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ADVANCED MATERIALS & ELECTROCHEMICAL TECHNOLOGIES

Intermediate Temperature SOFC Operation Using Lanthanum Gallate Electrolyte

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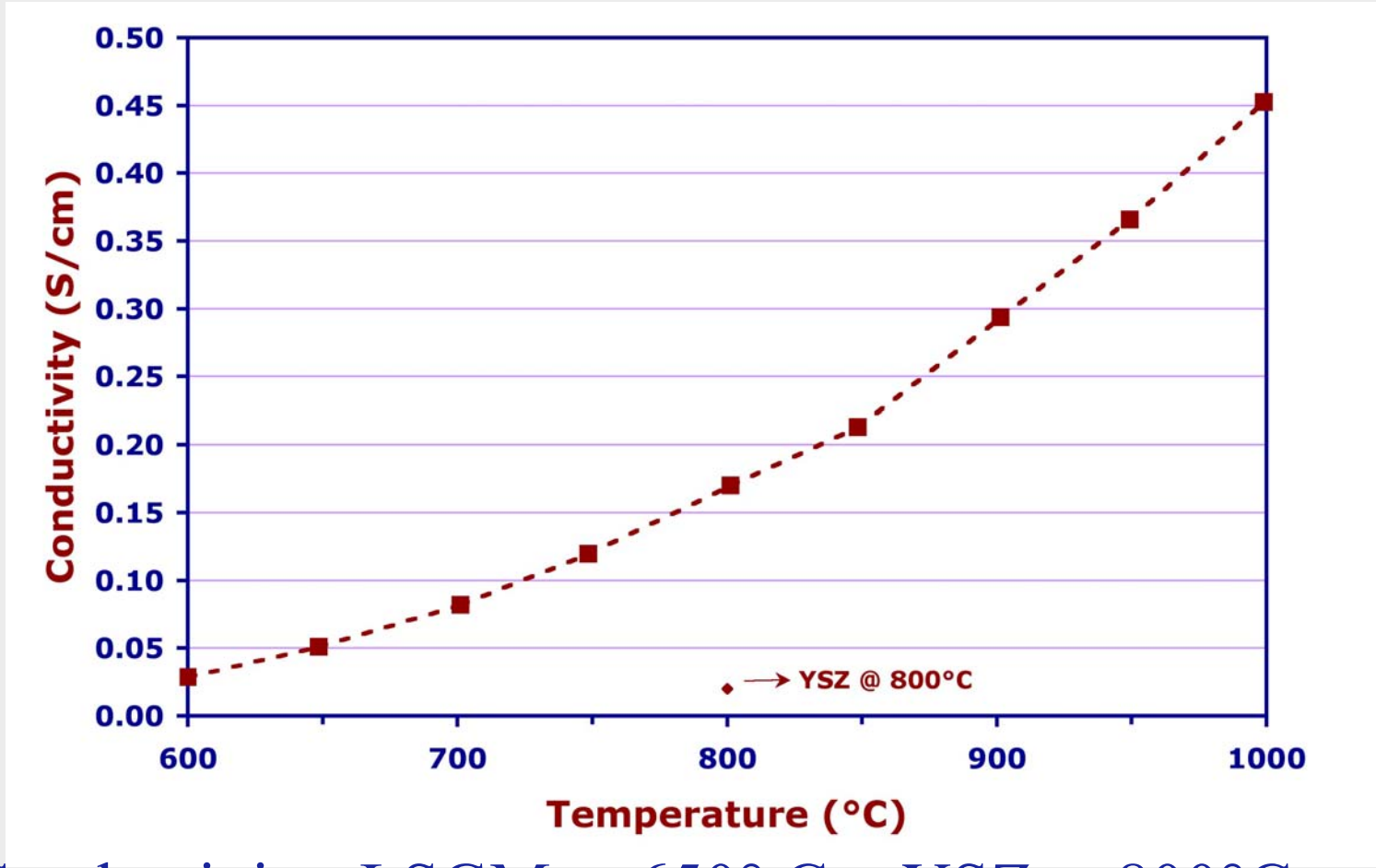
Present SOFC Electrolytes

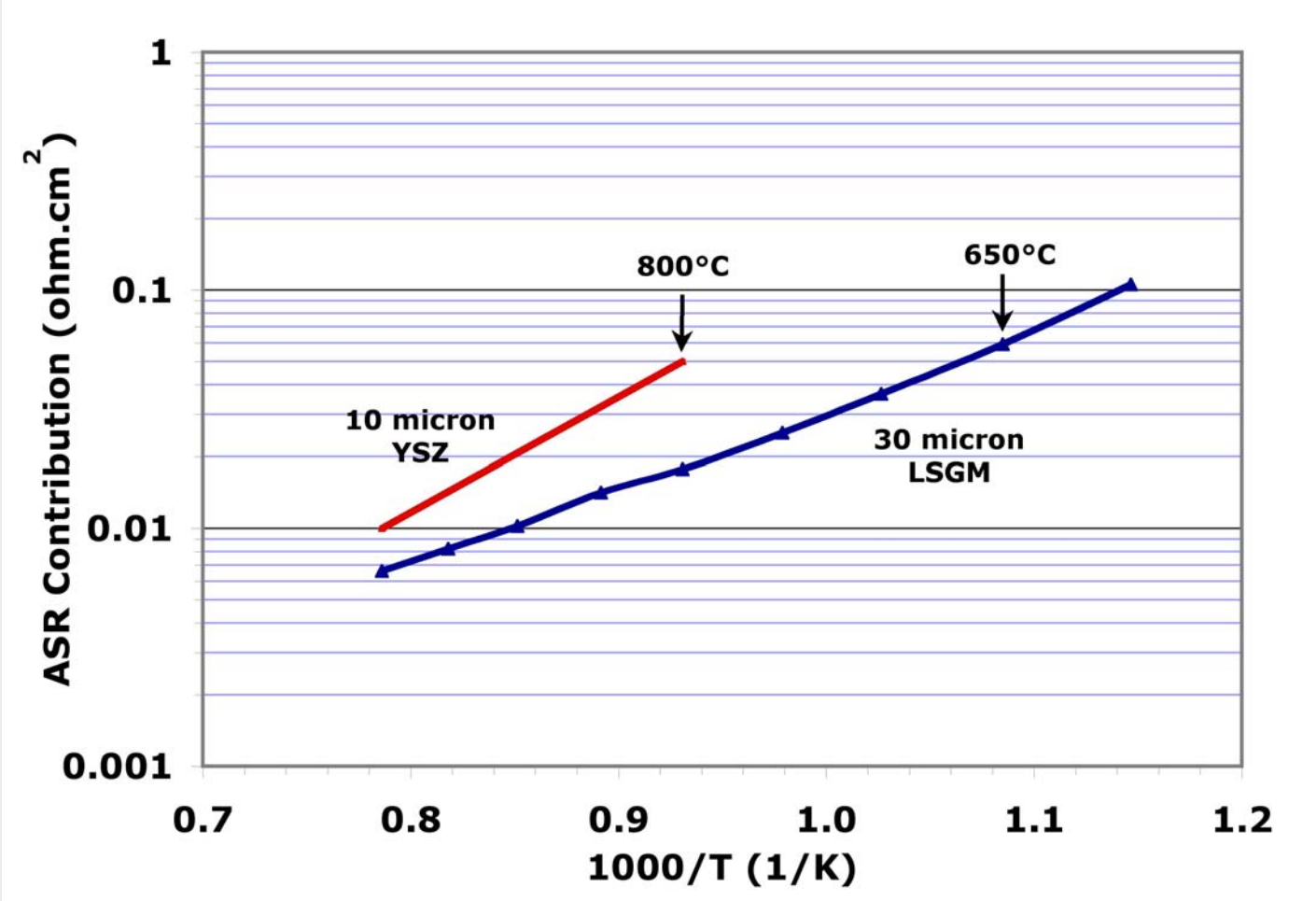
System	Electrolyte Issues	Anode Material and Issues	Cathode Material and Issues	General Comments
Zirconia	Low conductivity 0.1 S/cm at 1000°C 0.02 S/cm at 800°C	Ni-zirconia Ni coarsening	$La(Sr)MnO_3$ zirconate formation at the interface	Demonstrated No electronic leak current 1000°C Operation typical; very thin electrolyte allows 800°C operation; lower than 800°C?
Ceria	High conductivity (0.1 S/cm at 800°C)	Ni-ceria	$La(Sr)CoO_3$ CTE mismatch	Electronic short Differential expansion from air to fuel side
La gallate	High conductivity (>0.1 S/cm at 800°C)	Ni-ceria Formation of La-Ni-O insulating phases	$La(Sr)CoO_3$ CTE mismatch	No electronic leak current CTE ~~similar to zirconia~~ Long term cell stability is an issue, strength, material cost

Conductivity Comparison



- Conductivity: LSGM at 650° C > YSZ at 800°C

Conductivity Comparison: LSGM and YSZ Electrolyte



Benefits of LSGM Electrolyte

- **Stability in SOFC environment (air and fuel pO_2)**
  - Ionic transference number ~1
- **Potential for 650°C operation**
  - Conductivity comparable to YSZ at 800 - 850°C
  - Compatibility with perovskite cathode $La(Sr)CoO_{3-\partial}$, excellent cathode for 650°C operation
  - Metal interconnect challenges are reduced
  - Lower system cost
  - 650 - 700°C operation well-suited for partial internal reformation; offering a significant reduction in heat exchanger requirement

Challenges

Materials

- **Synthesis**
  - Phase Purity
- **Ceramic processing**
  - Densification
  - Thin layer fabrication
- **Strength**
- **Cost**

