NEXTECH MATERIALS

Low-Cost Manufacturing of Multilayer Ceramic Fuel Cells

Scott L. Swartz, Ph.D.
Director of Technology

NexTech Materials, Ltd.
Worthington, Ohio

SECA Core Technology Workshop
Pittsburgh, PA
June 18, 2002

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Outline

- Overview of MLFC Program
- Results
  - Fabrication Process Development
  - Electrical and SOFC Testing
  - Mechanical Property Testing
- Ceria-Based Electrolytes
- Closing Comments

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Low-Cost Manufacturing of Multilayer Ceramic Fuel Cells

DOE Contract No. DE-AC26-00NT40706

Program Manager: Bill Dawson

Principal Investigator: Scott Swartz

NETL Project Manager: Don Collins

Advanced Materials Technologies Edison Materials Technology Center Gas Technology Institute Michael A. Cobb & Company
NexTech Materials Northwestern University Oak Ridge National Laboratory Ohio State University University of Missouri-Rolla

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MLFC Program Timeline

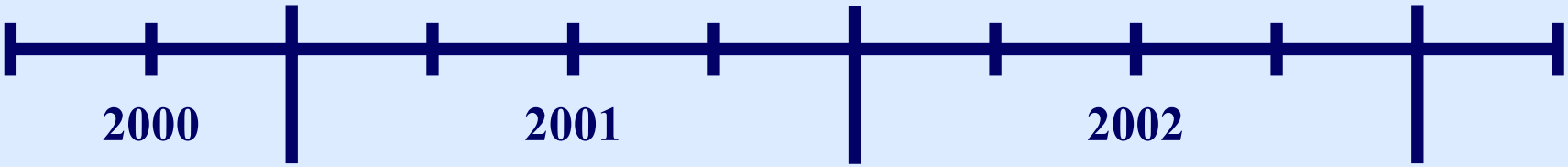
Manufacturing Analyses (Phase I)

Process Development (Phase II)

- LSM Powder Production Process
- Optimized Process for YSZ Coating Suspensions
- Fabrication Process for Cathode Supported Cells
- Fabrication Process for Anode Supported Cells

Testing (Phase III)

- Demonstrated High Performance
- Scale-Up of Cell Fabrication
- Samples for Property Testing at ORNL
- Screen Printing Process for Cathode Coatings
- Initiated Long-Term Cell Testing at GTI



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Program Plan

Phase I (3 months)

Manufacturing Cost and Risk Assessment

Michael A. Cobb & Co.
Advanced Materials Technologies
Gas Technology Institute

Phase II (12 months)

Development of Fabrication Processes for Planar Cells

NexTech Materials
Oak Ridge National Laboratory
University of Missouri-Rolla

Phase III (18 months)

SOFC Testing, Destructive and Non-Destructive Testing

Northwestern University
Gas Technology Institute
Ohio State University

Advanced Materials Technologies Edison Materials Technology Center Gas Technology Institute Michael A. Cobb & Company
NexTech Materials Northwestern University Oak Ridge National Laboratory Ohio State University University of Missouri-Rolla

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Process Development

NexTech	ORNL	UMR
Tape Casting (Anode or Cathode)	Tape Casting (Anode)	Tape Casting (Cathode)
Colloidal Spray (Electrolyte)	Screen Printing (Electrolyte)	Sintering
Co-Sintering	Co-Sintering	Spin Coating (Electrolyte)
Screen Printing (Cathode or Anode)	Screen Printing (Cathode)	Screen Printing (Anode)

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Phase I Lessons

❑ Keys to Cost Reduction

- ➢ Lower operating temperatures (interconnects)
- ➢ Increased power densities
- ➢ Low-cost raw materials (especially YSZ)
- ➢ Increased manufacturing yields
- ➢ Efficient materials utilization (advanced designs)

❑ Development Risk Elements

- ➢ Seals
- ➢ Thermal expansion mismatches
- ➢ Gas flow through porous electrodes
- ➢ Scale up to large electrolyte areas

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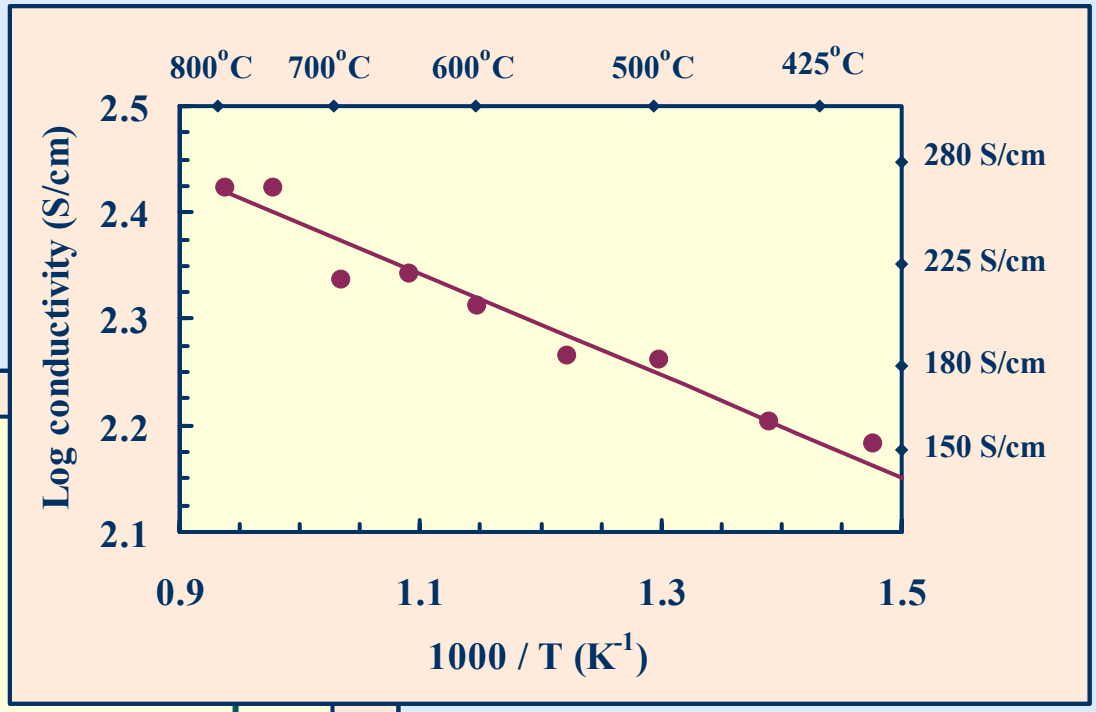
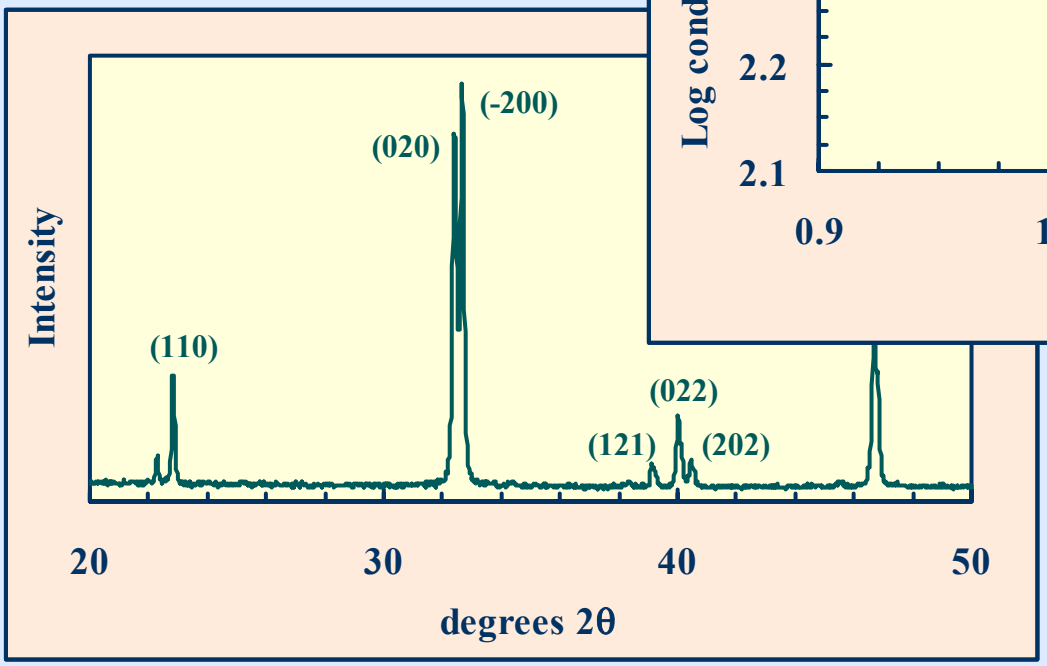
LSM Powder Production

Composition

$(La_{0.85}Sr_{0.15})MnO_3$





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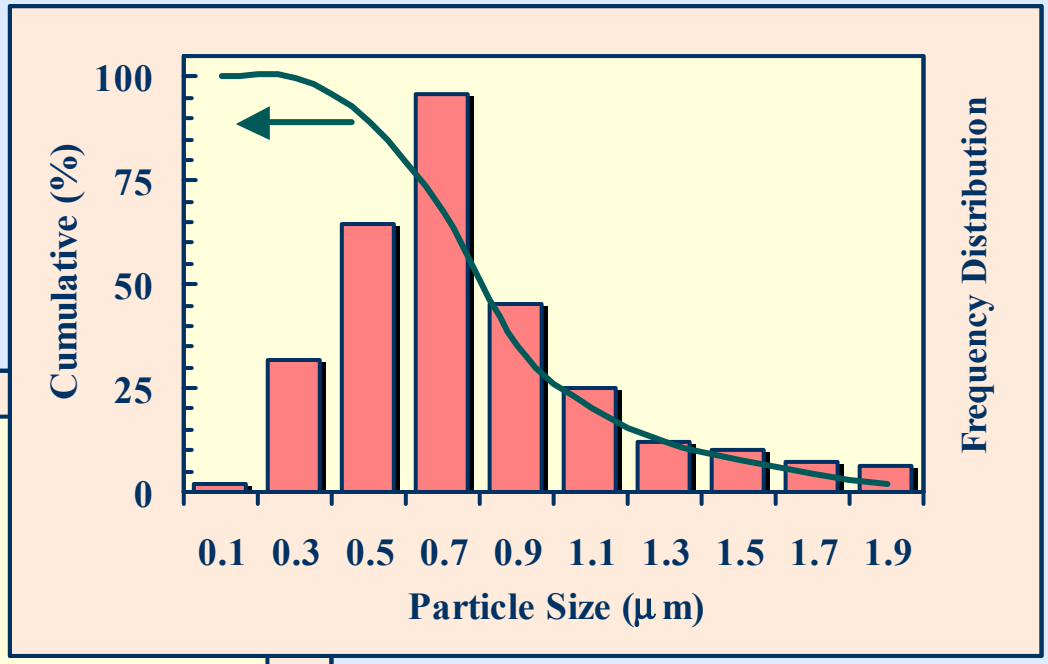
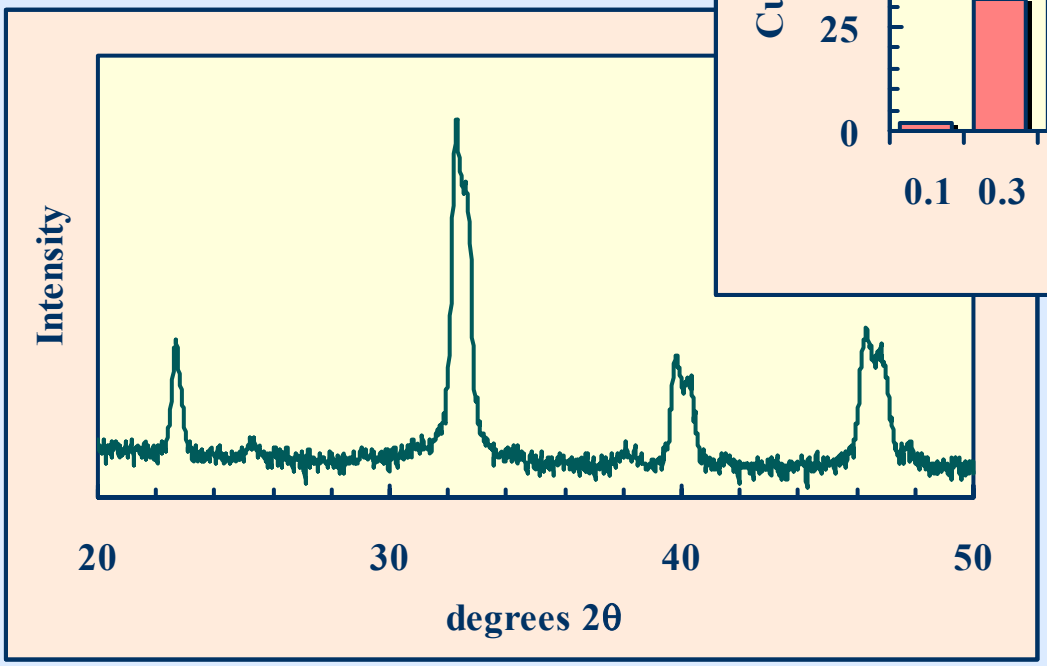
LSF Powder Production

Composition

$(La_{0.60}Sr_{0.40})FeO_3$





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Tape Casting

Process Variables

- Particle Size and Surface Area
- Formulation (binders, fugitives, etc.)
- Cleanliness (dust, hair, etc.)
- Tape Casting Layer Thickness
- Lamination Conditions
- Dicing Methods
- Binder Burnout Cycle
- Pre-Calcination Conditions

