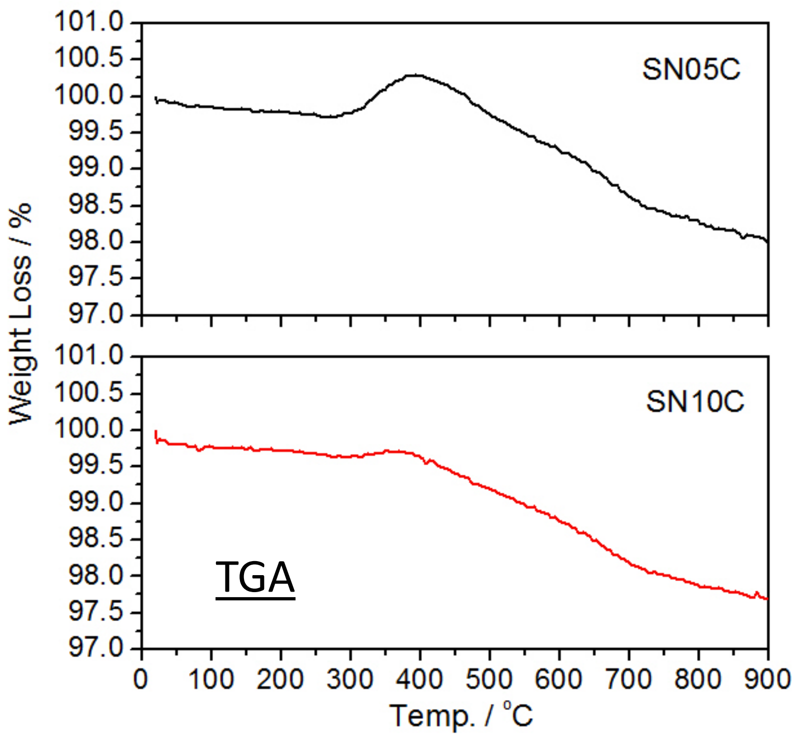


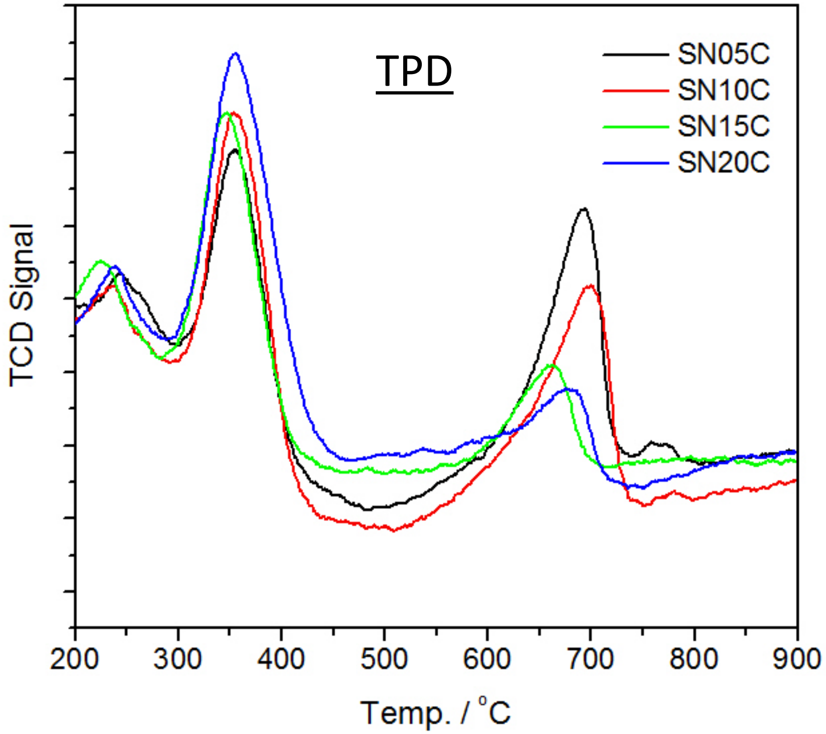



# Conductivity *vs* T – SCN Series