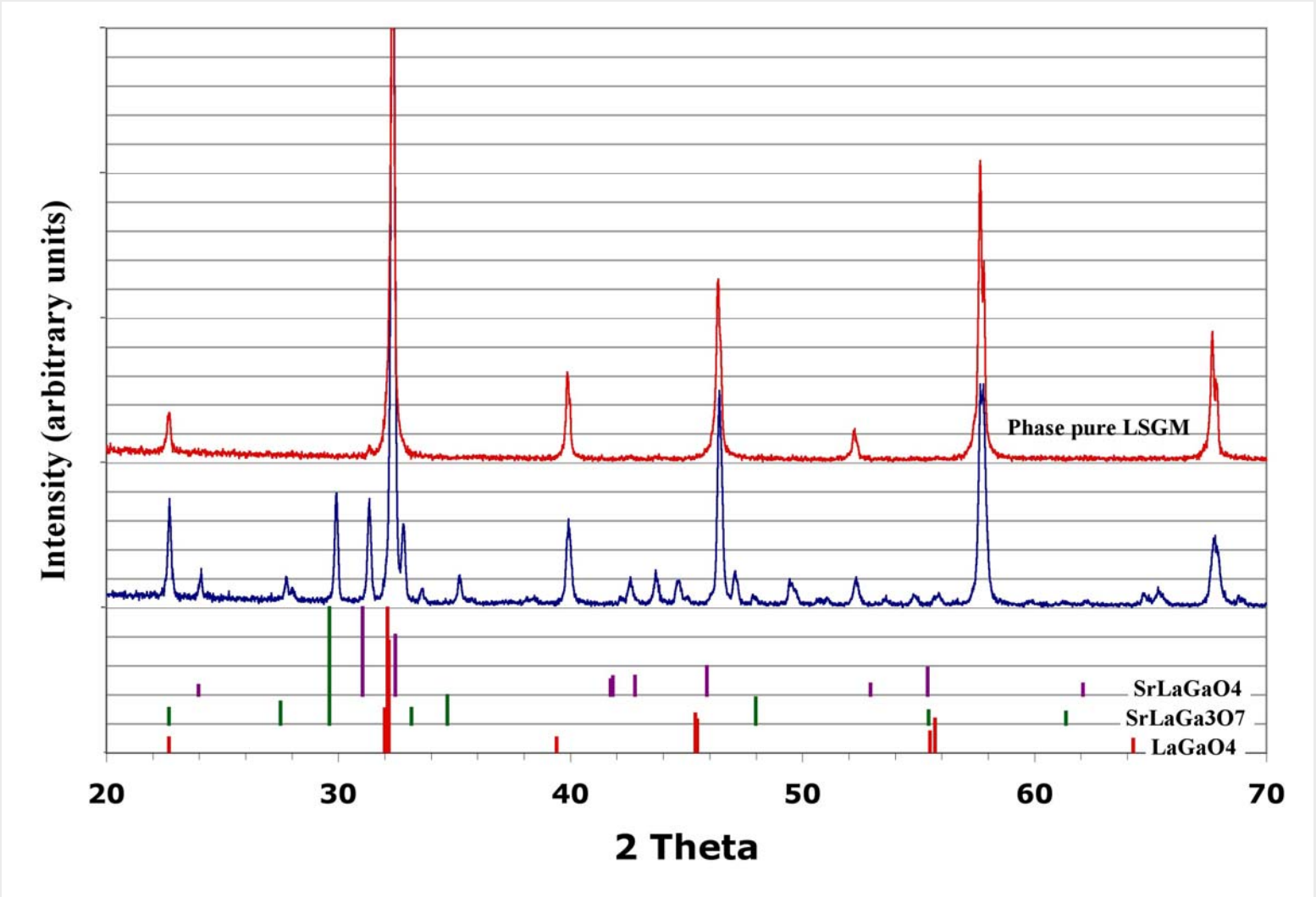
Fuel Cell

- **Anode material compatibility**
  - Reactivity with nickel
- **Cathode material**
- **Long-term stability**
- **Stack performance**

Synthesis

- **Multi-cation perovskite**
  - Preferred phase: $La(Sr)Ga(Mg)O_{3-\partial}$
  - Potential second phases: $SrLaGaO_4$ and $SrLaGa_3O_7$, $La_4Ga_2O_9$
- **Approach**
  - Precursor control
  - Milling / Calcination temperature

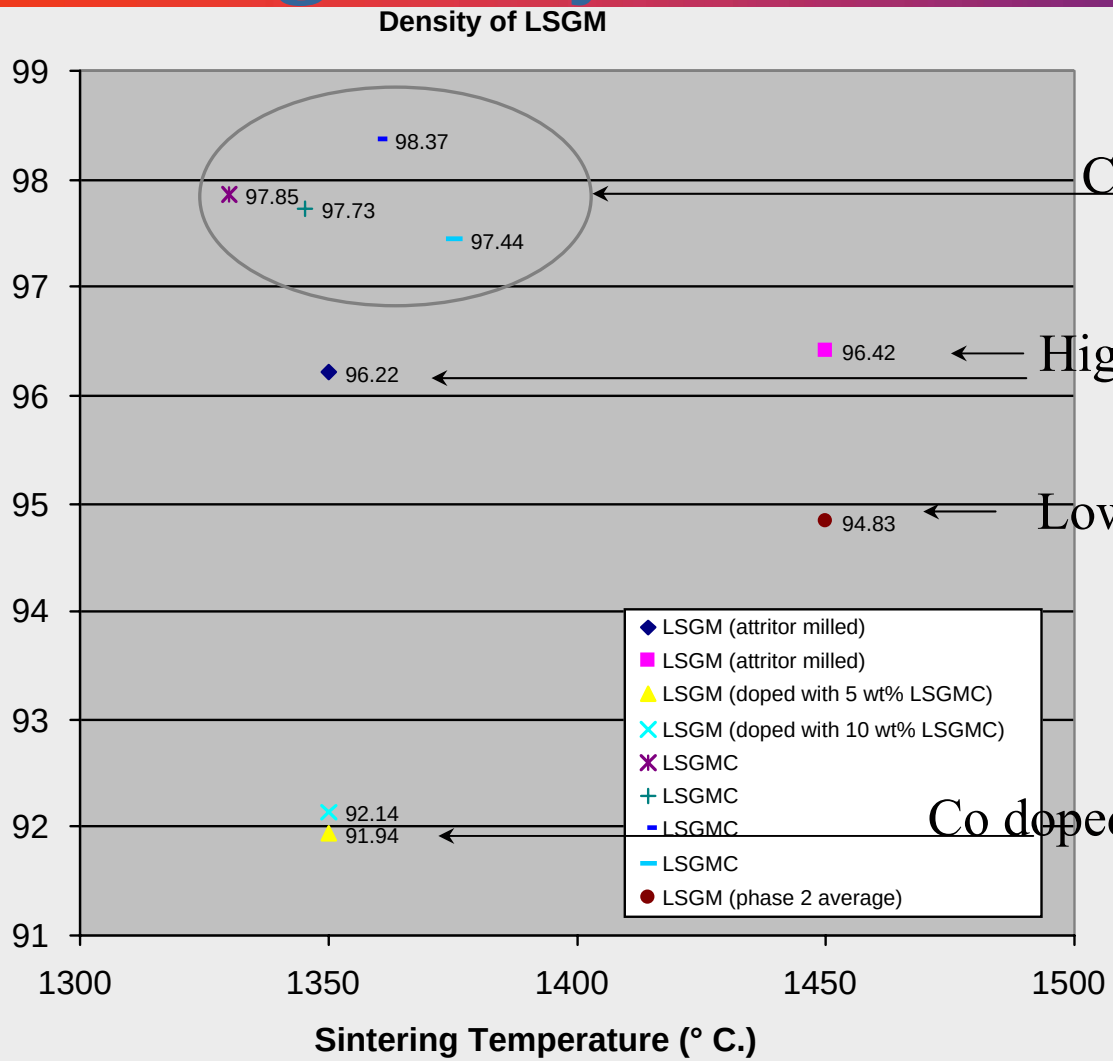
Process control: Phase pure LSGM



Ceramic processing

- **Densification**
  - Sintering temperature (literature: 1450 - 1550°C for several hrs)
    - Reactivity with setters
    - Ga evaporation?
  - Control of powder characteristics (eg. surface area) allows reduction in sintering temperature 1400 - 1450°C
  - Sintering aid

Sintering Study



Co doping on Mg-site

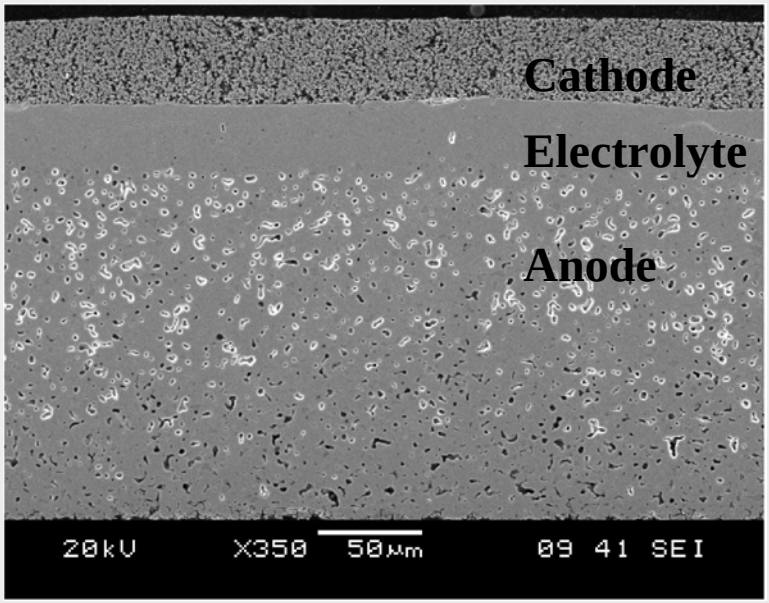
High surface area (~ 6 m^2/gm)

Low surface area (~ 1 m^2/gm)