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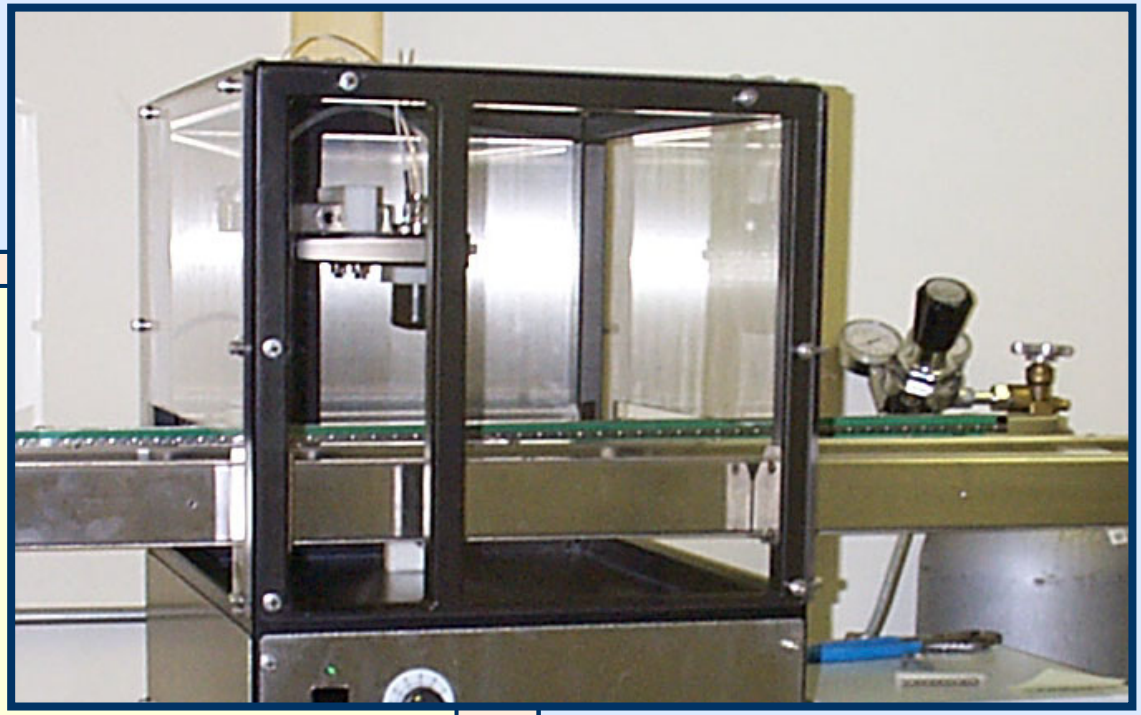
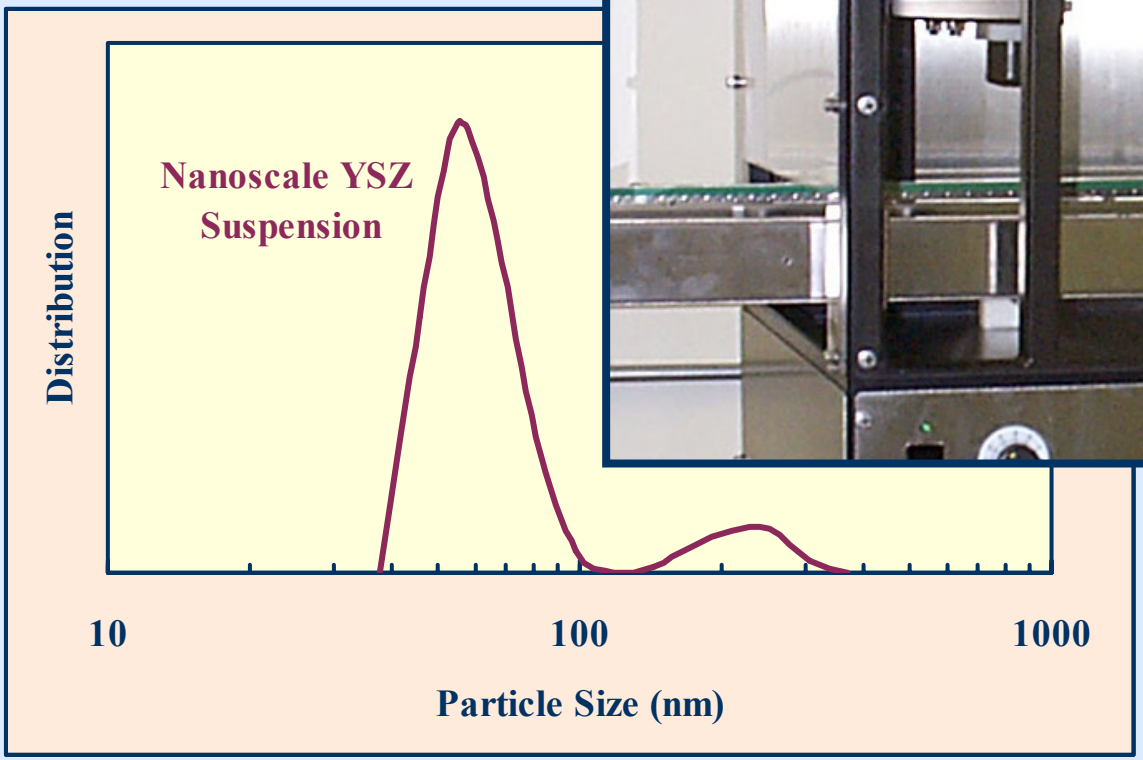
YSZ Coating Process





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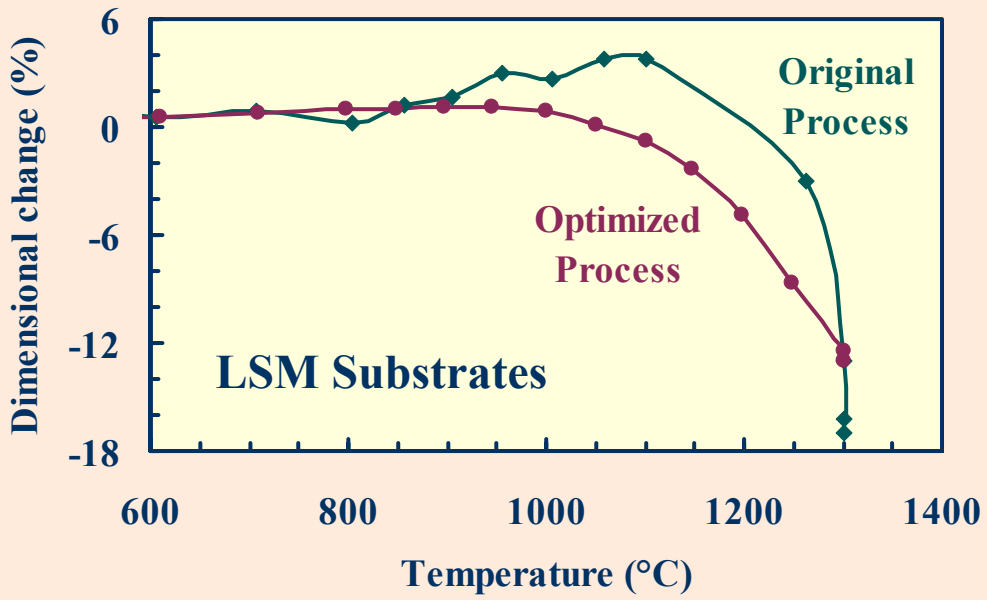
Co-Sintering



Process Variables

- Tape Formulations
- Coating Process
- Pre-Calcination
- Setter Tiles
- Control of Component Shrinkages
- Heating and Cooling Rates
- Constrained Sintering
- Creep Flattening

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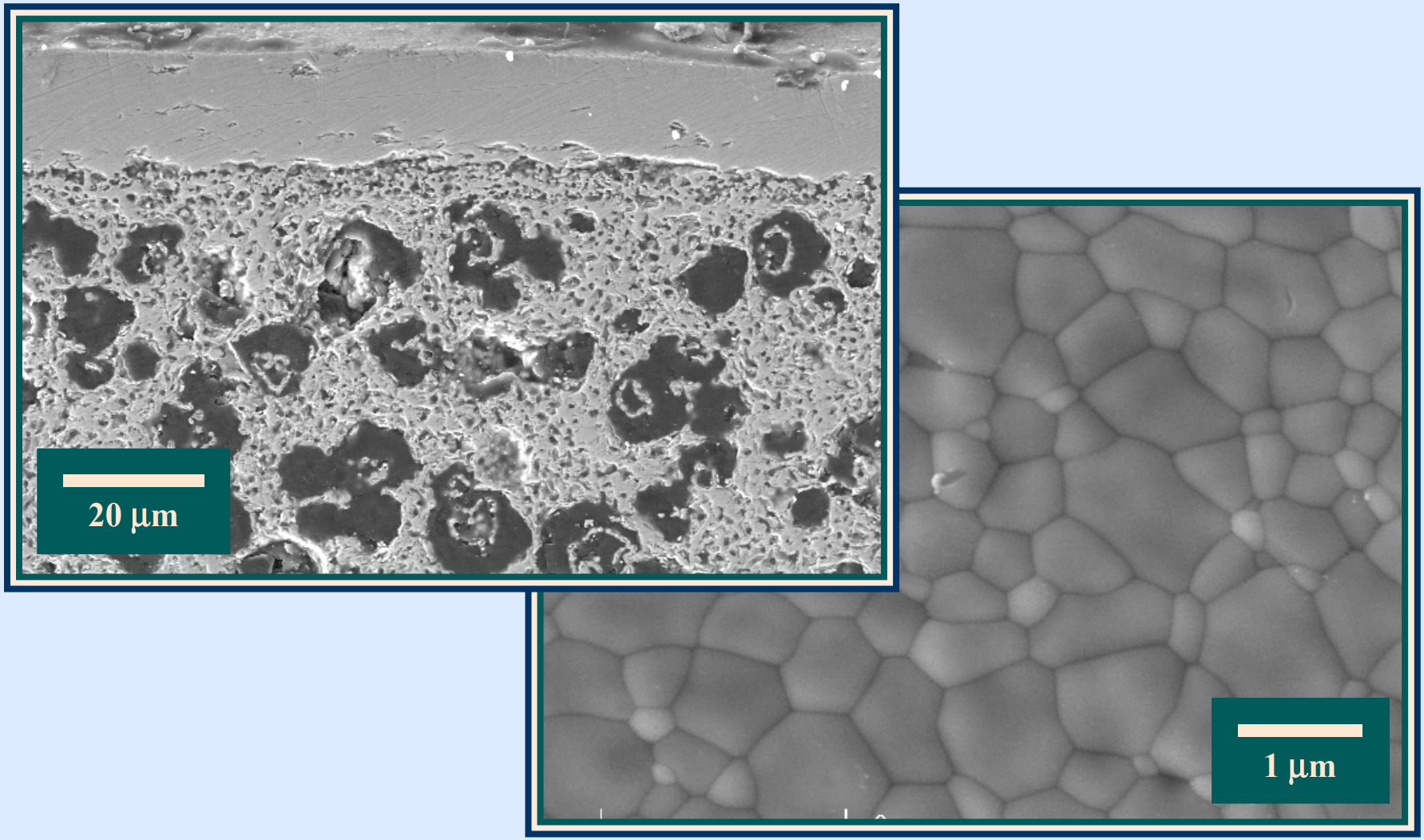
Cathode Supported Cells



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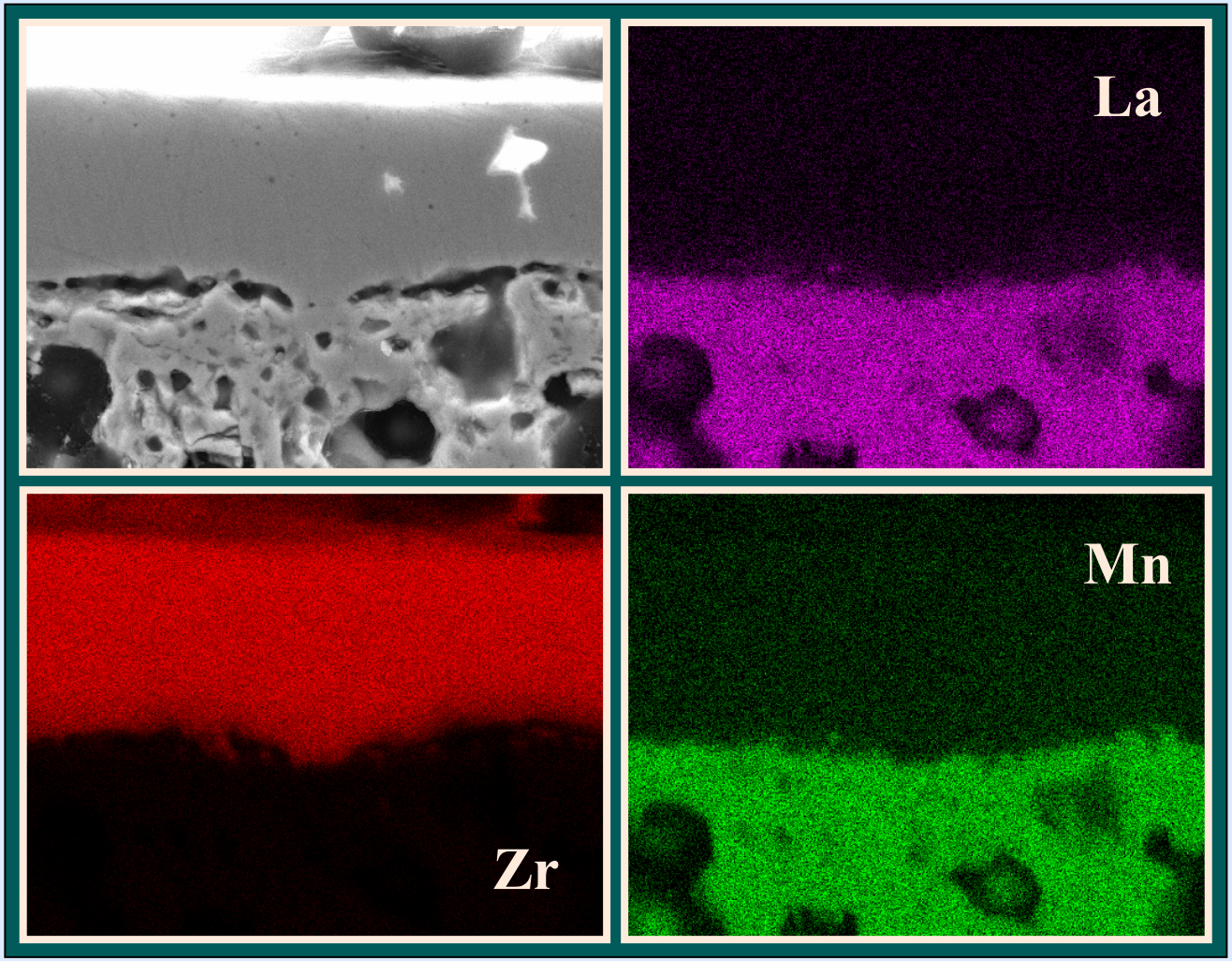
Cathode Supported Cells