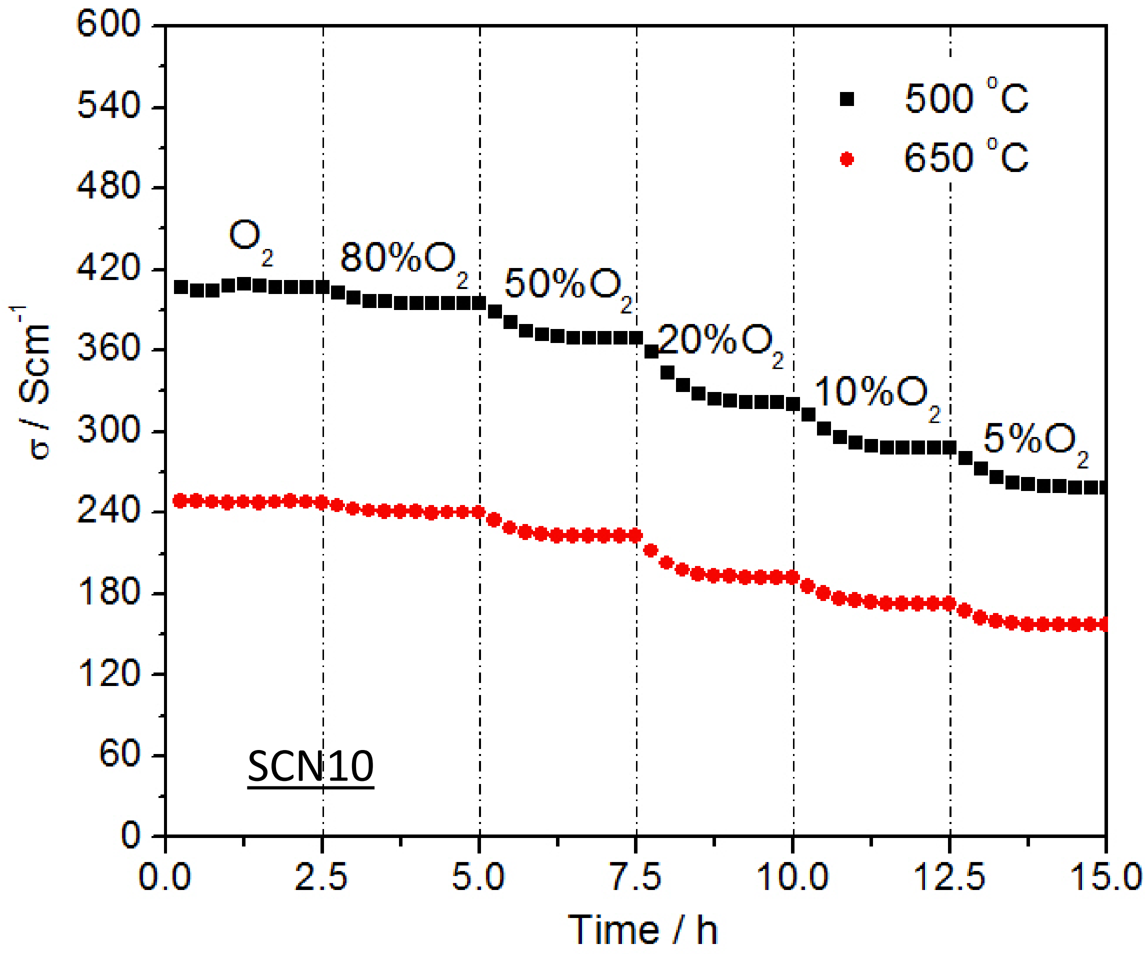


# TGA and TPD: SCN Series



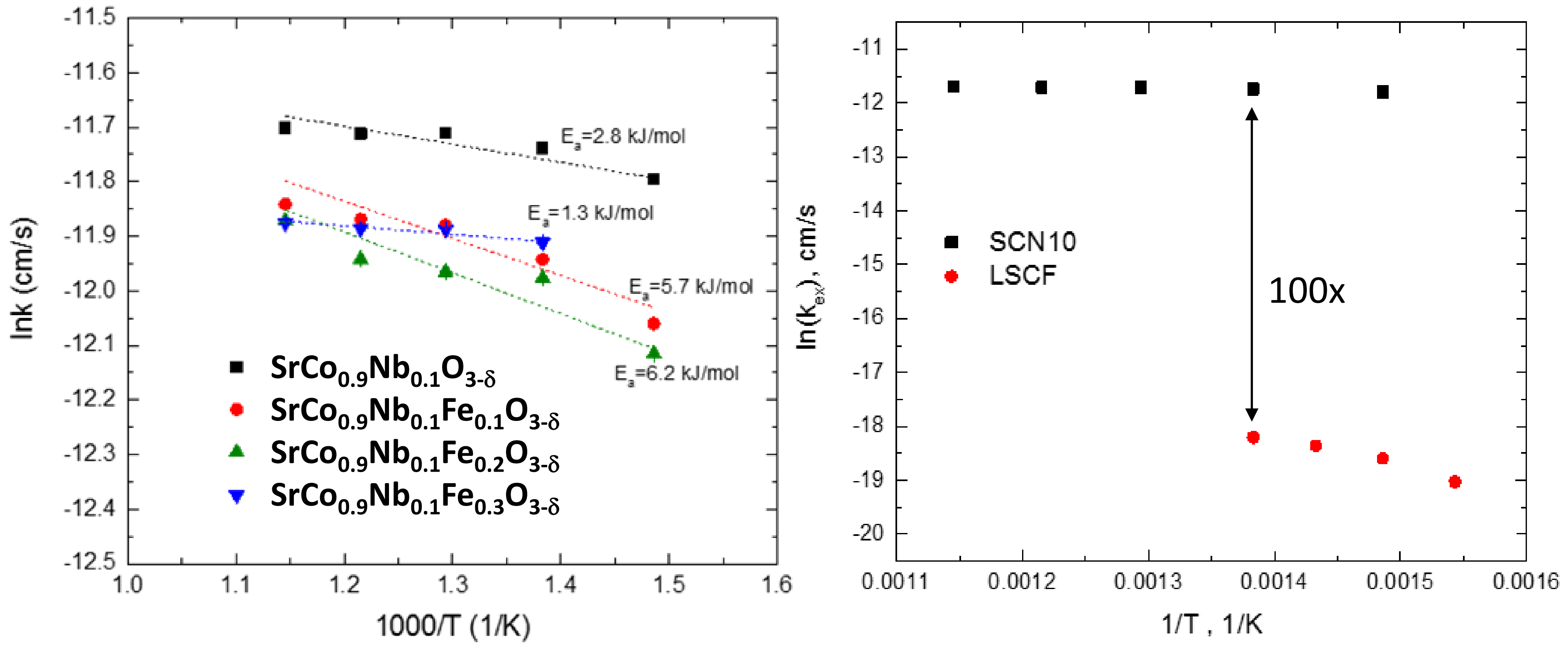