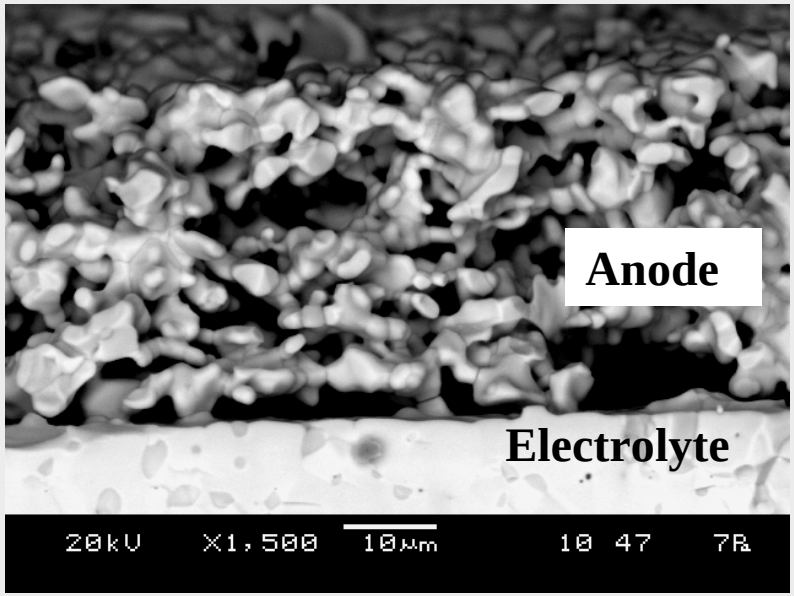
Co doped LSGM as sintering aid

Thin LSGM electrolyte

- **Multiple approaches to making thin LSGM electrolyte**



Tape cast support
Screen printed electrolyte

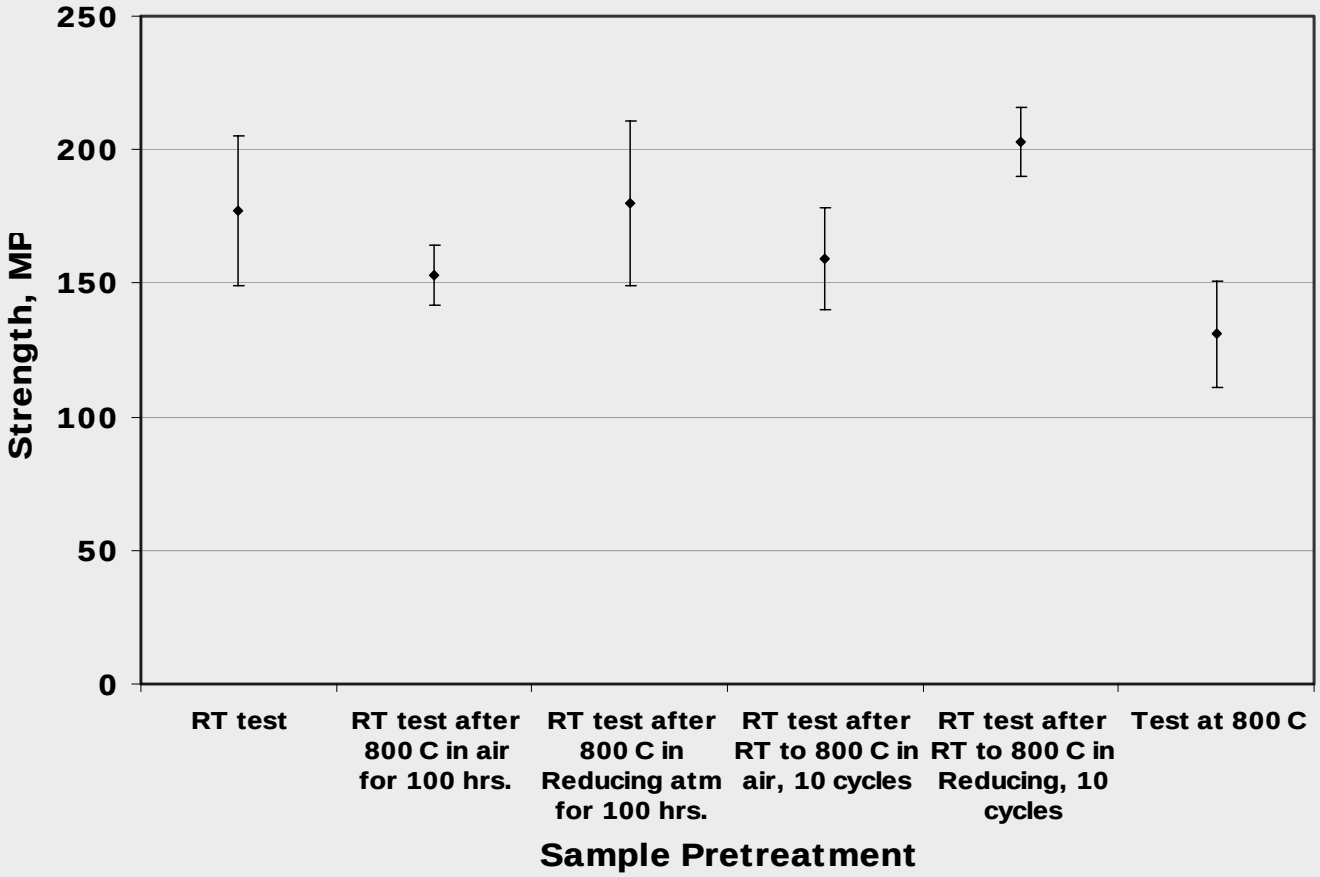


Tape cast laminated structure

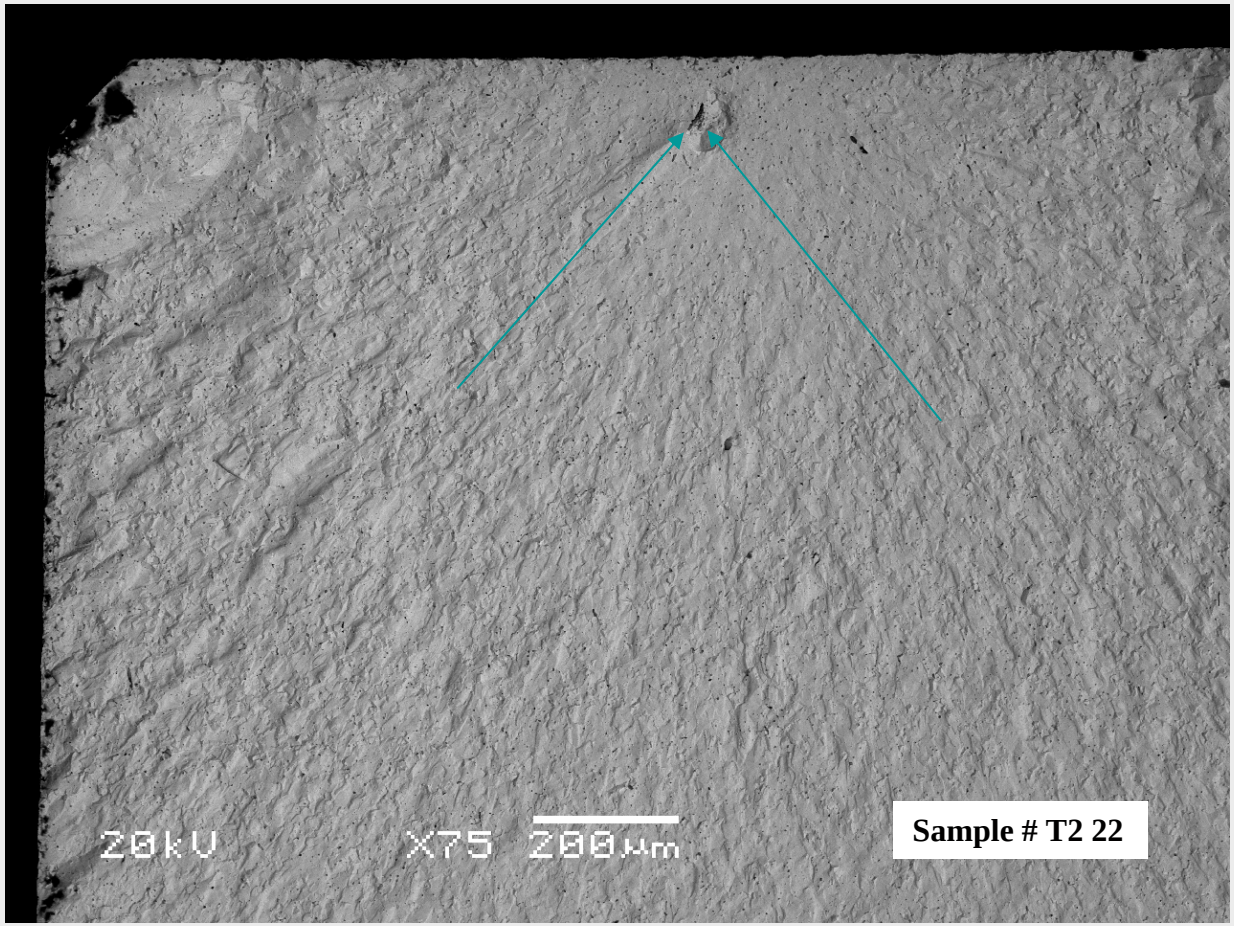
Strength

- **Limited information in the literature**
  - 147 MPa (isopressed bar) Du et al.
  - 113 MPa Sammes et al.
- **Preliminary Result: 129 MPa**
- **Additional work done at Sandia National Lab. (Raj Tandon and Ron Loehman)**