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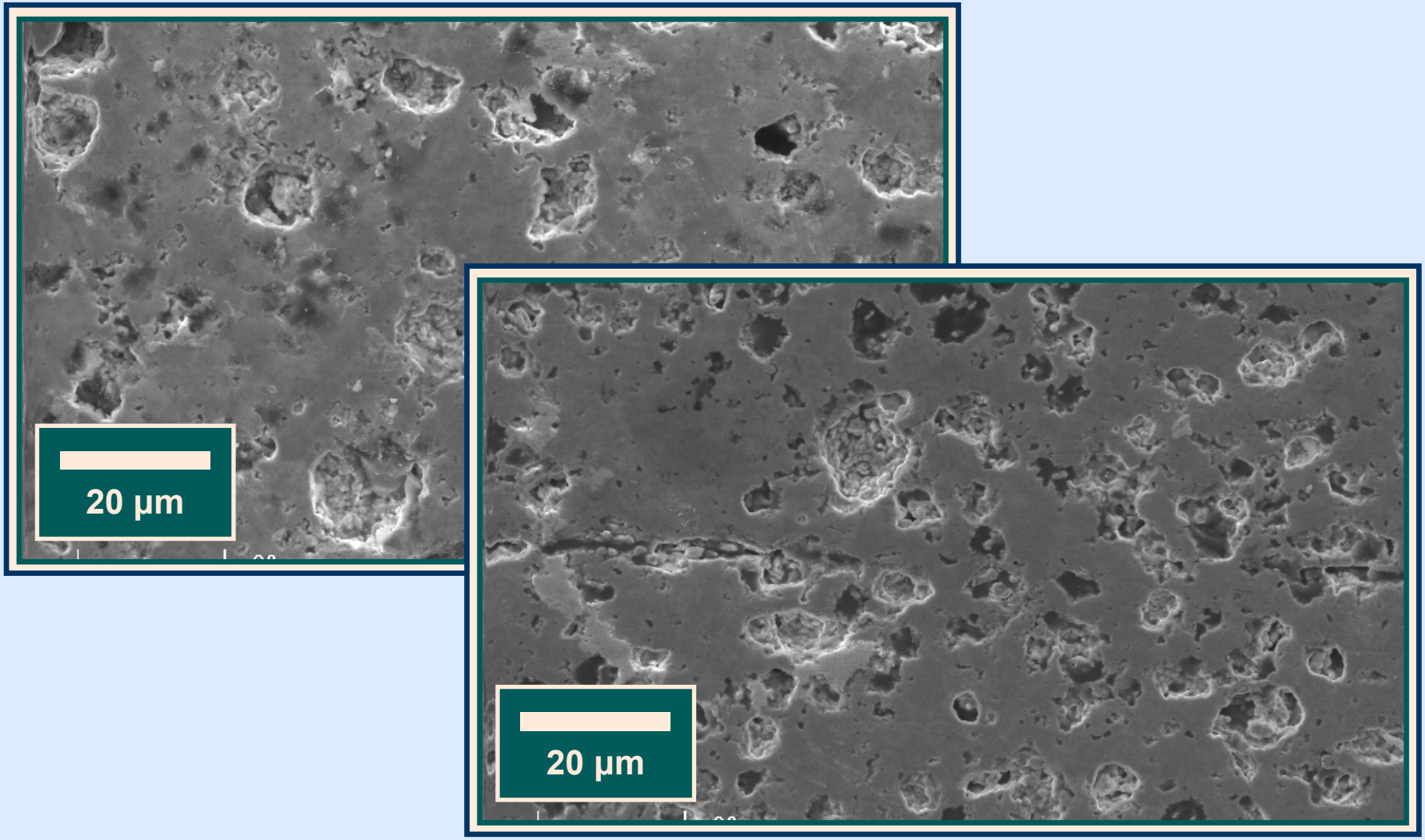
Anode Microstructure



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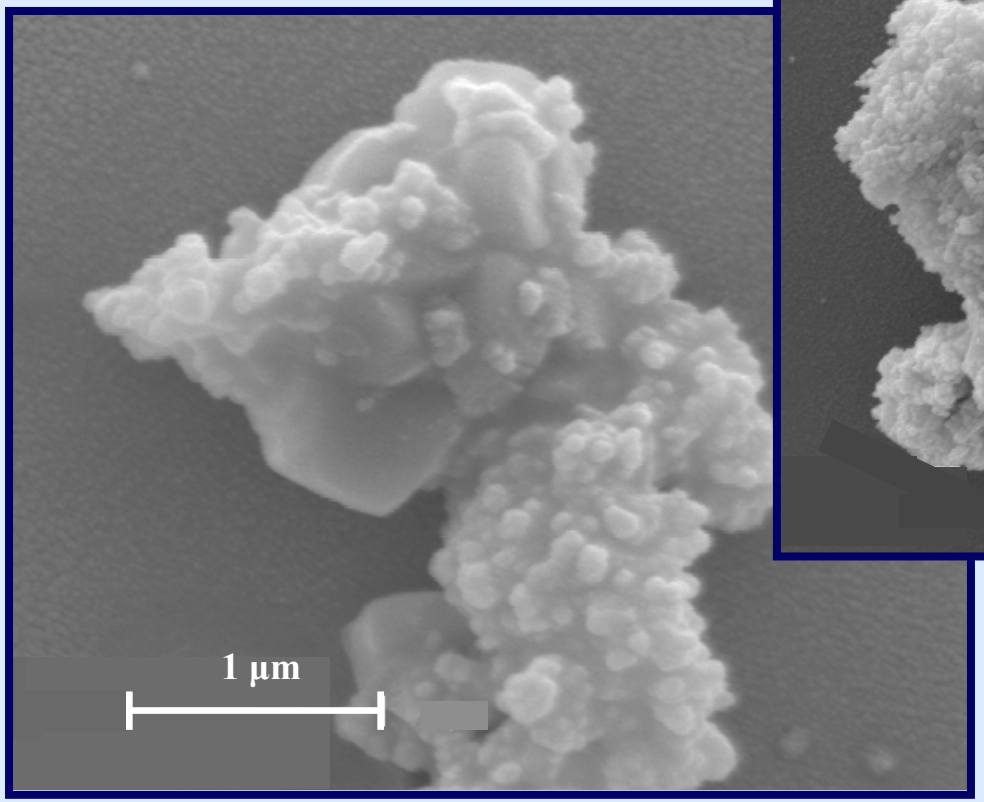
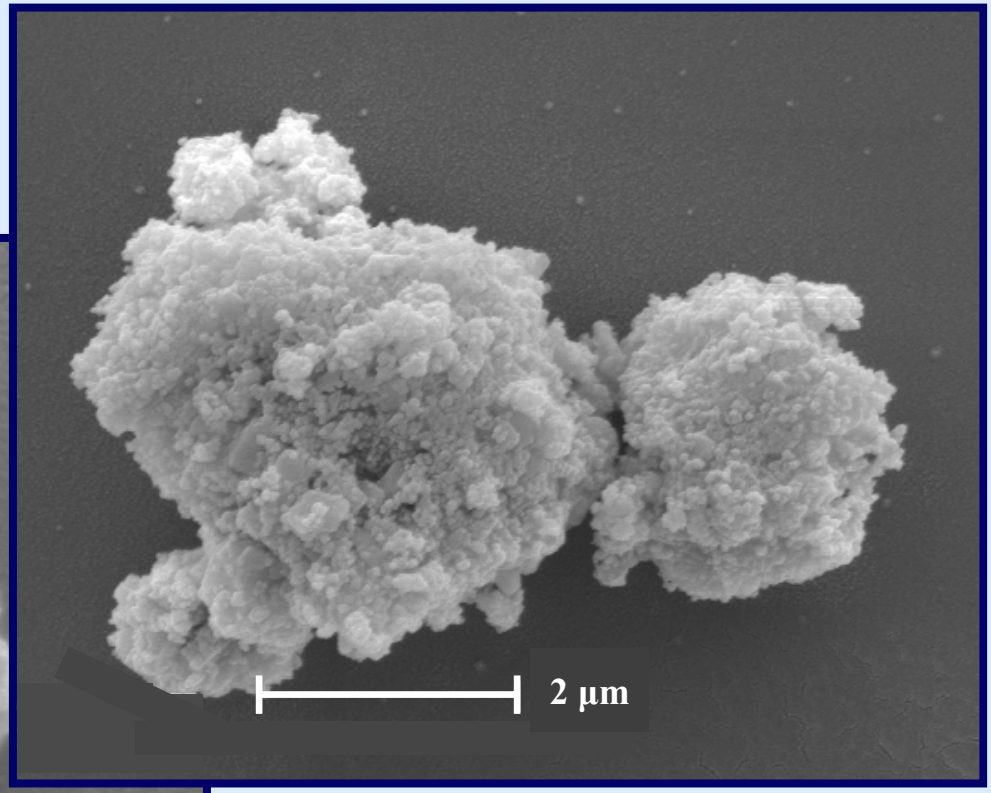
Nano-Composite Anodes

Conventional Method





New Method

U.S. Patent Pending

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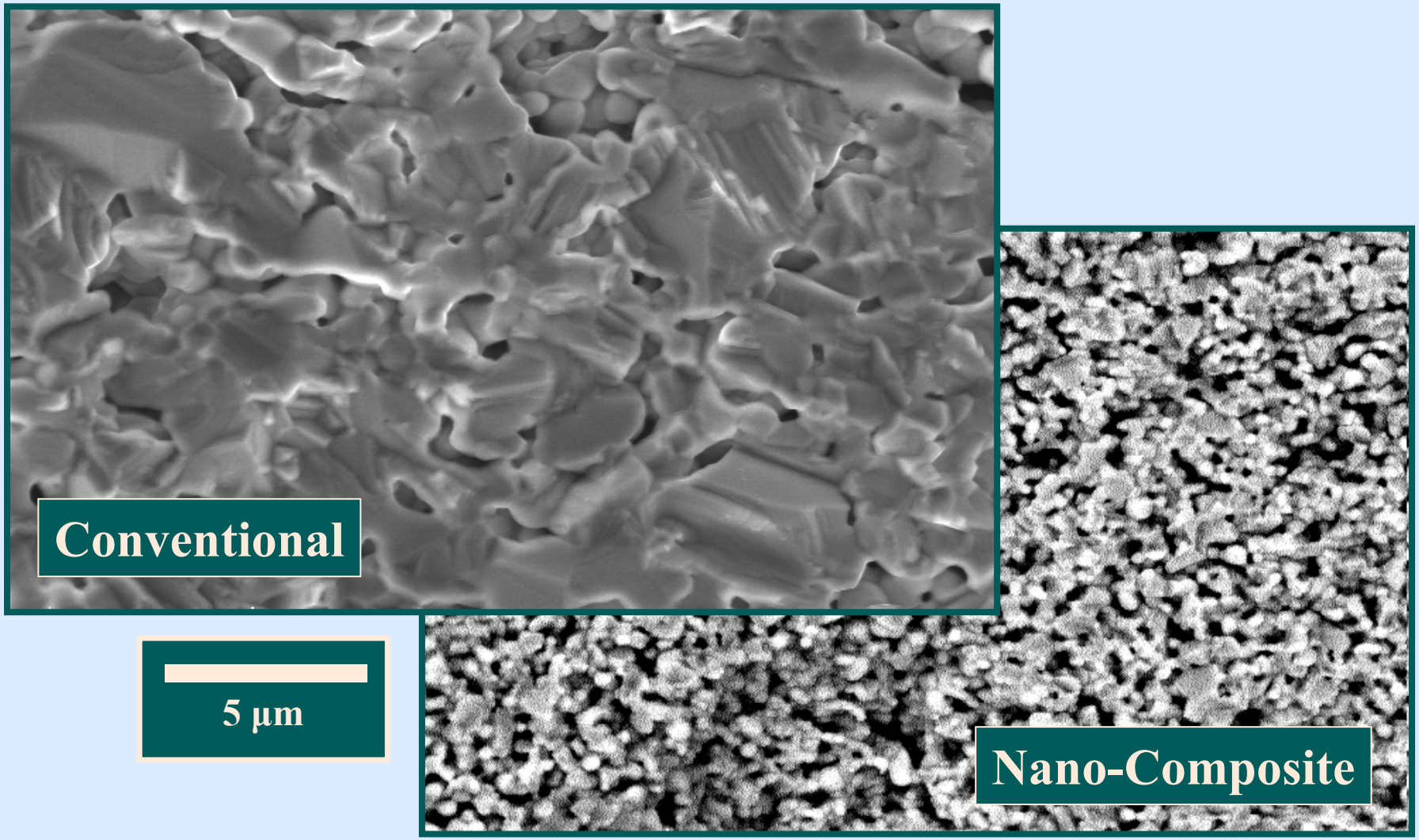
Nano-Composite Anodes