# Conductivity *vs* $Po_2$ – SCN Series



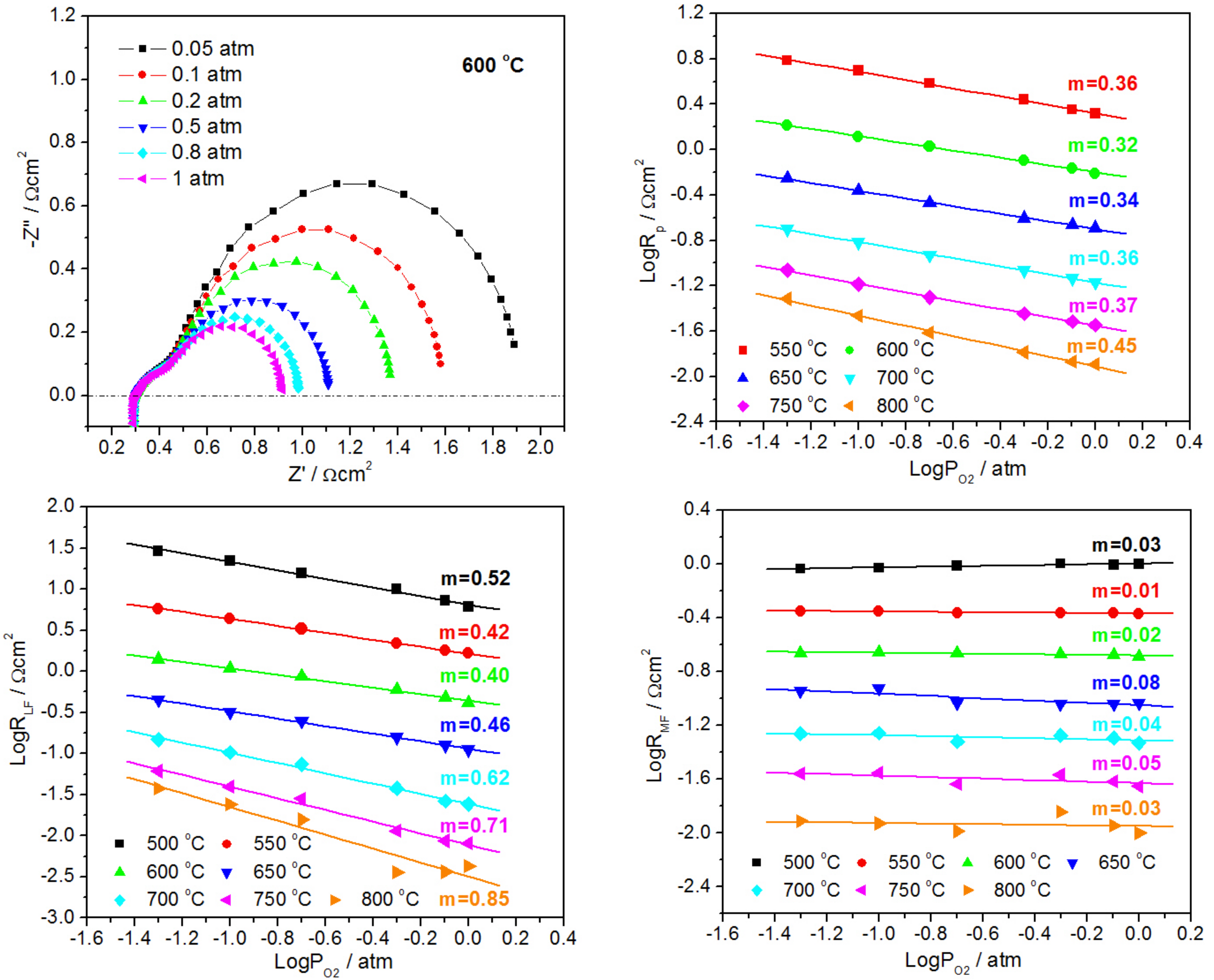
# Surface $O_2$ Exchange Coefficient

Oxygen Isothermal Isotope Exchange