LSGM Strength

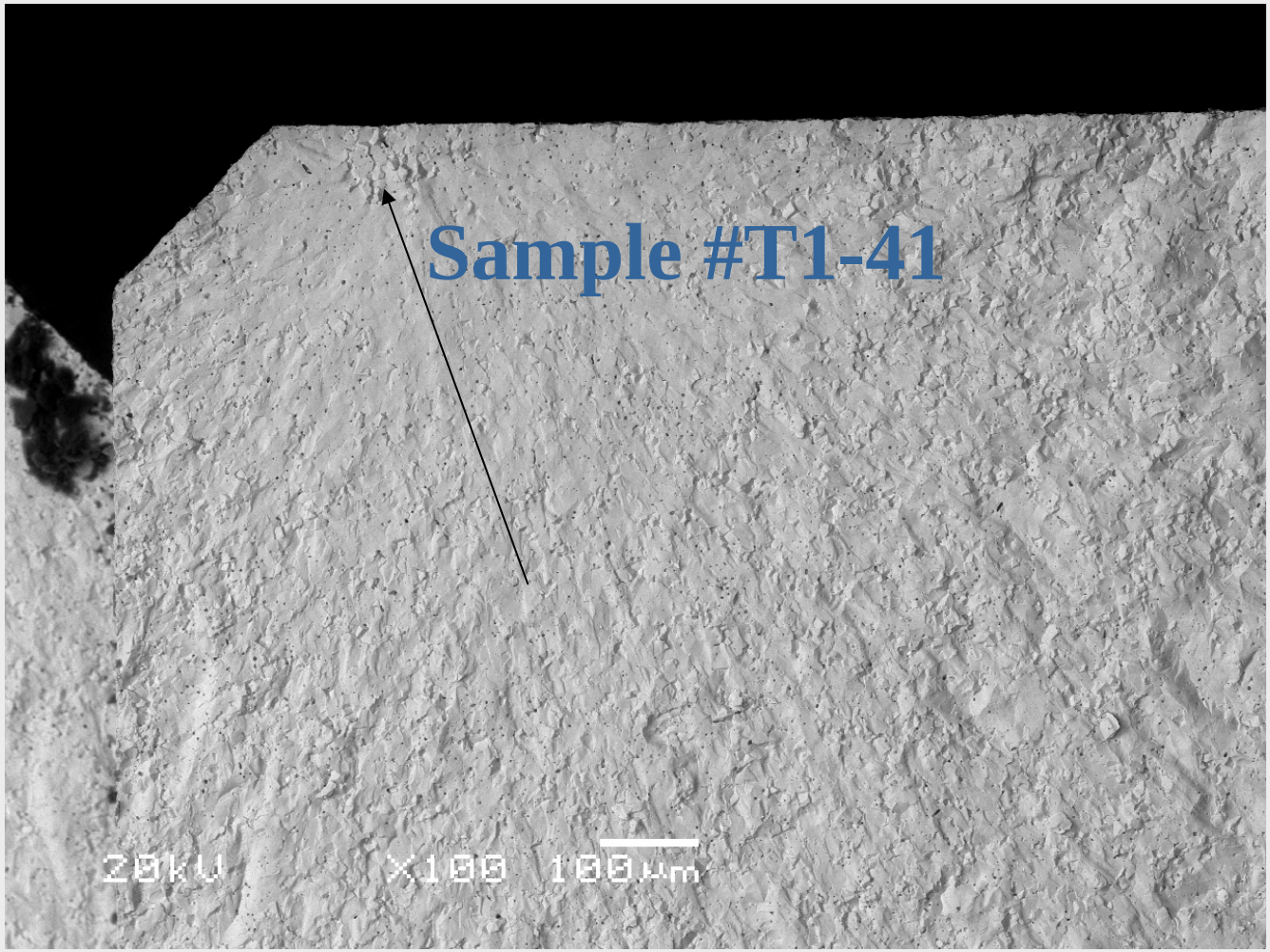


Test Conditions: 800 C exposure for 100 hr. in air, strength=168 MPa



Failure origin appears to be a near surface defect

Strength test at 800 C in air; 132 MPa



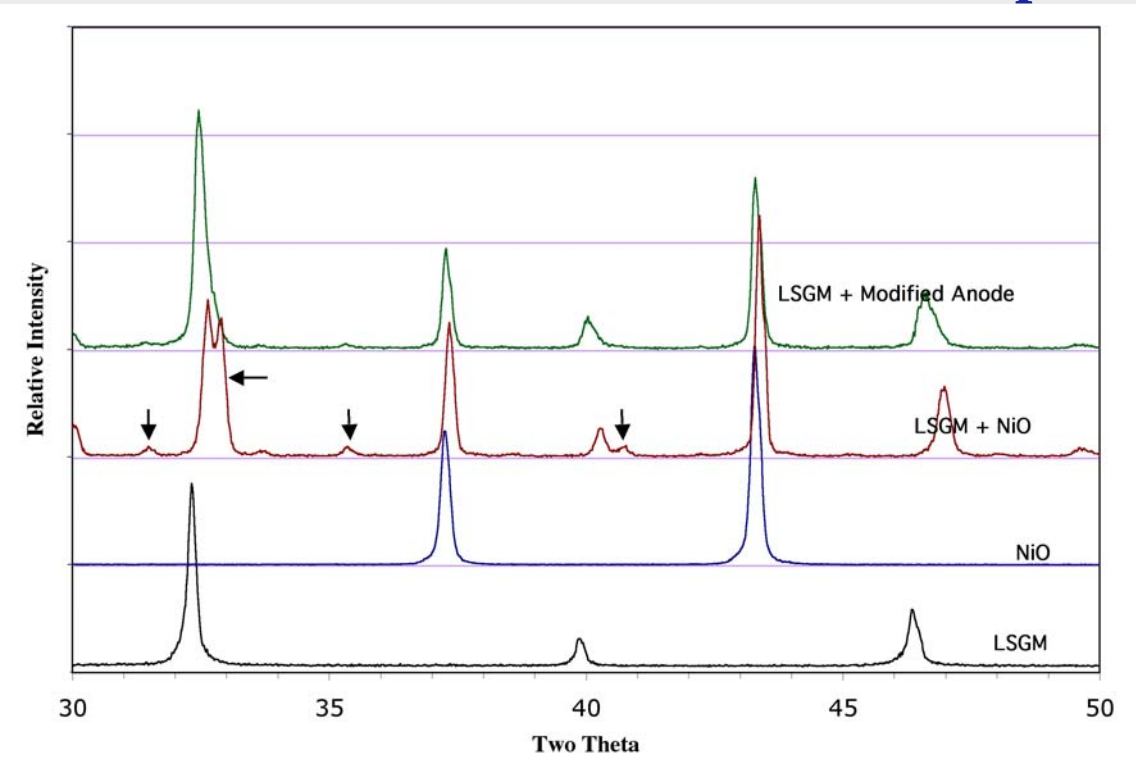
Failure origin appears to be a near surface defect

Summary of strength test

- Pores are still the major failure causing defects
- Exposure to high temperature in air - slight reduction in strength
- Exposure to high temperature in hydrogen - no change
- Thermal cycling in air - slight reduction
- Thermal cycling in hydrogen - increase in strength
- Test at high temperature - reduction in strength
- Process improvement in reducing flaws should improve strength