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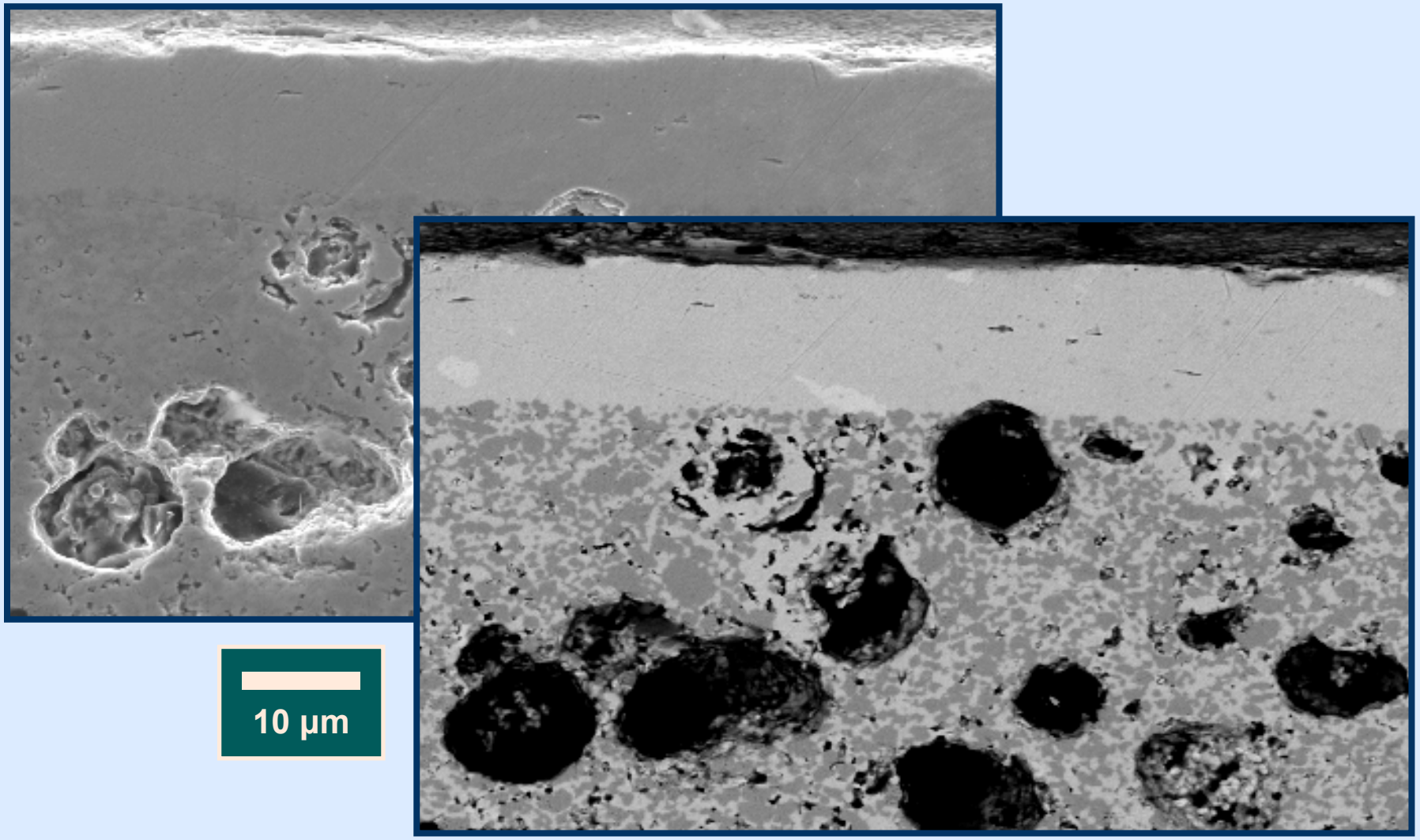
Anode-Supported Cells



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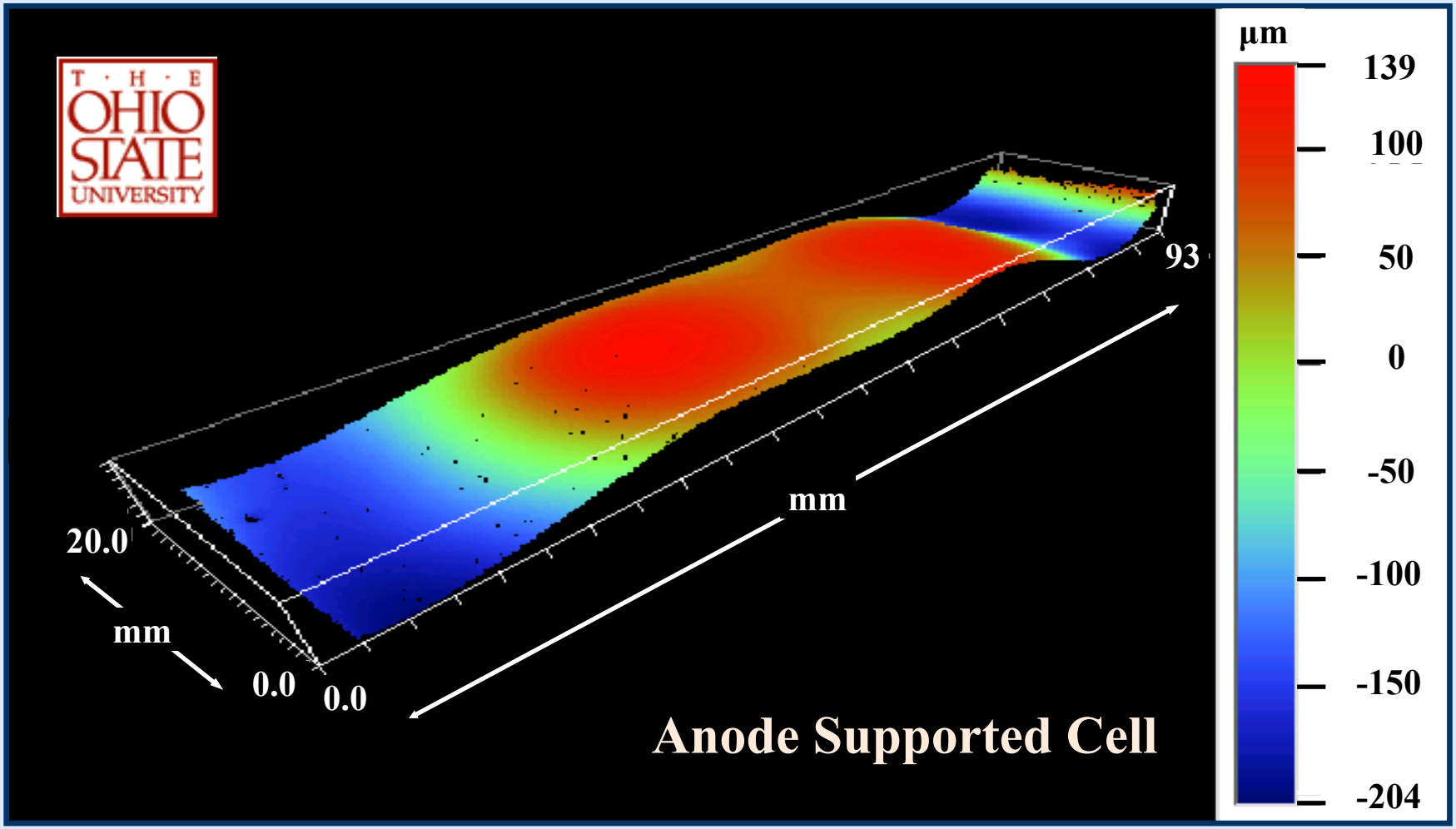
Flatness Measurements



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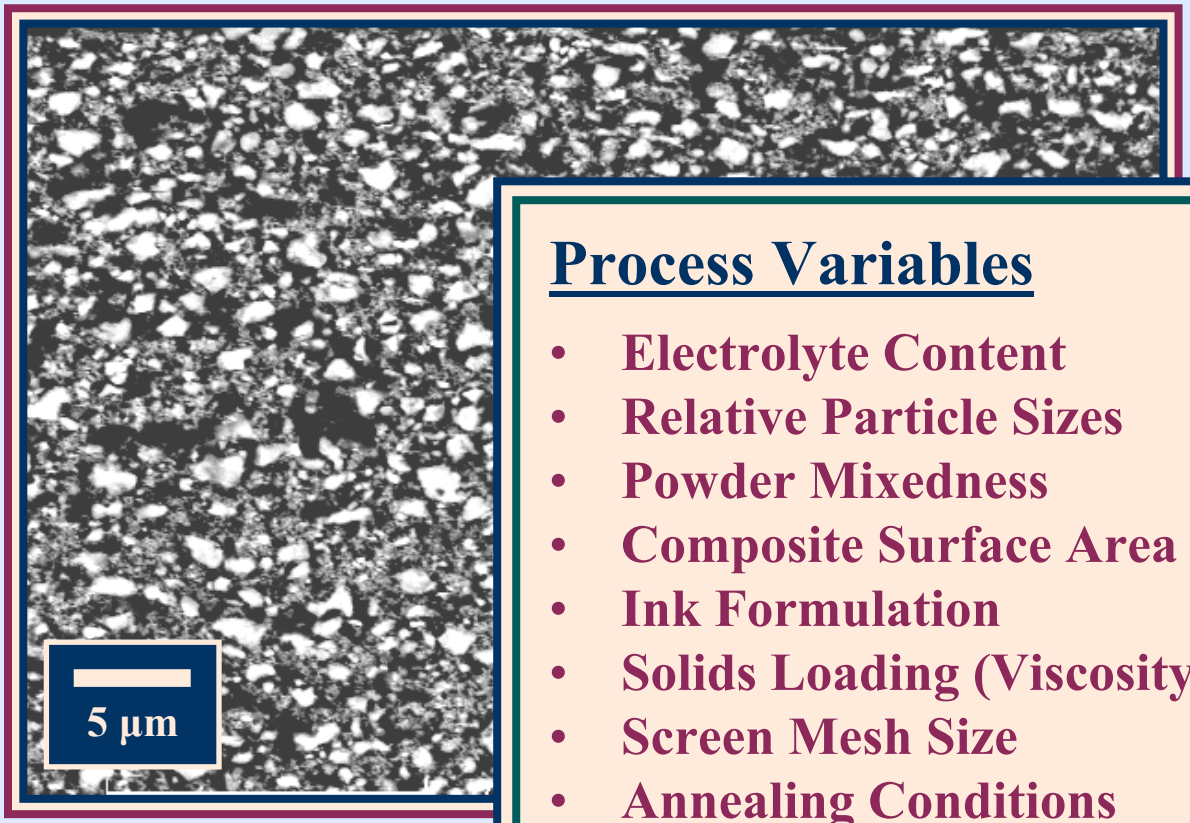
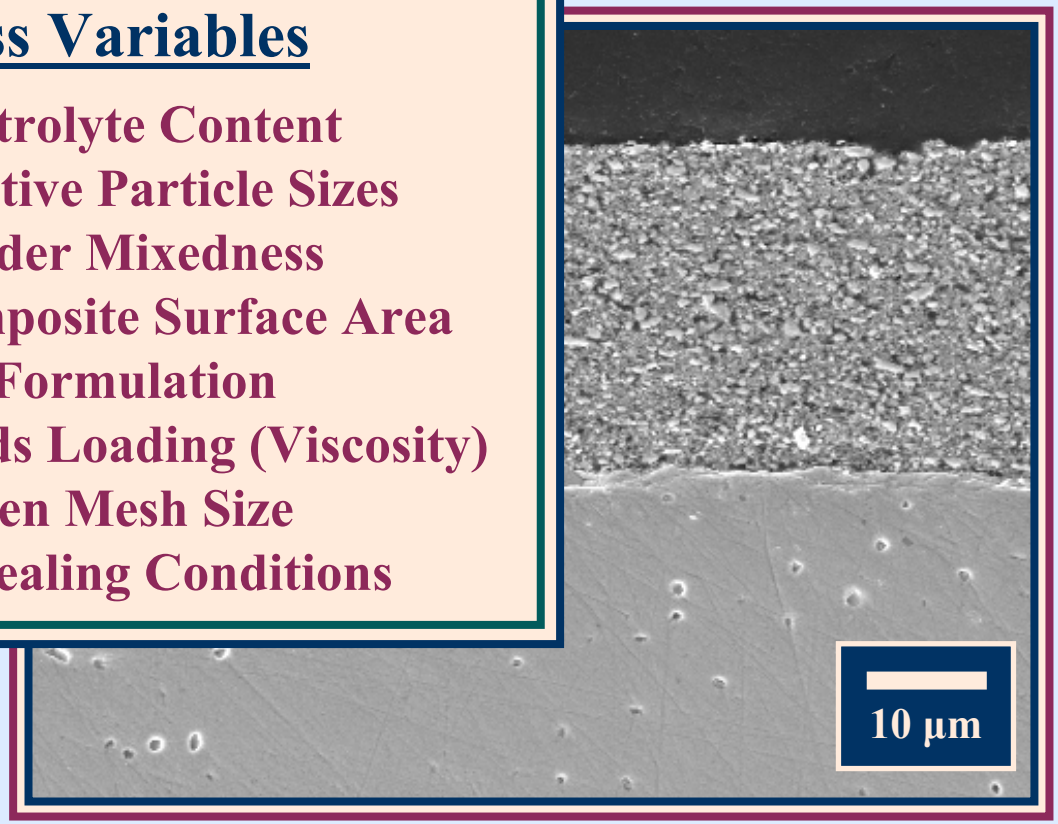
Cathode Screen Printing