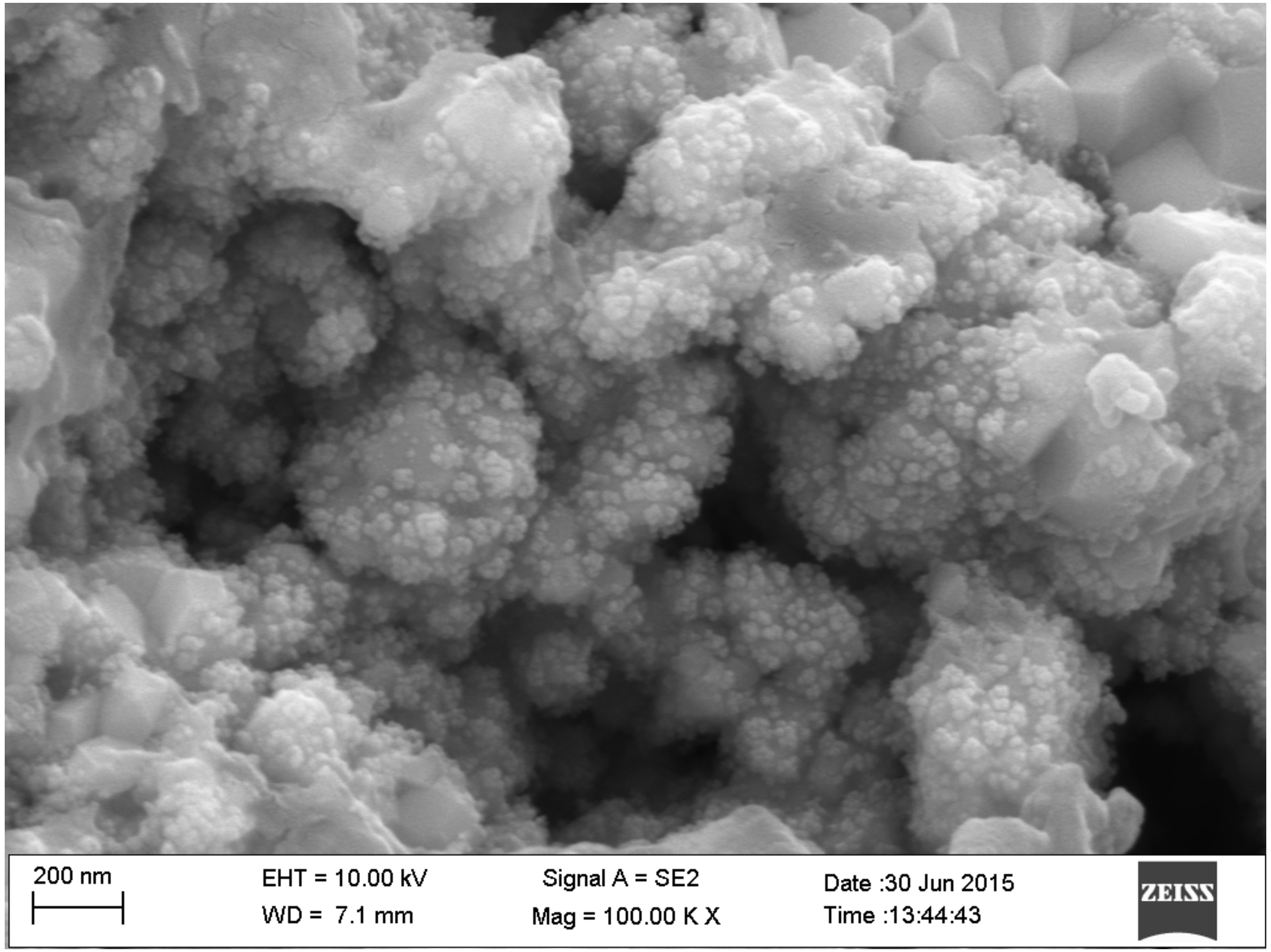



By E. Wachsman's group at University of Maryland