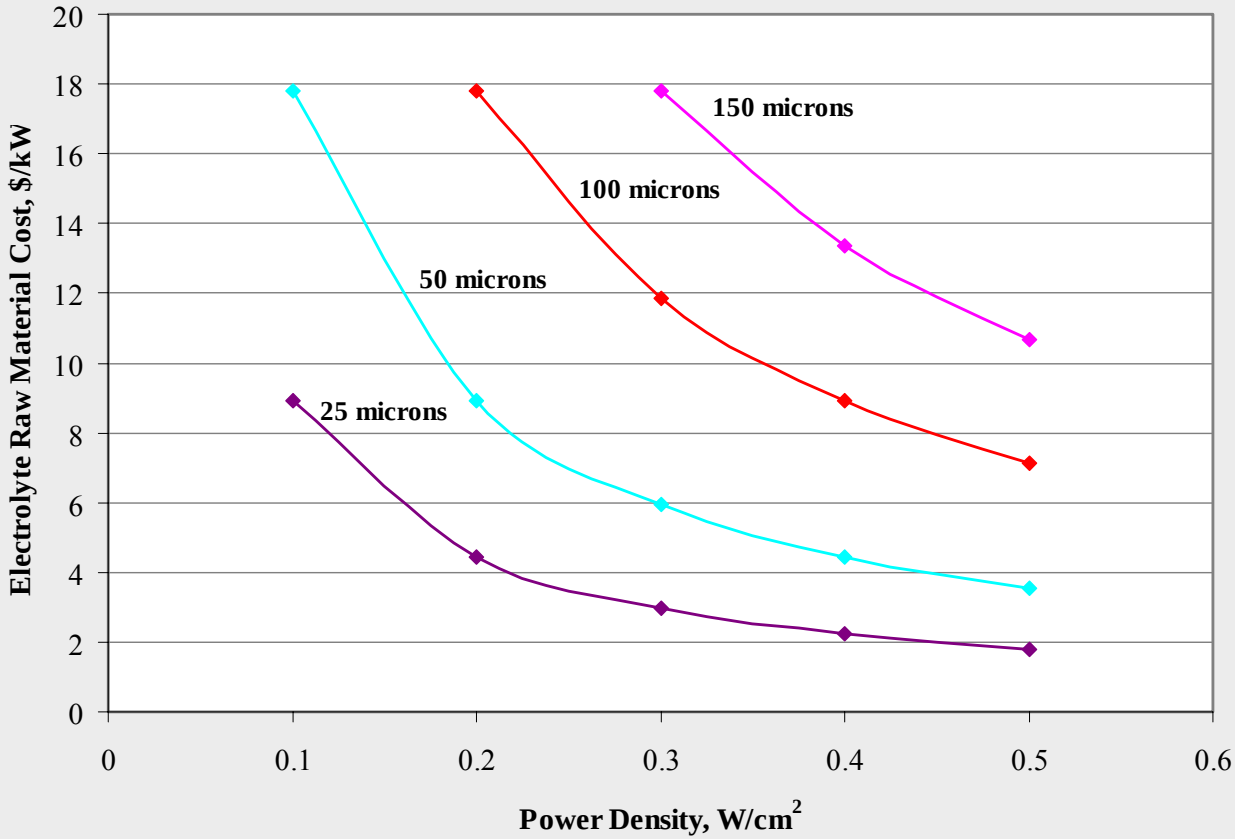
Anode material compatibility

- **Reduce Ni reaction with modified anode composition**



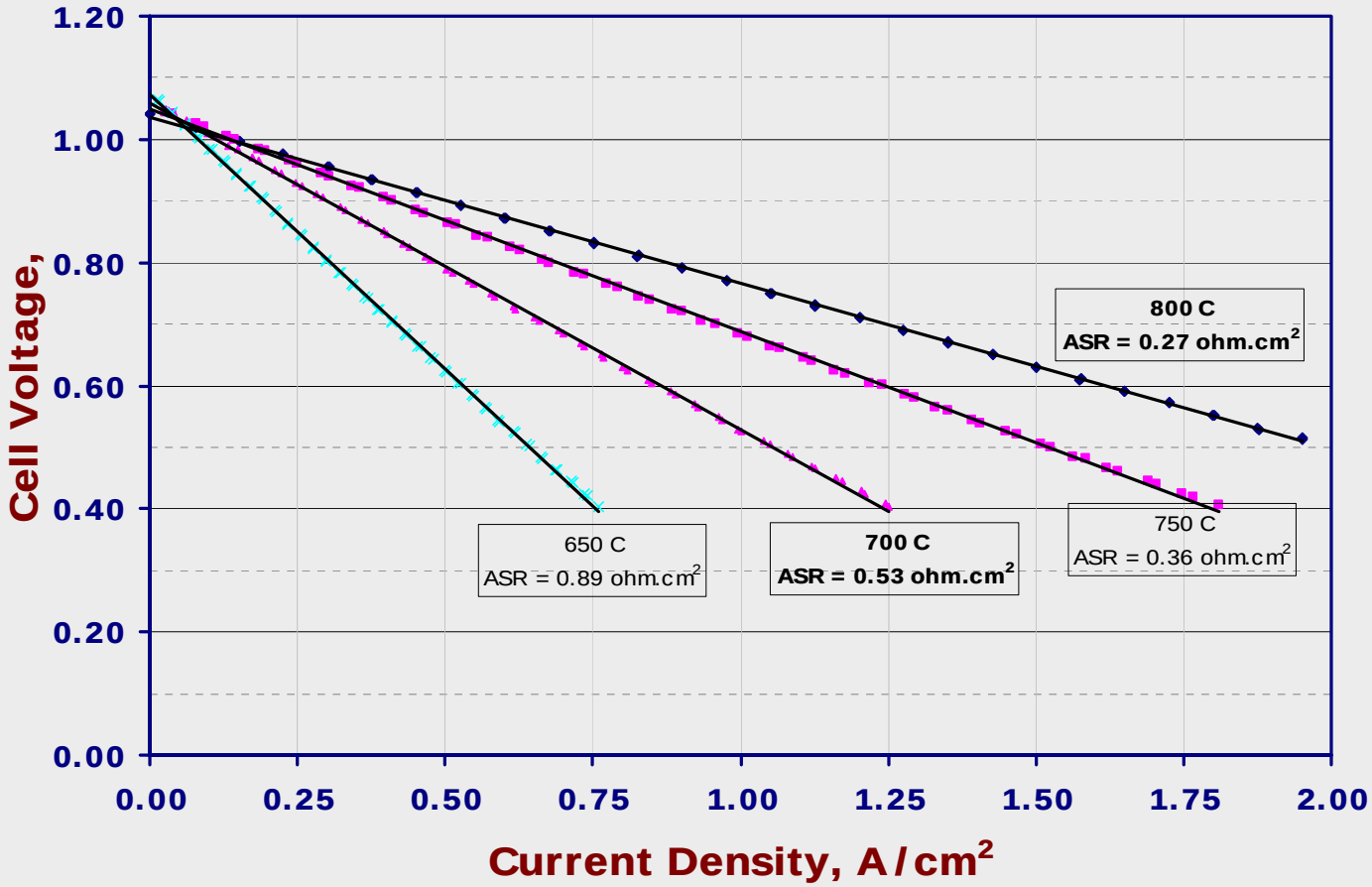
- **Powder mixture (LSGM + modified anode) calcination at 1350°C for four hours**

Cost



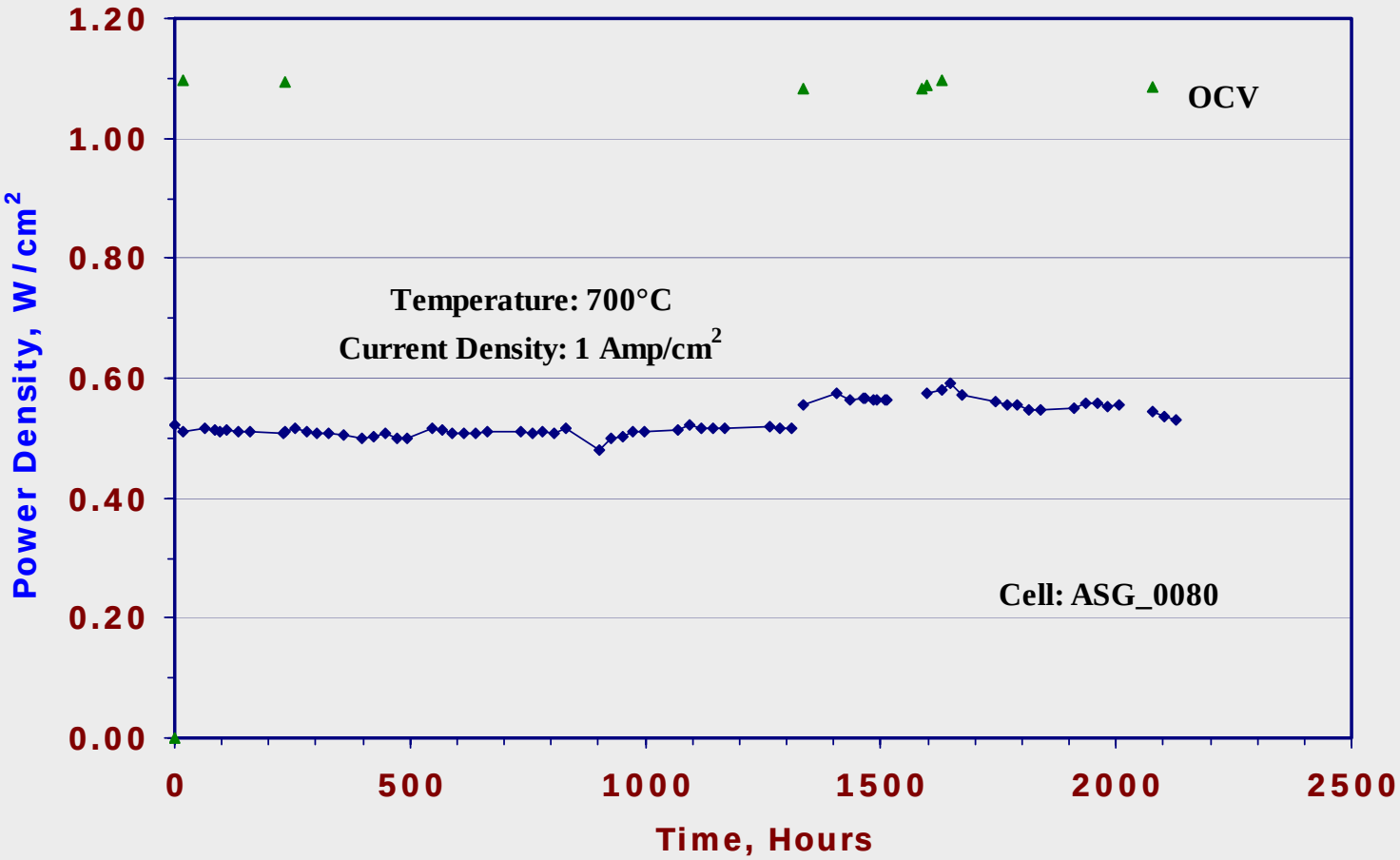
- **Parametric cost estimate of raw material oxides**
  (using USGS published cost of high purity oxides)