Process Variables

- Electrolyte Content
- Relative Particle Sizes
- Powder Mixedness
- Composite Surface Area
- Ink Formulation
- Solids Loading (Viscosity)
- Screen Mesh Size
- Annealing Conditions



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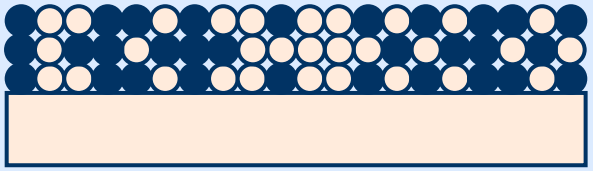
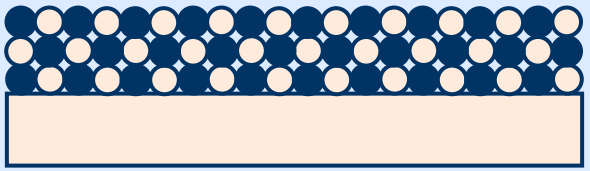
Composite Cathodes



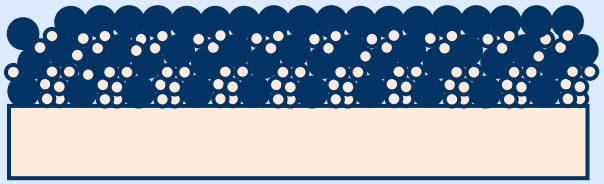
Conventional Ink Routes

- Improved Low-Temperature Performance
- Inhomogeneous Microstructure
- Limited Increase In TPB Area



Improved Homogeneity

- Greater TPB Area
- More Uniform Shrinkage
- Low Connectivity Current Paths



Nanoscale Composites

- Maximized TPB Area
- Uniform Distribution of Electrolyte
- High Connectivity Current Paths

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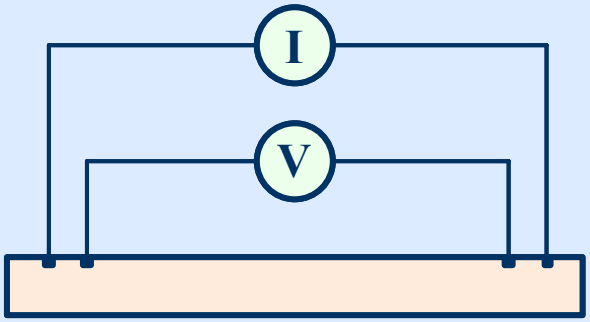
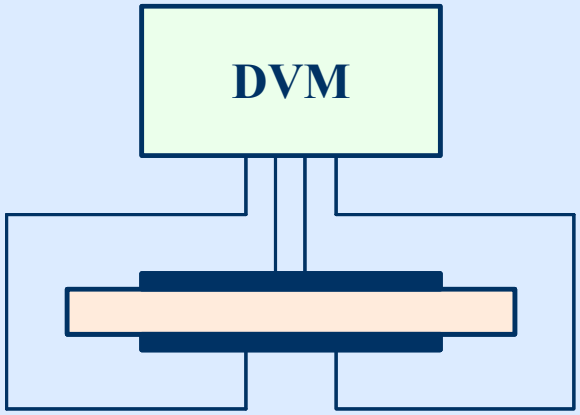
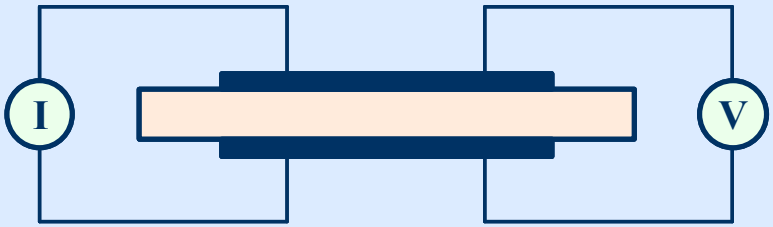
Electrical Testing



Four-Point Conductivity

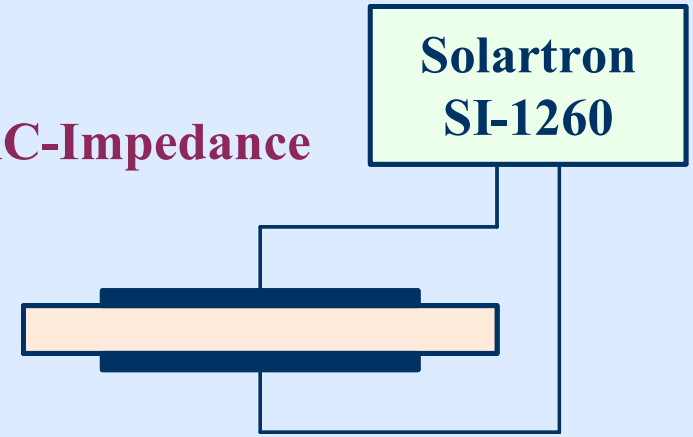


Four-Point Resistance



I-V Measurements

AC-Impedance



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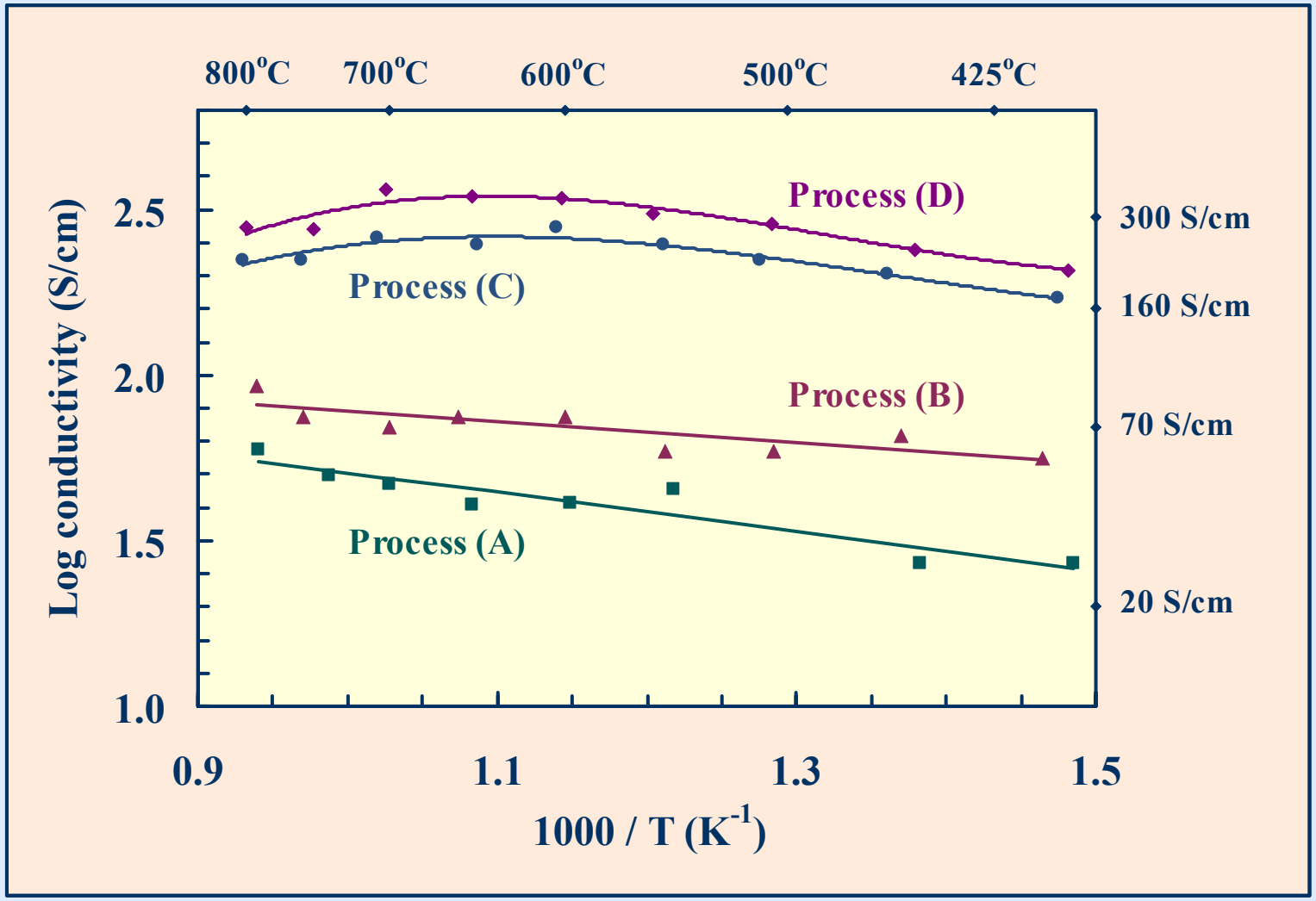
Effect of Processing (LSF-40)



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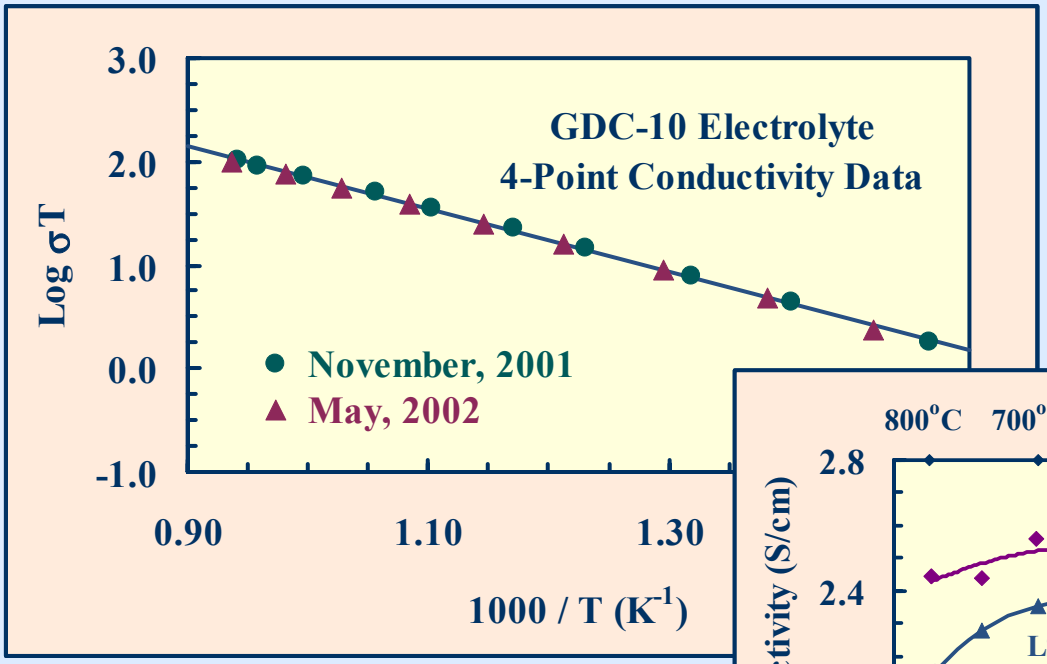
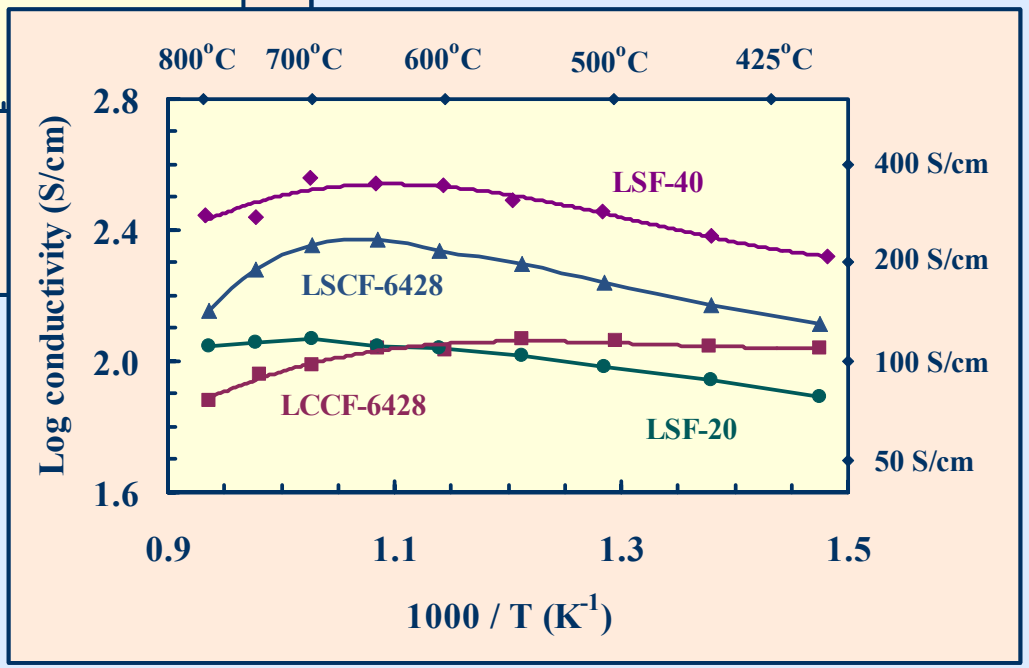
Electrical Testing