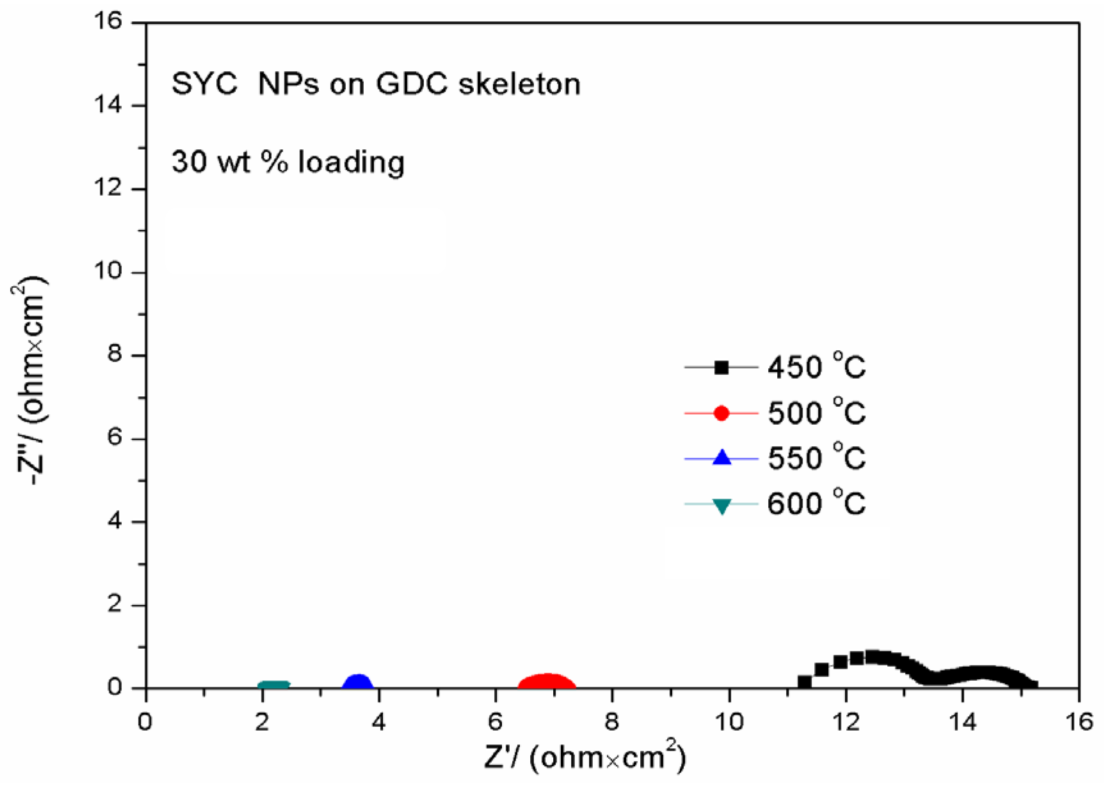
# SCN Series
# Micron size

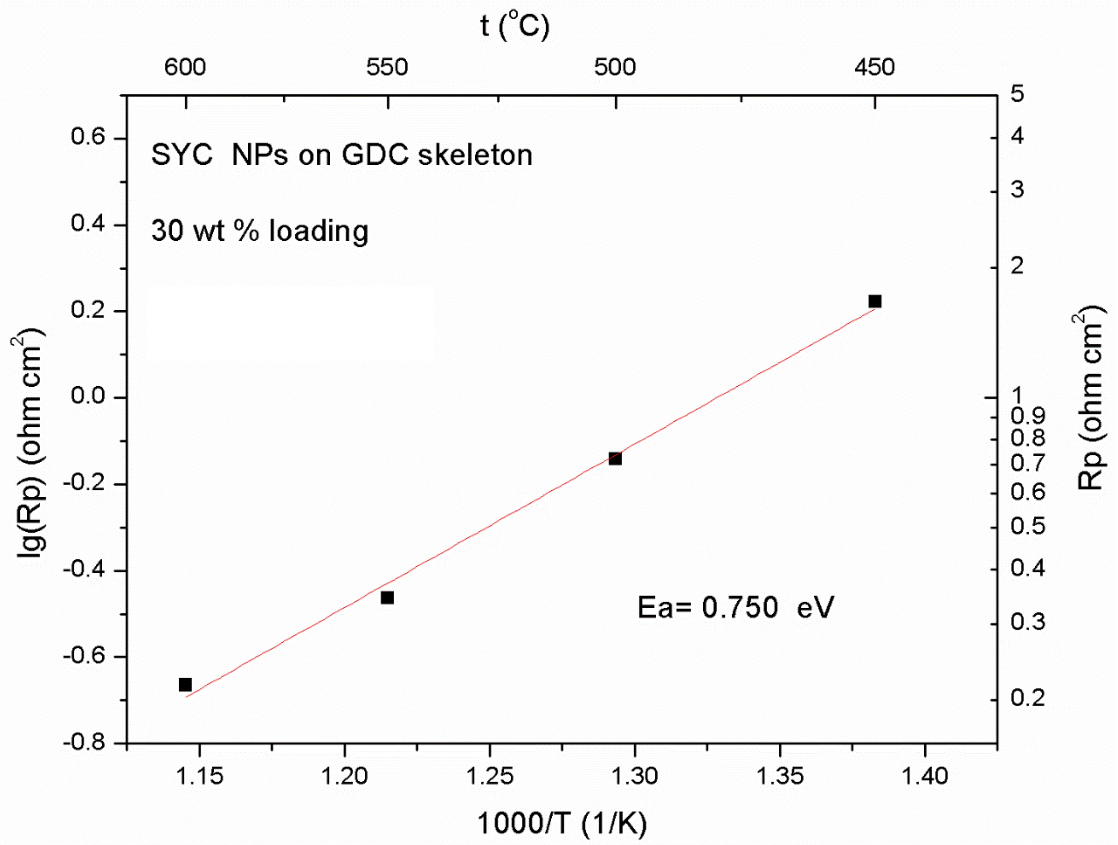


# Microstructure of a