Single Cell Performance



- ASR at 700°C, thin LSGM supported on anode structure:~ 0.5 ohm.cm^2

Single cell long-term test

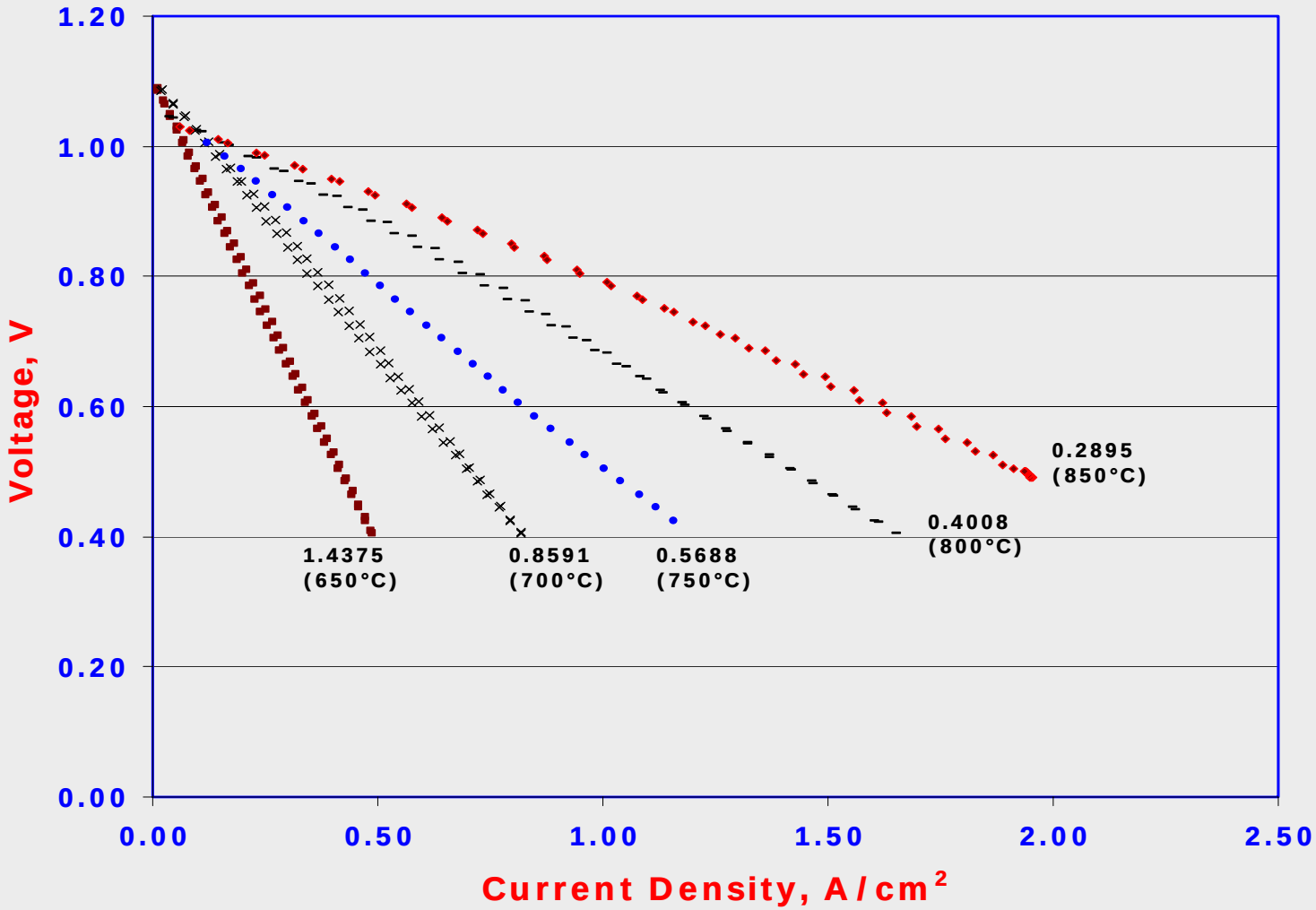


- **Stable button cell performance (anode as support)**

Cathode as support

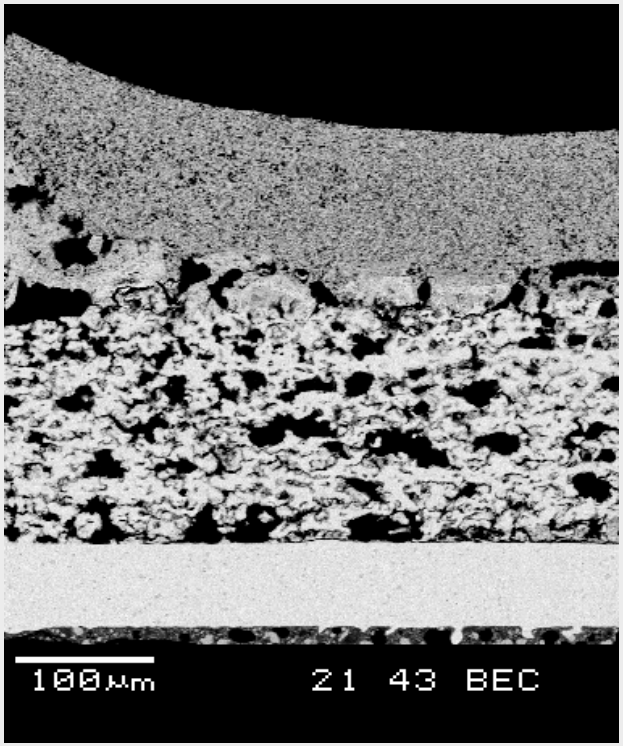
- **Benefits**
  - Materials compatibility - Perovskite electrolyte and cathode
  - Allows use of thin anode => high fuel utilization
  - No phase change from fabrication to operation compared to anode that undergoes reduction (associated volume shrinkage)

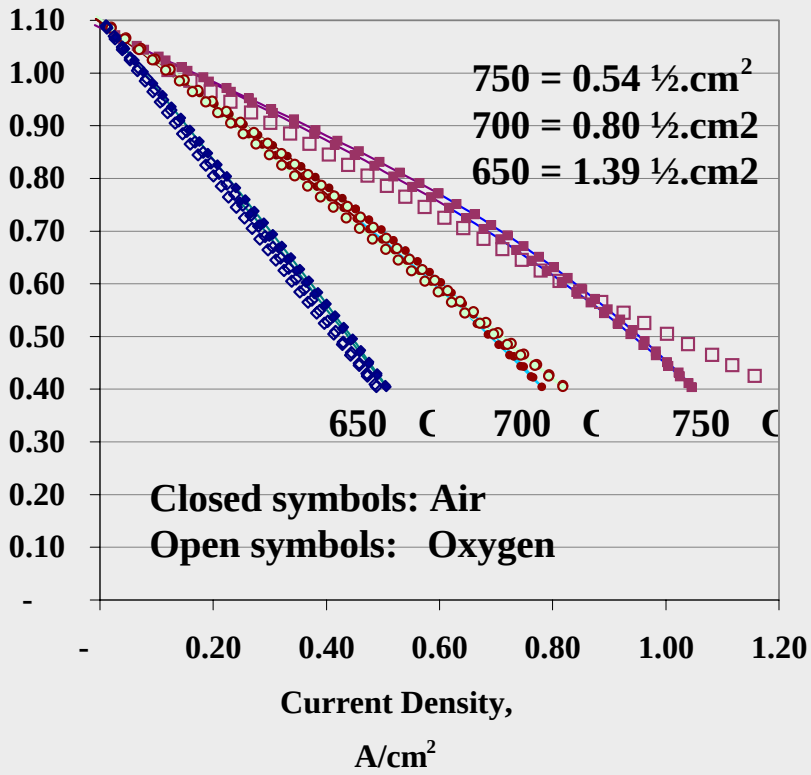
Cell Performance (Cathode Support)