LSF-20: $(La_{0.80}Sr_{0.20})FeO_3$

LSF-40: $(La_{0.60}Sr_{0.40})FeO_3$

LSCF-6428: $(La_{0.60}Sr_{0.40})(Co_{0.20}Fe_{0.80})O_3$

LCCF-6428: $(La_{0.60}Ca_{0.40})(Co_{0.20}Fe_{0.80})O_3$

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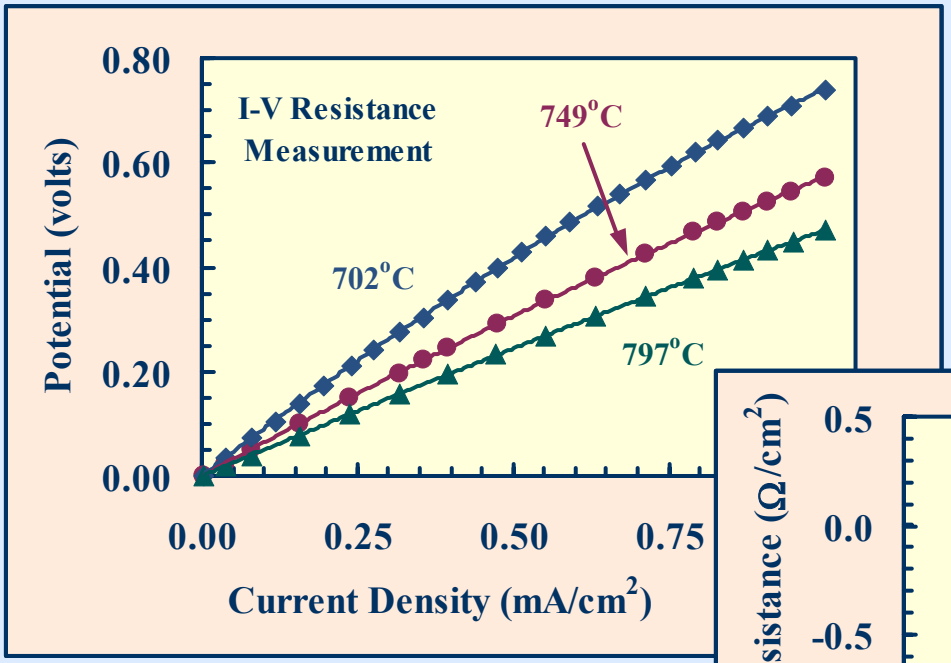
Electrode Resistance

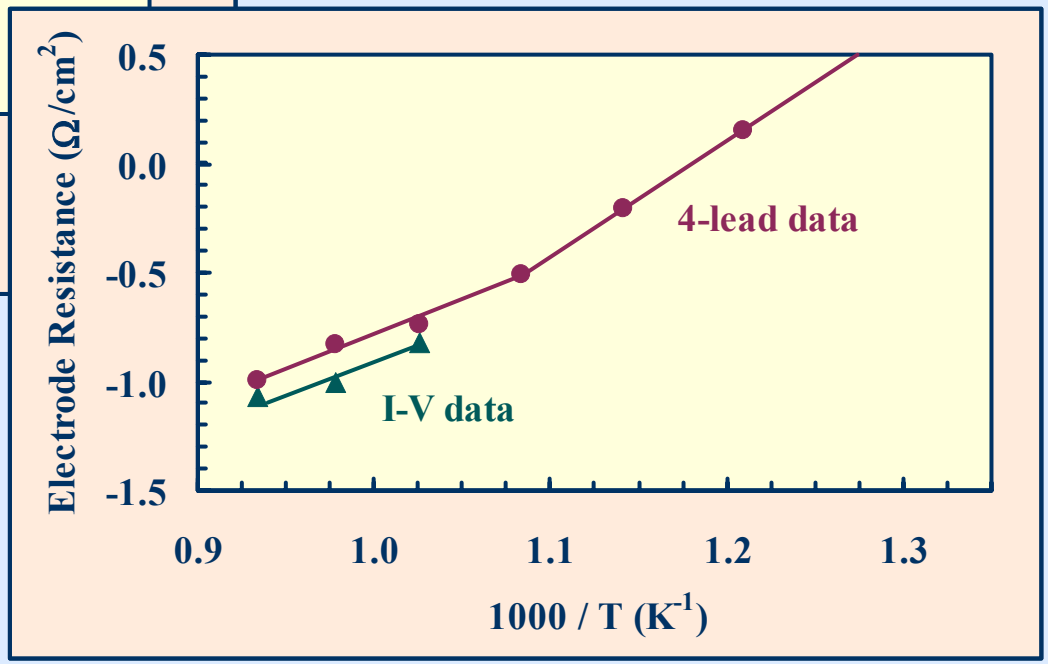


GDC Electrolyte Disc

300 µm thick

Screen-Printed Electrodes

LSCF/GDC Composition
1.27 cm² area, ~50 µm thick



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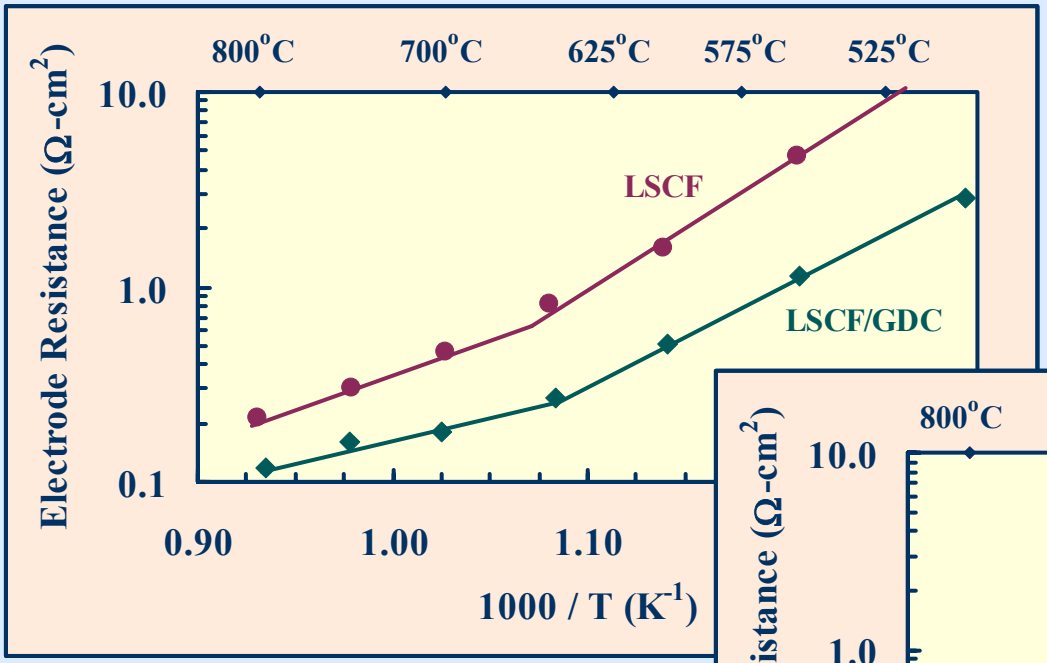
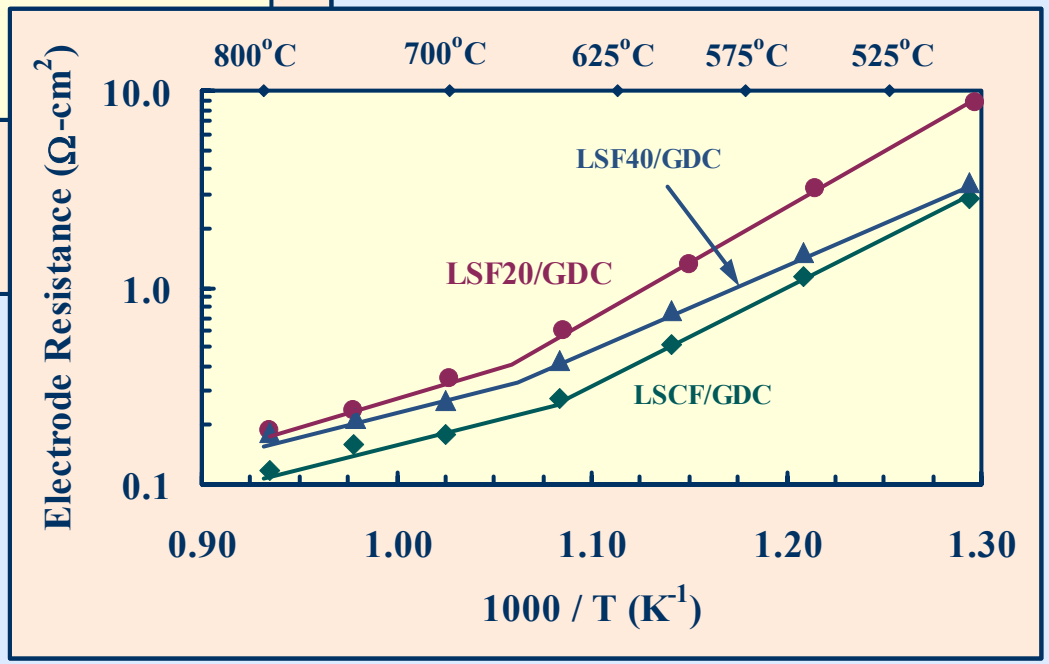
Electrical Testing





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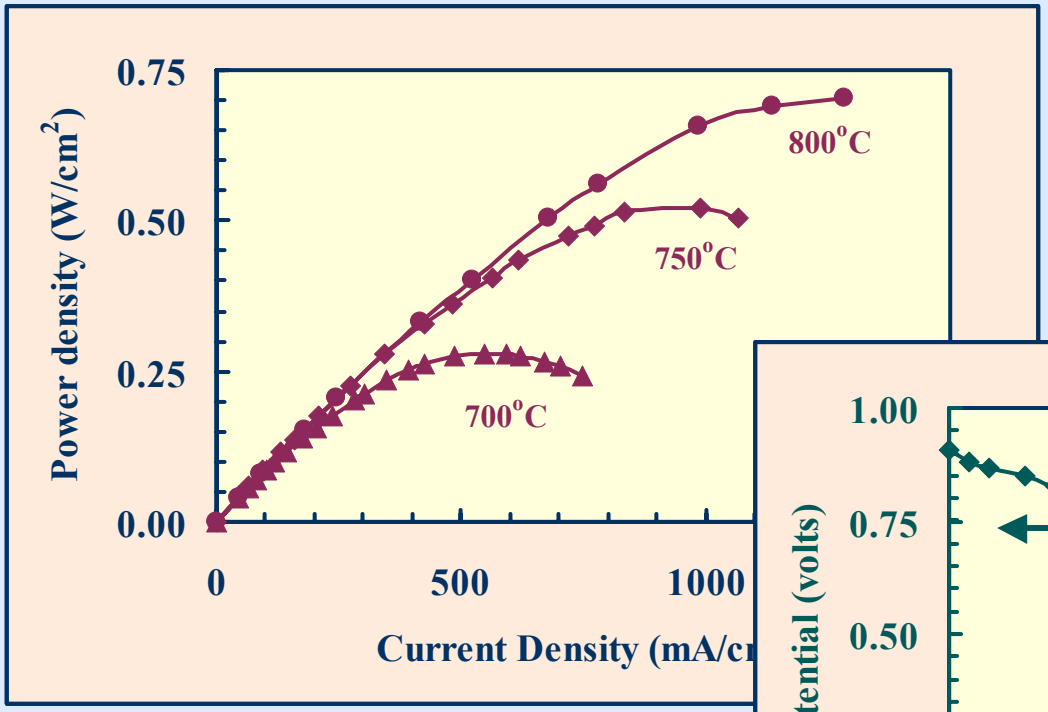
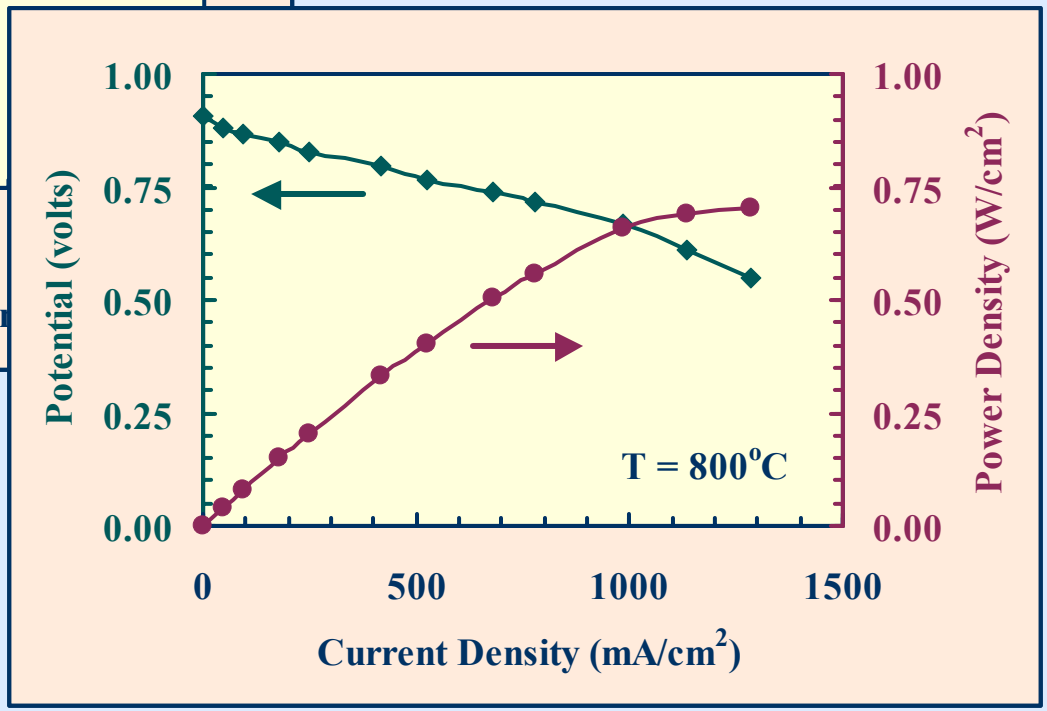
SOFC Testing