Nanostructured SYC

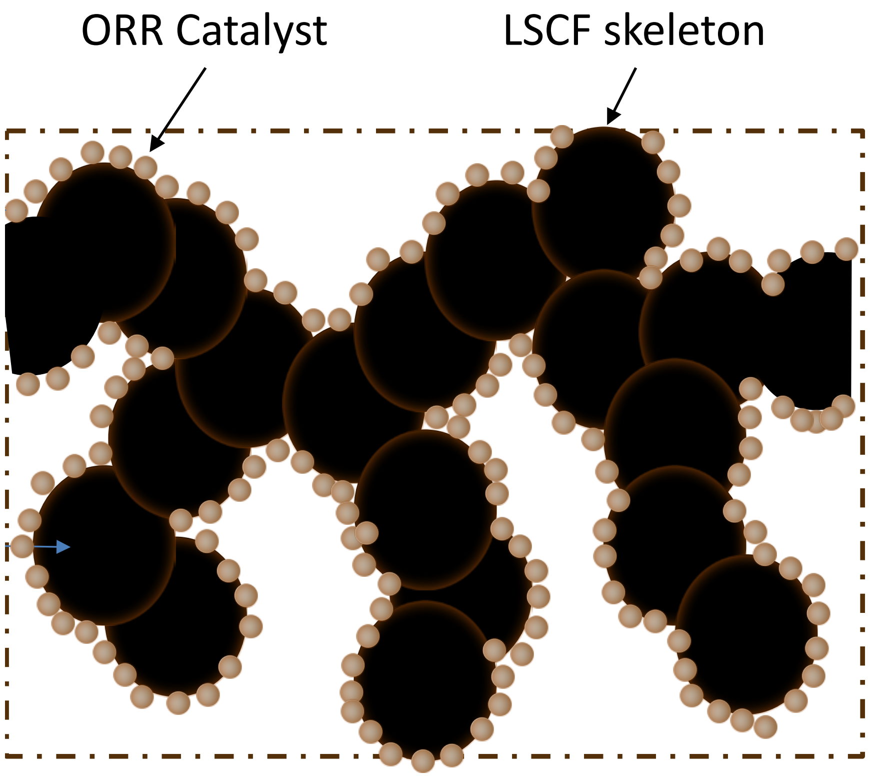


# Performance of Nanostructured SYC Cathode

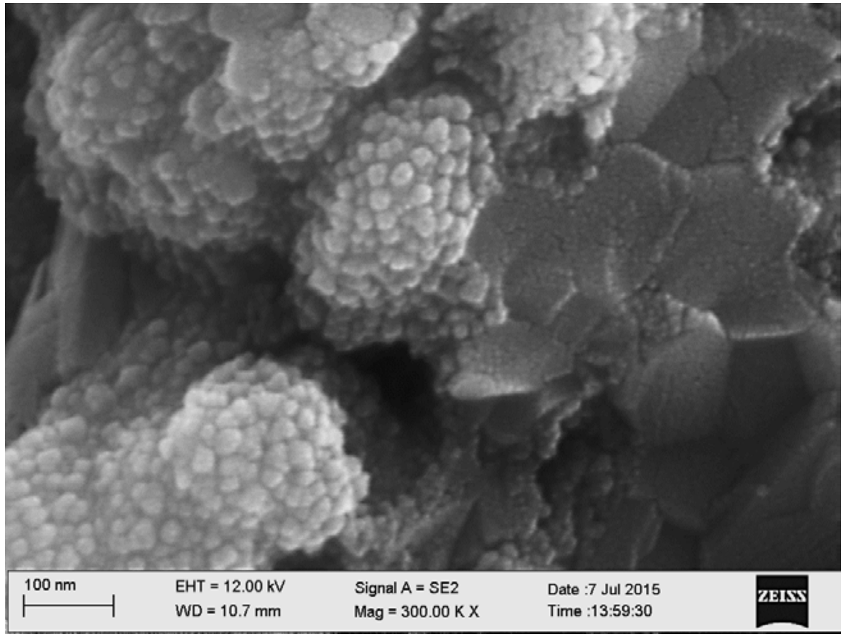