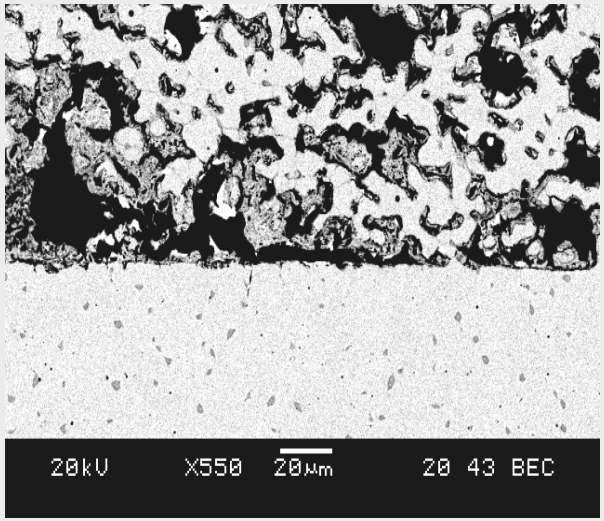
- **Electrolyte thickness 75 µm**

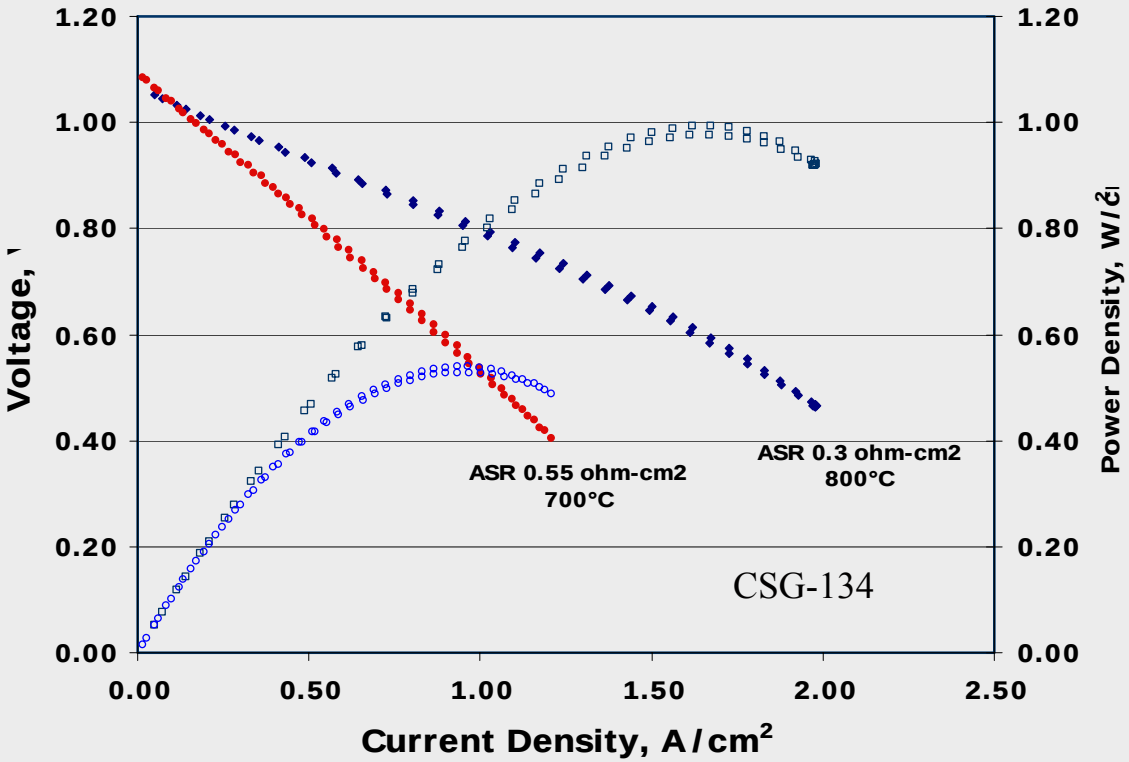
Cathode supported cell





Performance Improvement

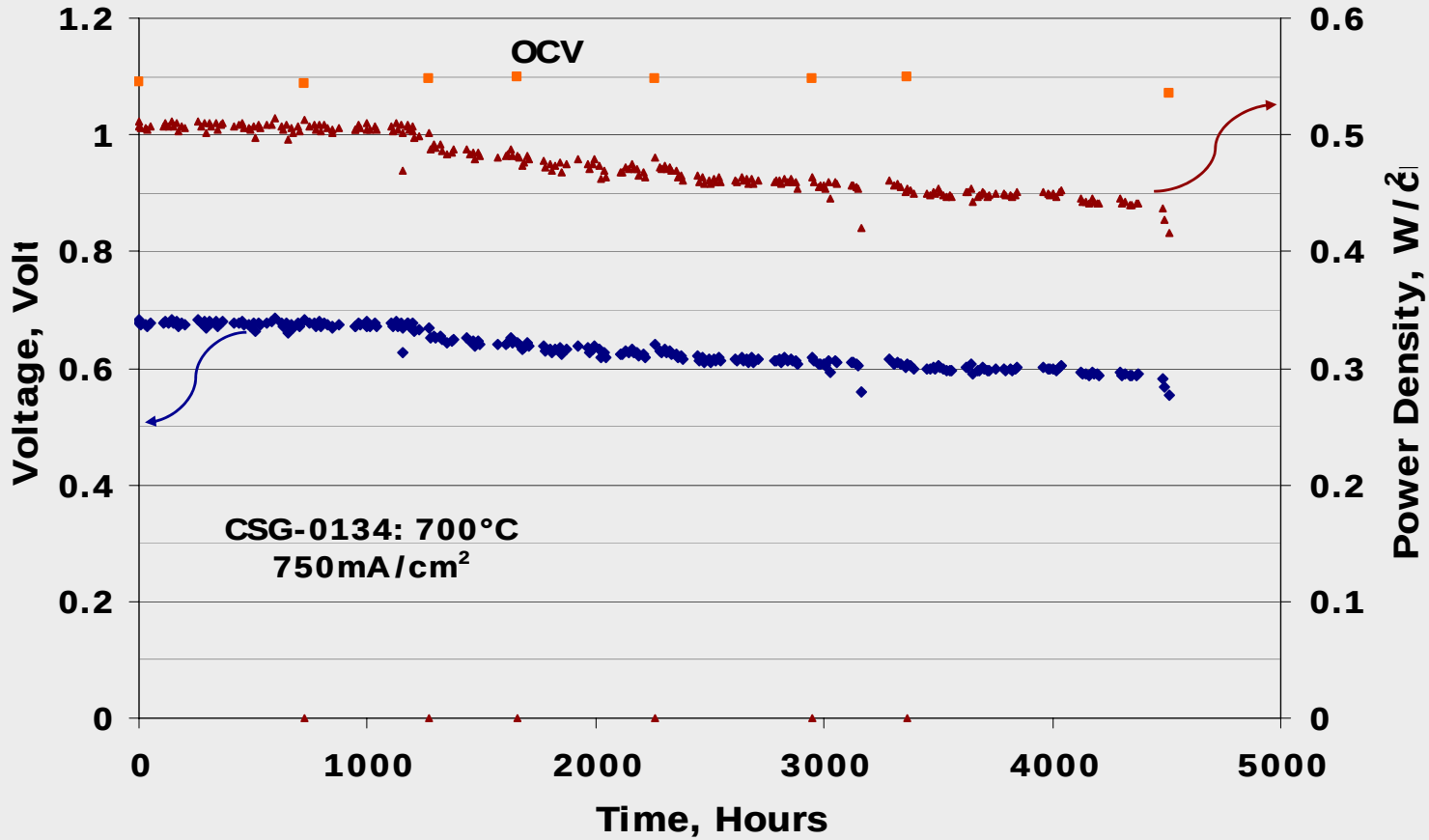




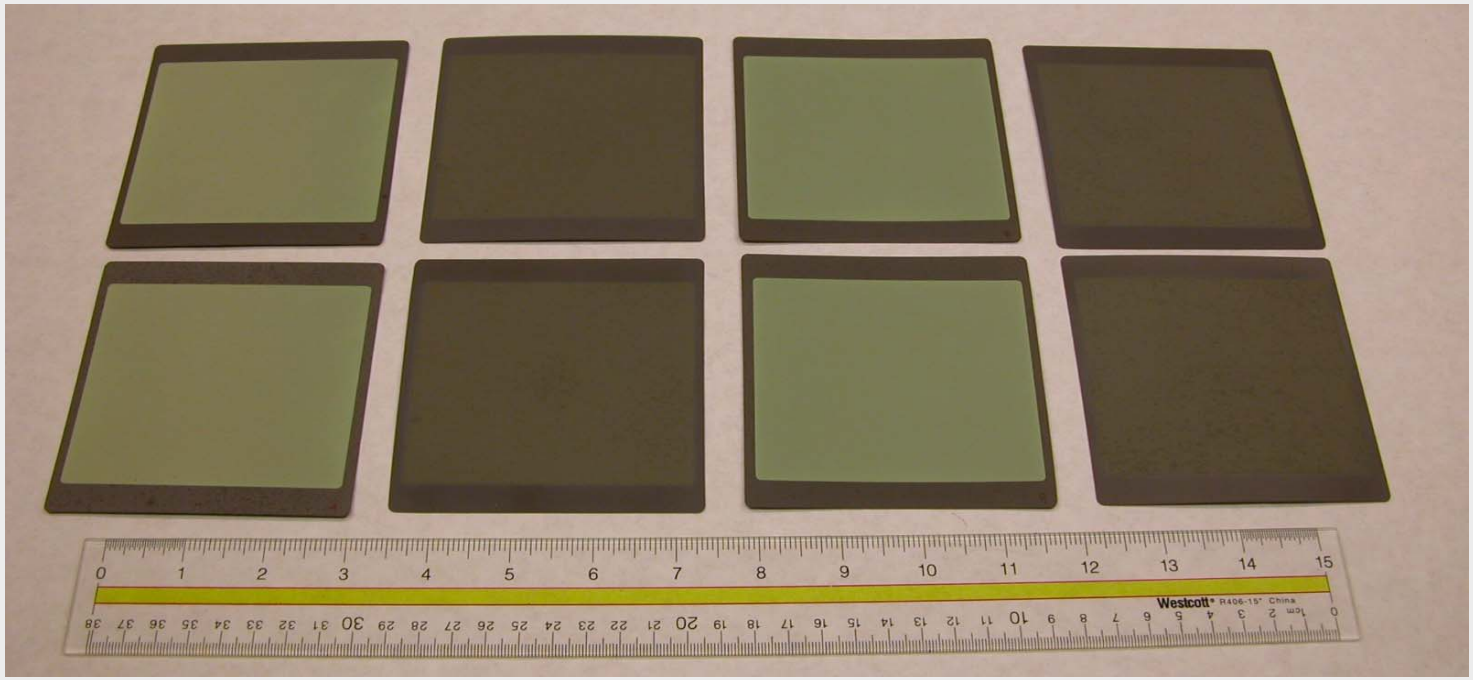
- 75 micron electrolyte
- Additional porosity in thick cathode structure