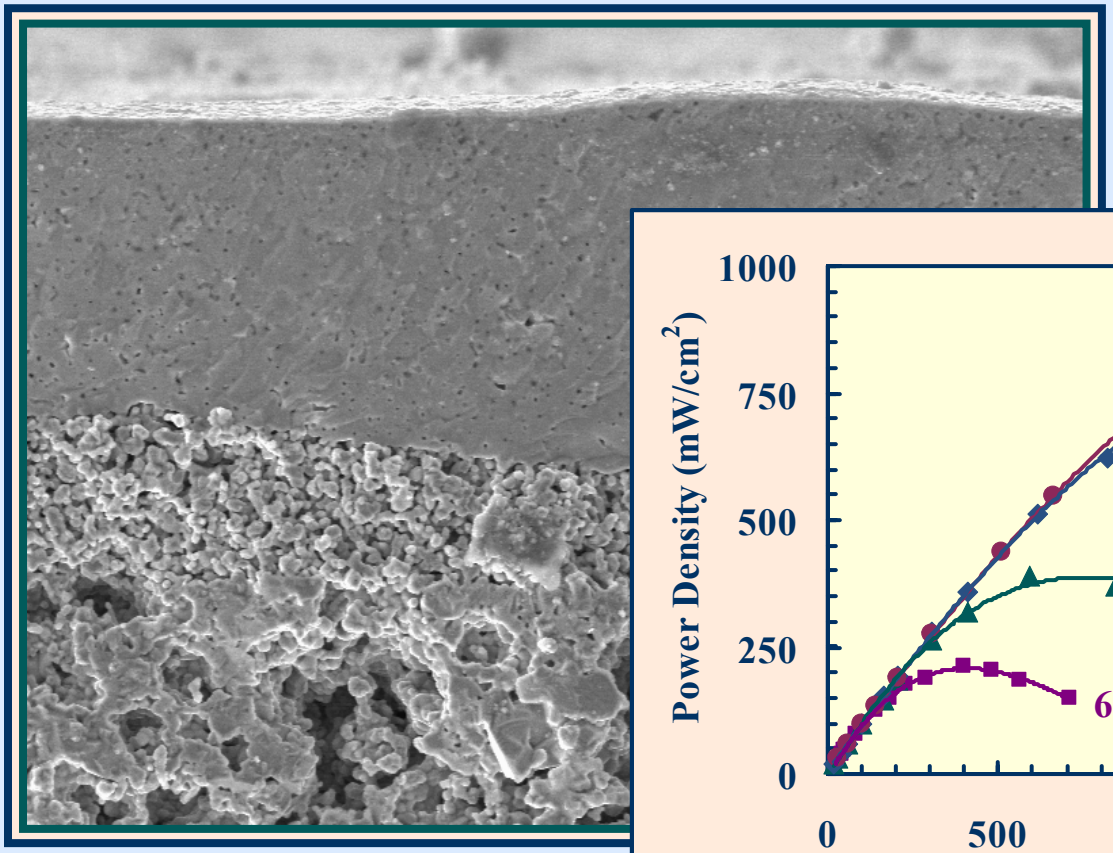


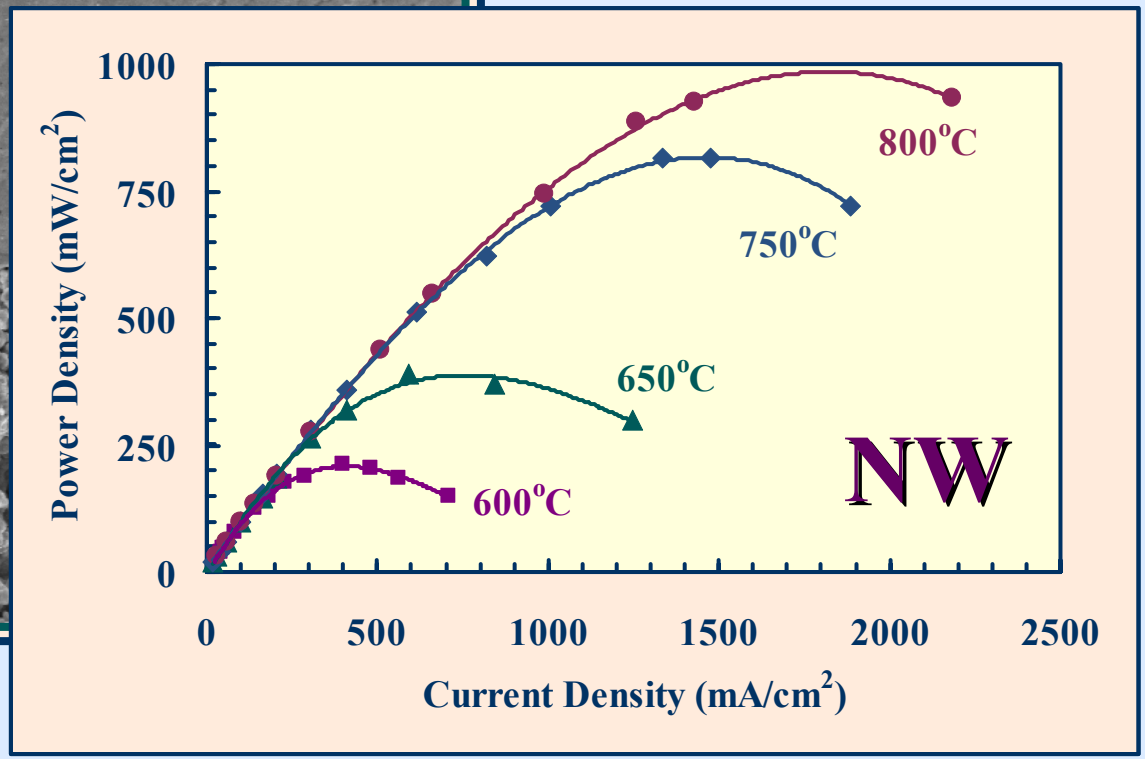


NexTech Anode-Supported Cell LSCF/GDC Cathode

ornl

SOFC Testing





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Mechanical Properties

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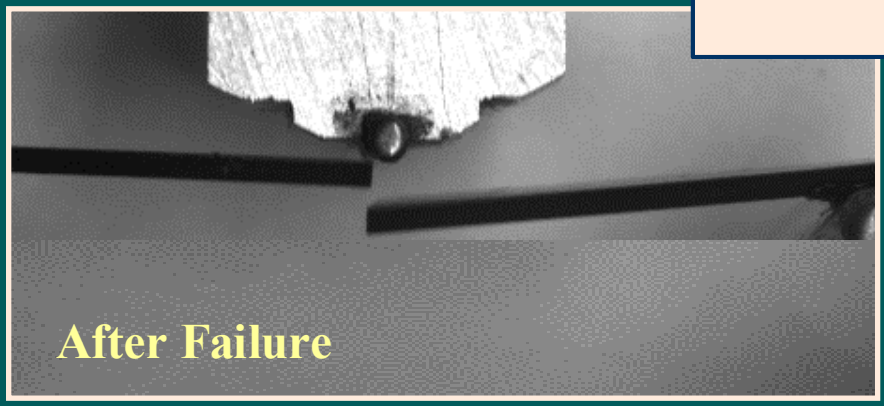
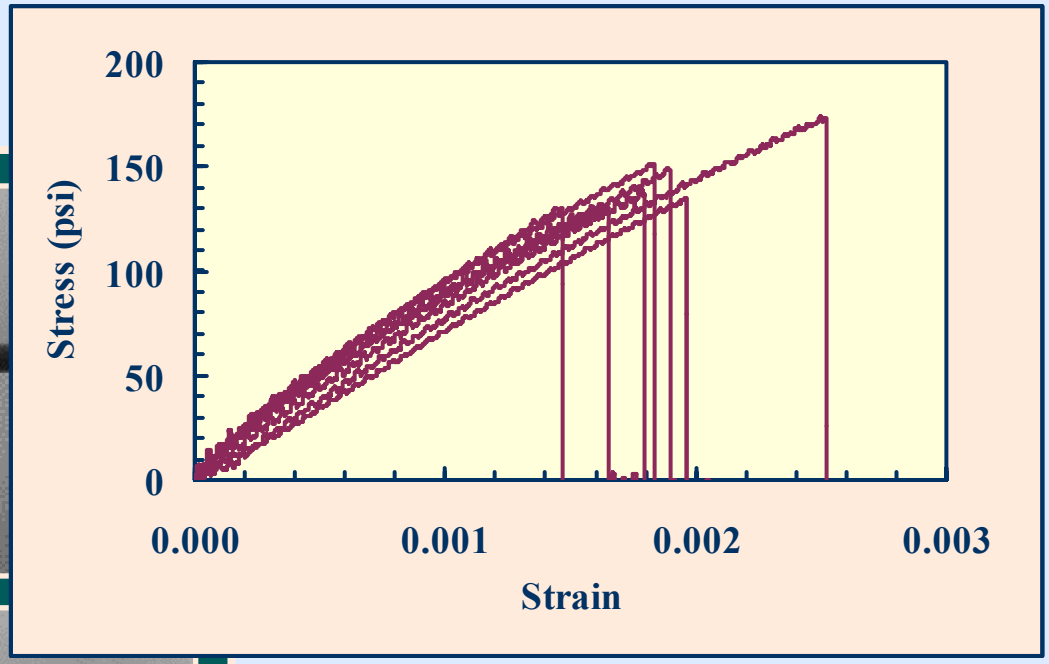
LSM Cathode Substrates





Flexural Modulus:	83,546 psi
Flexural Failure Stress:	142.5 psi
Flexural Failure Strain:	0.00185

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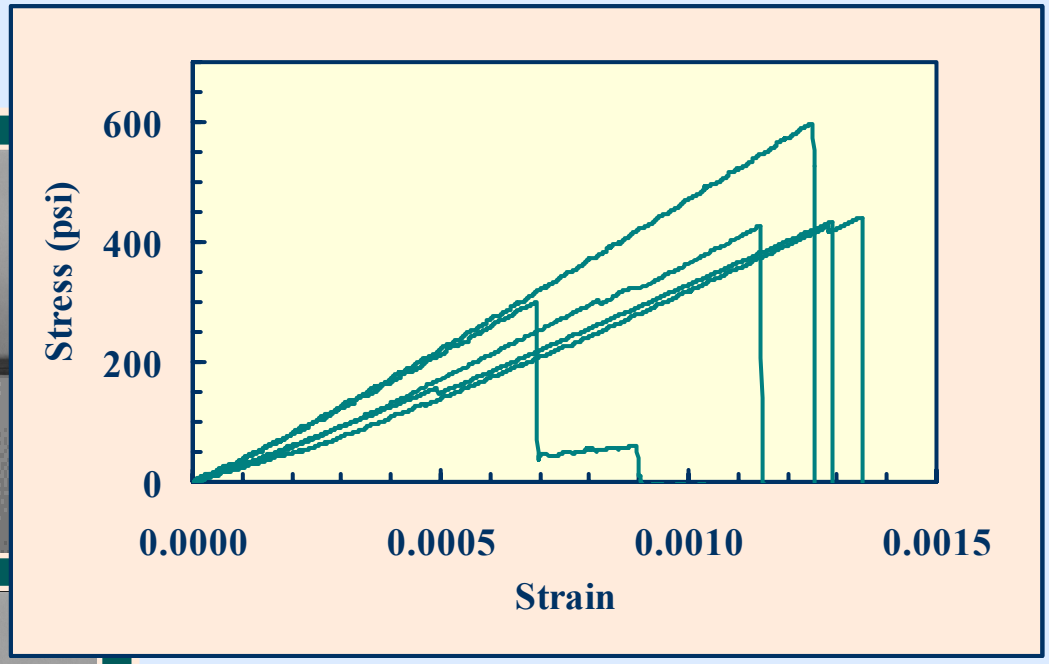
Mechanical Properties

THE OHIO STATE UNIVERSITY

NiO/YSZ Anode Substrates



Flexural Modulus:	364,000 psi
Flexural Failure Stress:	440.2 psi
Flexural Failure Strain:	0.00115

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Ceria-Based Electrolytes

DOE Contract No. DE-AC26-00NT40706

Principal Investigator: Matt Seabaugh

NETL Project Manager: Lane Wilson

❑ Objectives:

- ➢ Improve performance of ceria-based electrolytes
- ➢ Fabricate anode-supported, thin-film ceria SOFCs
- ➢ Achieve high power density at T < 700ºC

❑ Accomplishments

- ➢ Improved processes for ceria electrolytes
- ➢ Higher-conductivity ceria formulations
- ➢ Lower-cost ceria formulations
- ➢ Co-sintering process for anode-supported cells
- ➢ Screen-printed composite cathode coatings

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Technical Approach

Processing Strategies

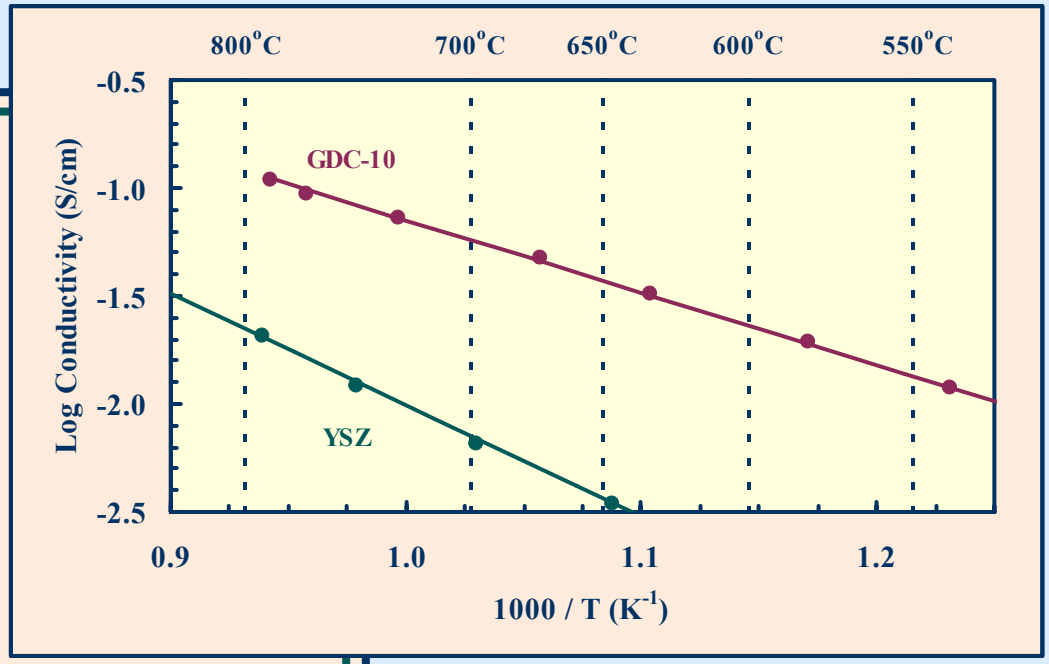
- ❑ Eliminate impurities
- ❑ Low-temperature sintering
- ❑ Maintain fine grain size
- ❑ Anode-supported cells

Compositional Strategies

- ❑ Multiply-doped ceria (👎)
- ❑ Use of inexpensive dopants
- ❑ Reduce lattice strain - increase conductivity

👎 Previously demonstrated by:

- van Herle, et al. (EPFL)
- Mori, et al. (NIRIM)



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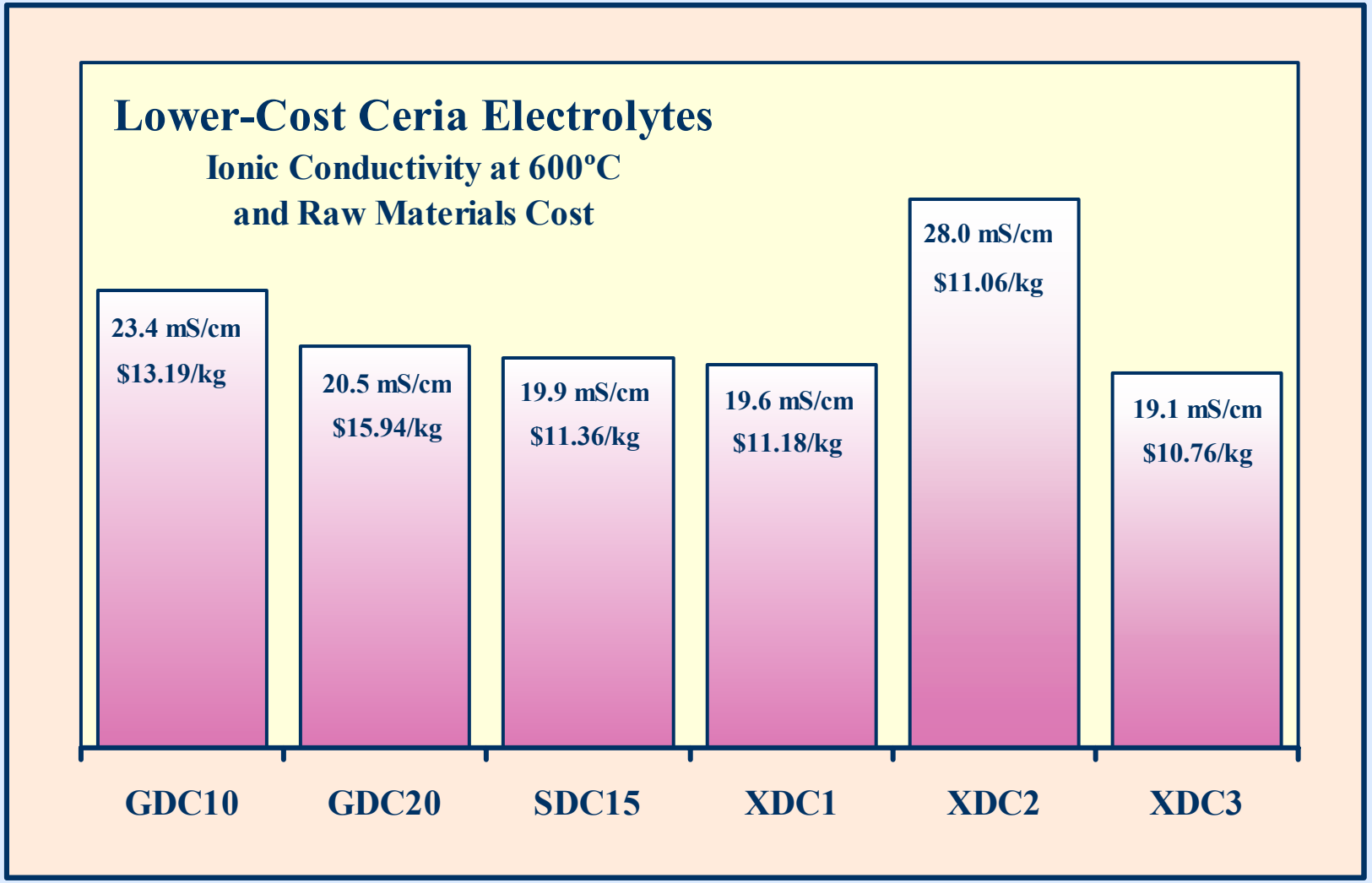
Ceria-Based Electrolytes



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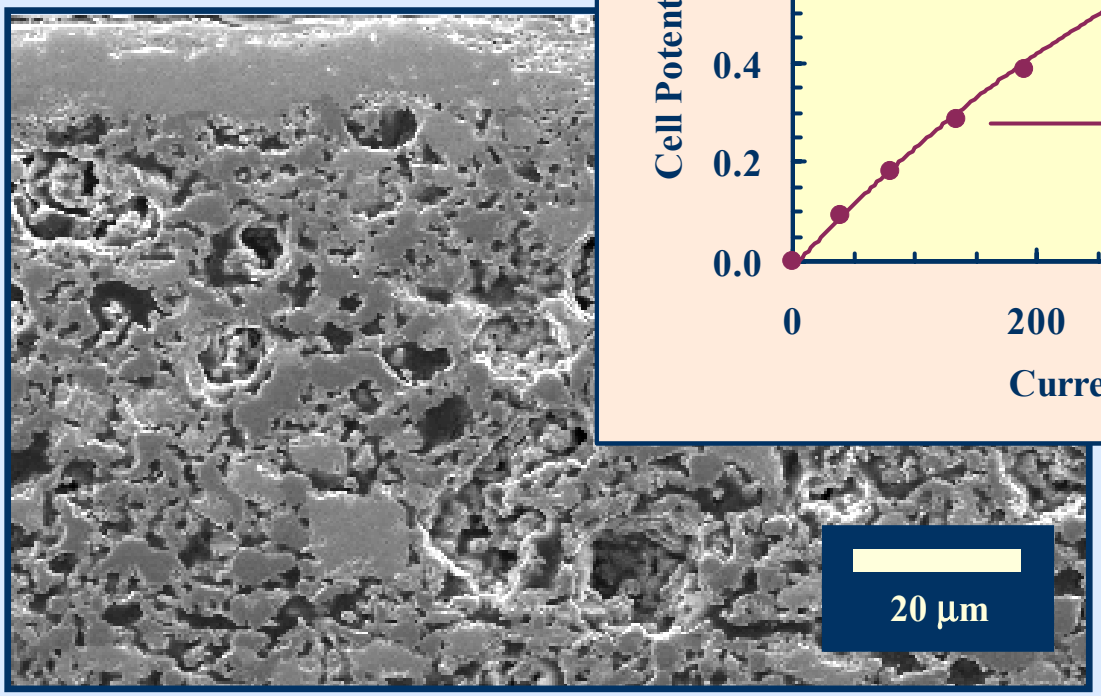
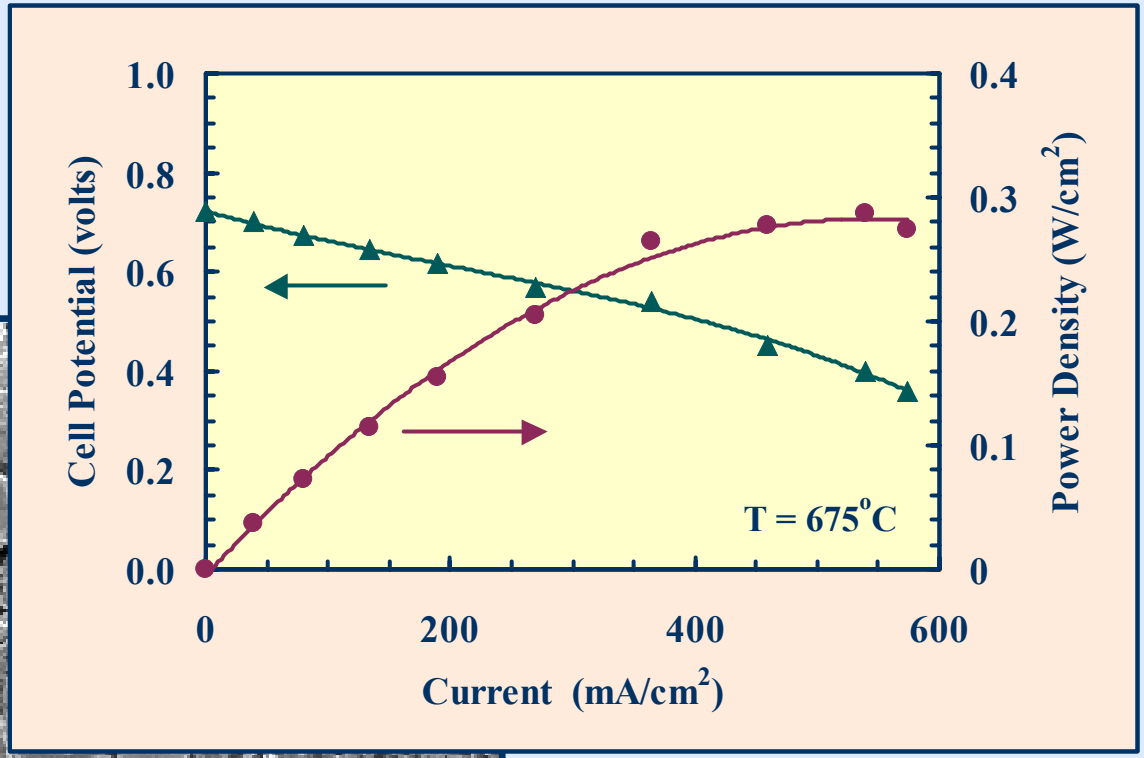
Thin-Film Ceria SOFCs





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Future Work

- Cathode Development
  - Evaluate nano-composite approaches
  - Optimization of formulations and processing
  - Integrate ac-impedance into measurement protocol
- SOFC Testing (NexTech and Northwestern)
  - Effect of cathode material
  - Effect of anode microstructure
  - Functional interlayers
- Additional Collaboration with Ohio State and ORNL on Mechanical Property Measurements
- Long-Term Single-Cell Testing (GTI)

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Acknowledgments

Thanks to DOE, NETL, and the State of Ohio!

Team Members

- Harlan Anderson (UMR)
- Tim Armstrong (ORNL)
- Scott Barnett (Northwestern)
- Bob Remick and Chuck Sishtla (GTI)
- Mike Cobb and Kirby Meacham (Cobb & Co.)
- Jim Stephan (Advanced Materials Technologies)
- John Lannutti and Mark Walter (Ohio State University)
- Russ Bennett and Gary Kapp (EMTEC)

NexTech Colleagues

- Bill Dawson
- Matt Seabaugh
- Buddy McCormick
- Kathy Hasinska
- Chris Holt
- A-M Azad
- Jerry Jayjohn