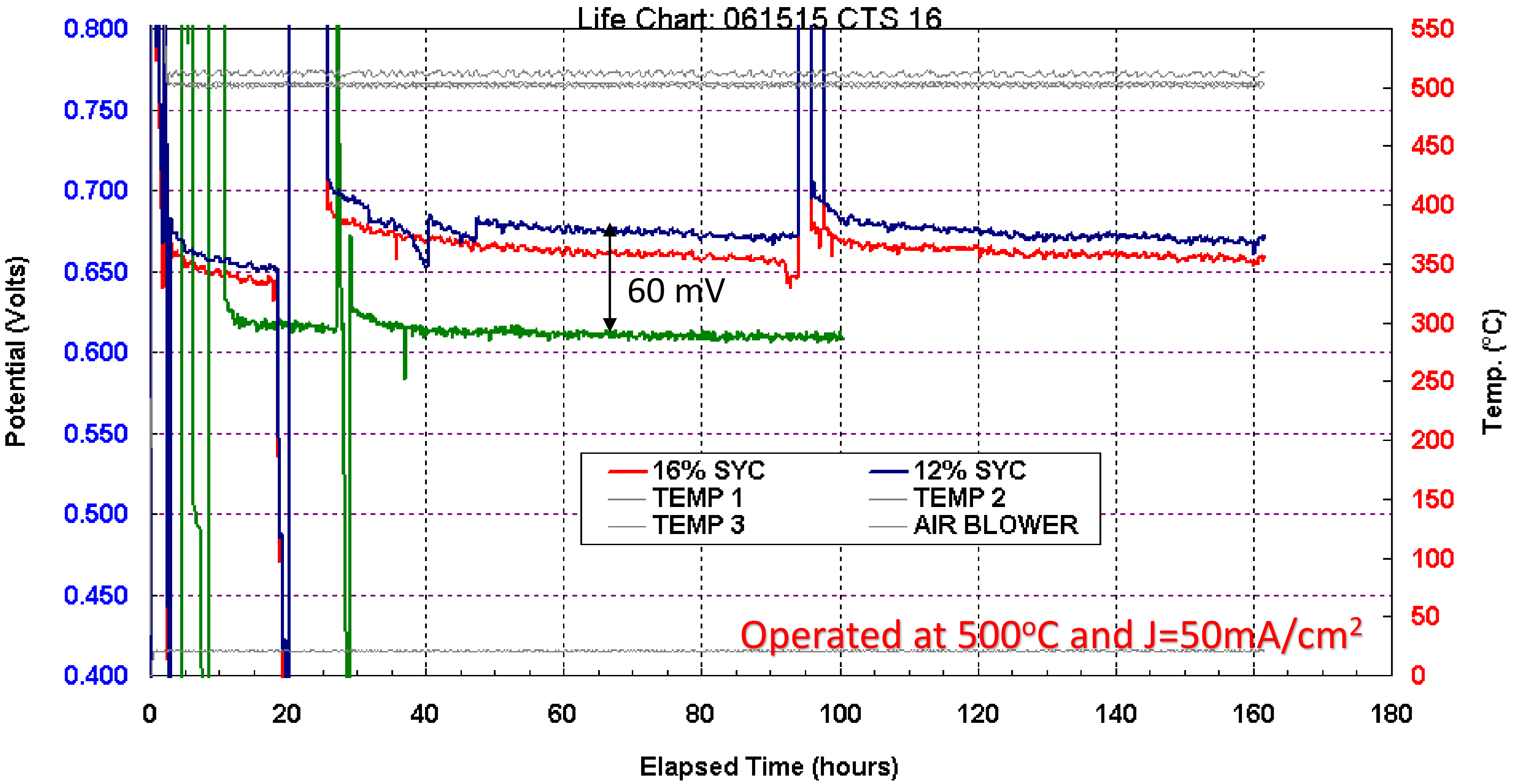
# Nanostructured SYC as an ORR/OER Catalyst for Air-electrodes