Single cell stability

- **ASR at 700°C with thin LSGM supported on cathode structure: ~ 0.5 ohm.cm^2**



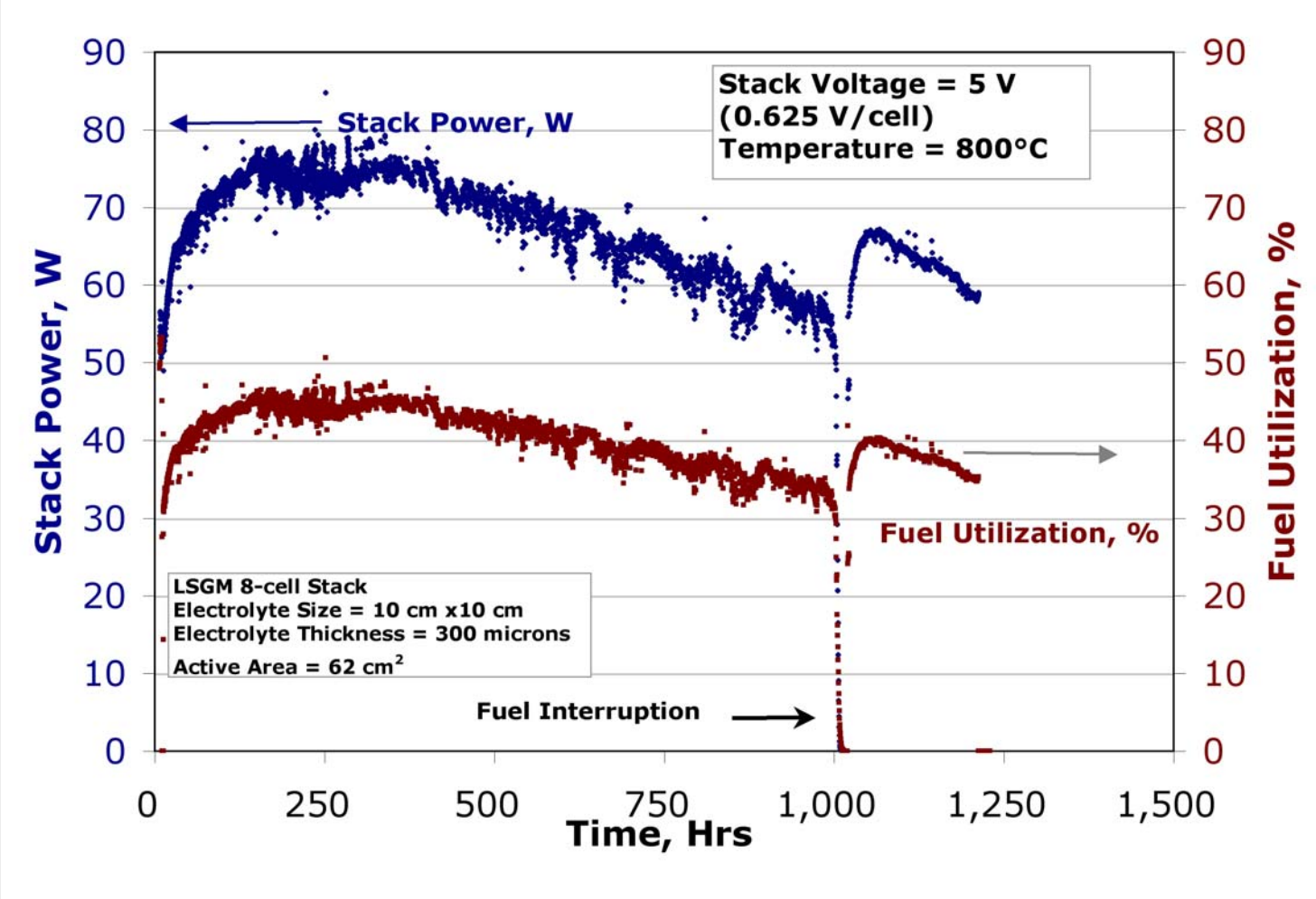
Cell Scale-up



- **Tape cast development to fabricate 10 x 10 cm cells**

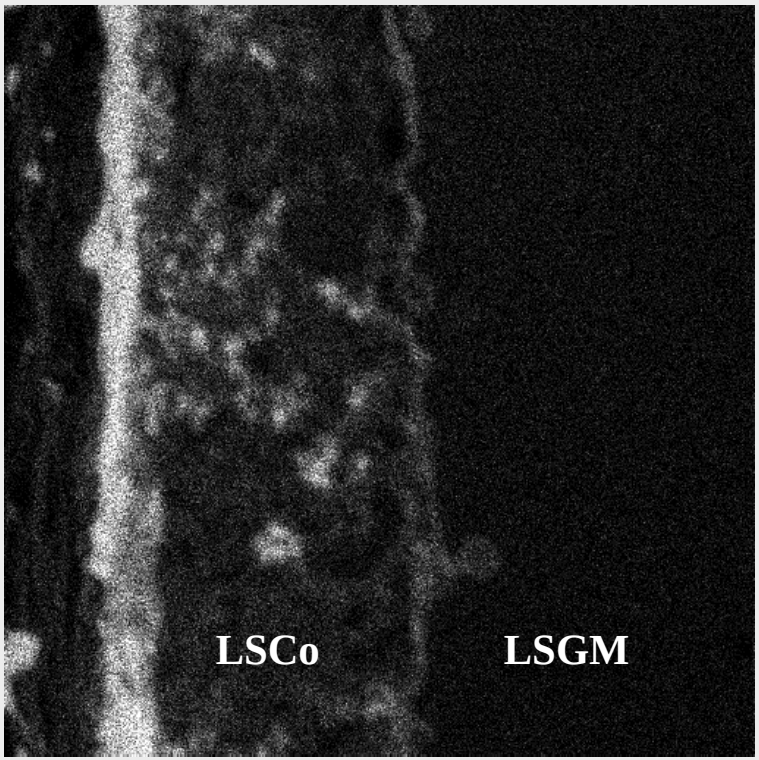
Stack Test (10x10cm 8-Cells)

Stack test

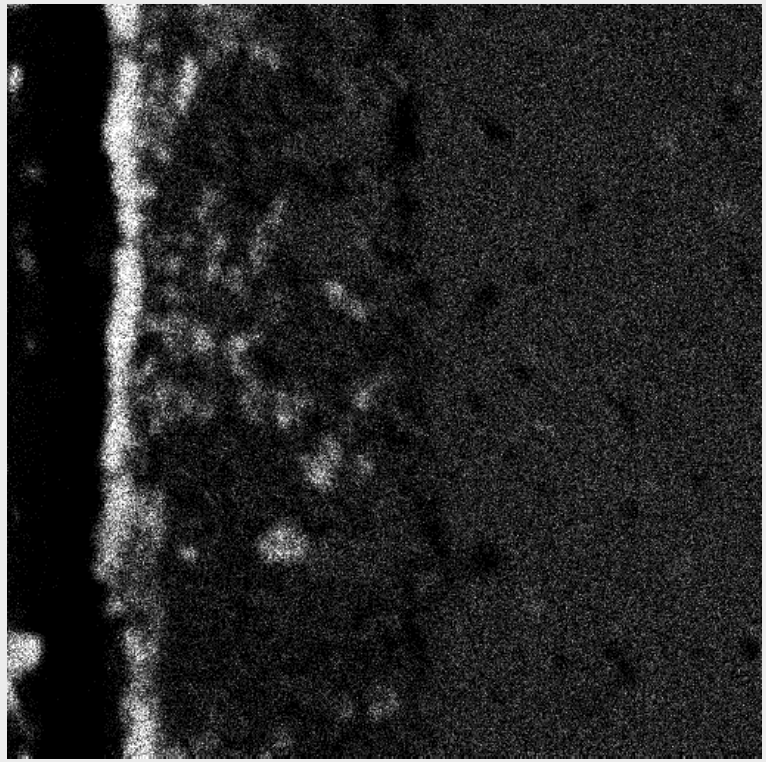

Stack Voltage = 5 V
(0.625 V/cell)
Temperature = 800°C
Stack Power, W
Fuel Utilization, %
LSGM 8-cell Stack
Electrolyte Size = 10 cm x10 cm
Electrolyte Thickness = 300 microns
Active Area = 62 cm2
Fuel Interruption
Stack Power, W
Fuel Utilization, %
Time, Hrs
0
10
20
30
40
50
60
70
80
90
0
250
500
750
1,000
1,250
1,500

Stack post-test analysis

- **Interaction of Cr from interconnect with Sr in cathode**

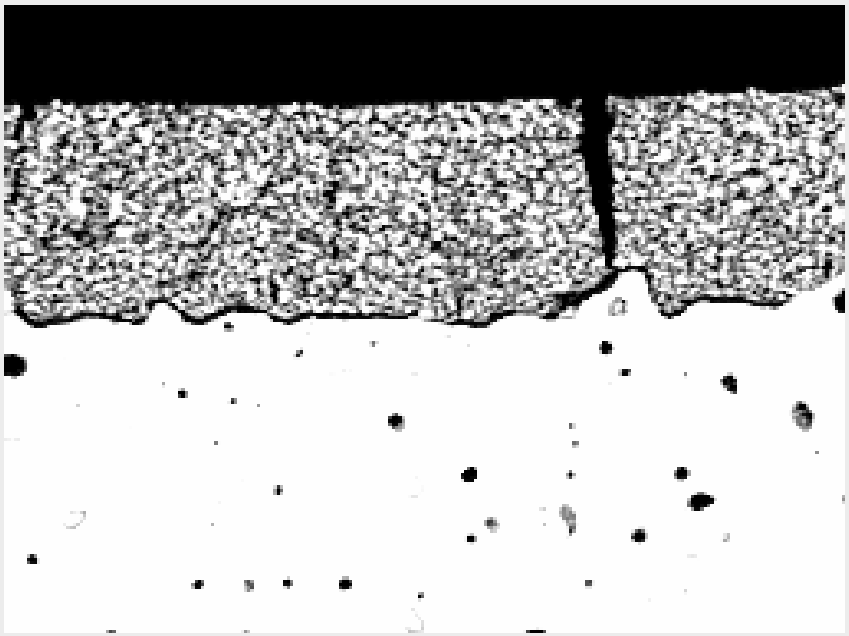


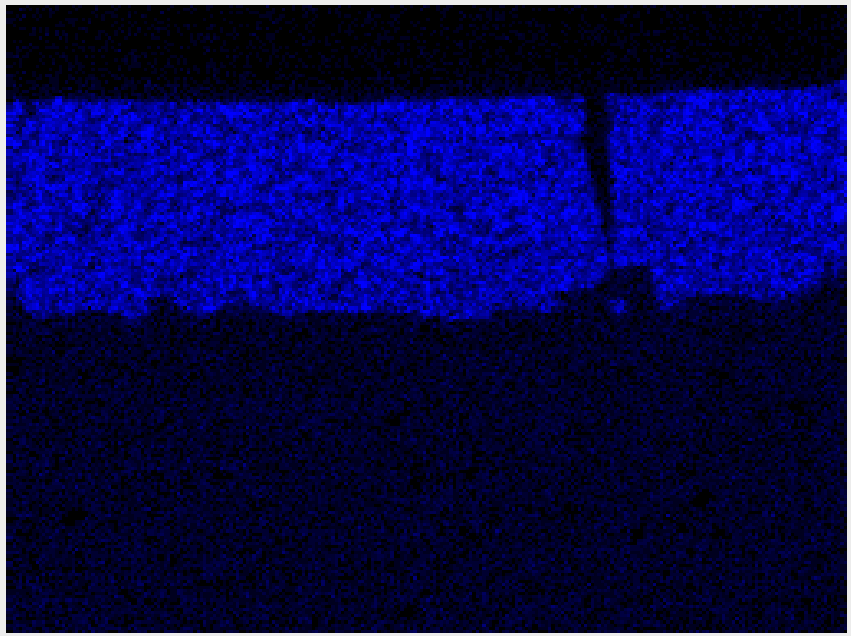
Cr map



Sr map

Anode-Electrolyte Interface





- **Post-test analysis (1200-hr test) did not show evidence of Ni diffusion**

Summary

- **LSGM is a promising electrolyte candidate for intermediate temperature SOFC**
- **Technical hurdles can be solved by a combination of basic and applied R&D**
  - Cathode as support provides certain benefits not available to anode supported cells
- **Progress in zirconia stack R&D can be applied directly (e.g., metal interconnects)**