SYC on LSCF



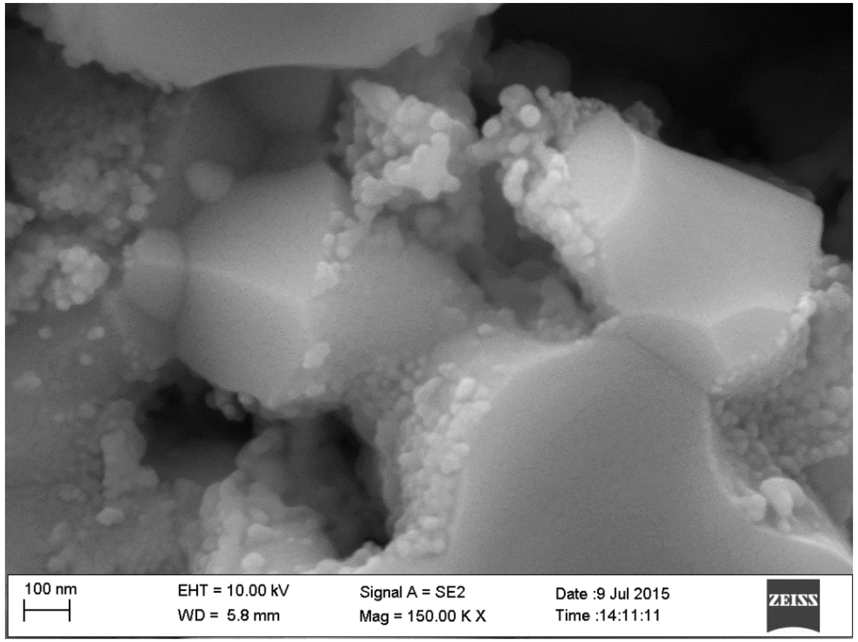
# Performance Improvement by SYC Catalyst

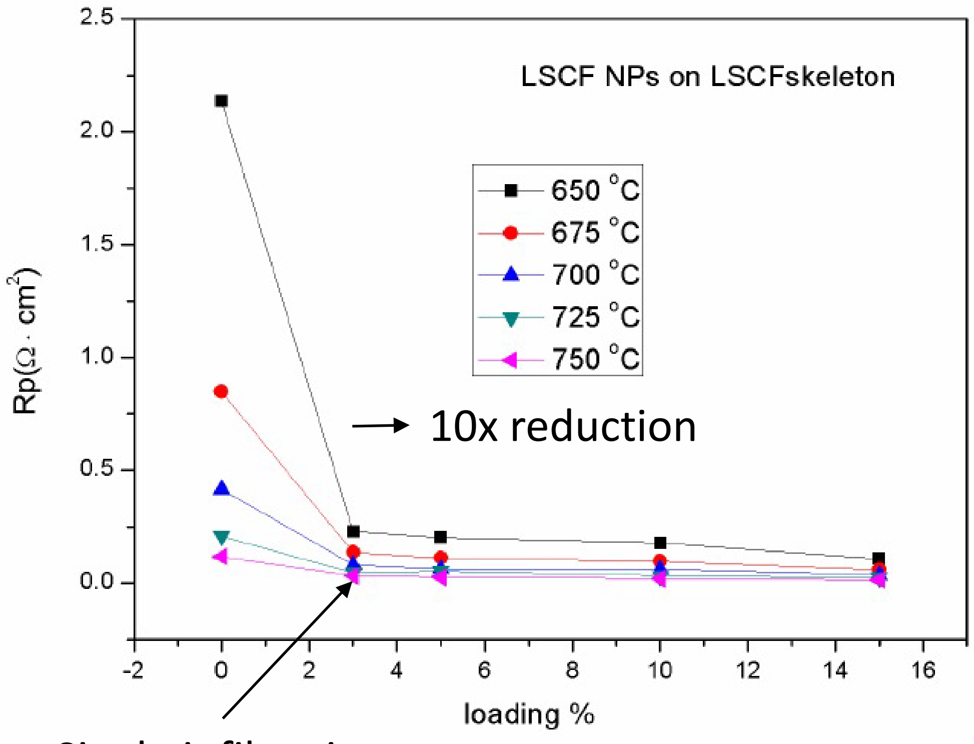



Acumentrics 50-cm long anode-supported tubular YSZ cell
Provided by Dr. Doug Schmidt and Dr. Wensheng Wang

# Decorating LSCF NPs on Commercial LSCF

5wt% loading




Single infiltration

# Summary

- Integration of a redox chemical bed can enable energy storage functionality of conventional RSOFC
- Donor doped $SrCoO_{3-\delta}$ oxygen-deficient perovskites are a class of promising reversible ORR/OER catalysts for IT-RSOFCs
    - Phase stabilization by chemical doping
    - Nanostructuring by solution infiltration
    - Morphological stability by ALD
- Decorating nanoscaled SYC ORR catalysts on a commercial IT-SOFC cathode LSCF can be beneficial

# Acknowledgements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  - Acumentrics: Dr. Doug Schmidt and Dr. Wensheng Wang
  - USC: Dr. Fengzhan Si, Dr. Jie Wang, Dr. Long Jiang
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