Innovative, Versatile and Cost-Effective Solid Oxide Fuel Cell Stack Concept

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Innovative, Versatile and Cost-Effective SOFC Stack Concept Project

- Project: Innovative, Versatile and Cost-Effective Solid Oxide Fuel Cell Stack Concept (DE-FE0026211)

- Project Objective: Develop and evaluate a versatile stack configuration based on a prime-surface interconnect design that can incorporate different types of cell construction for a broad range of power generation applications

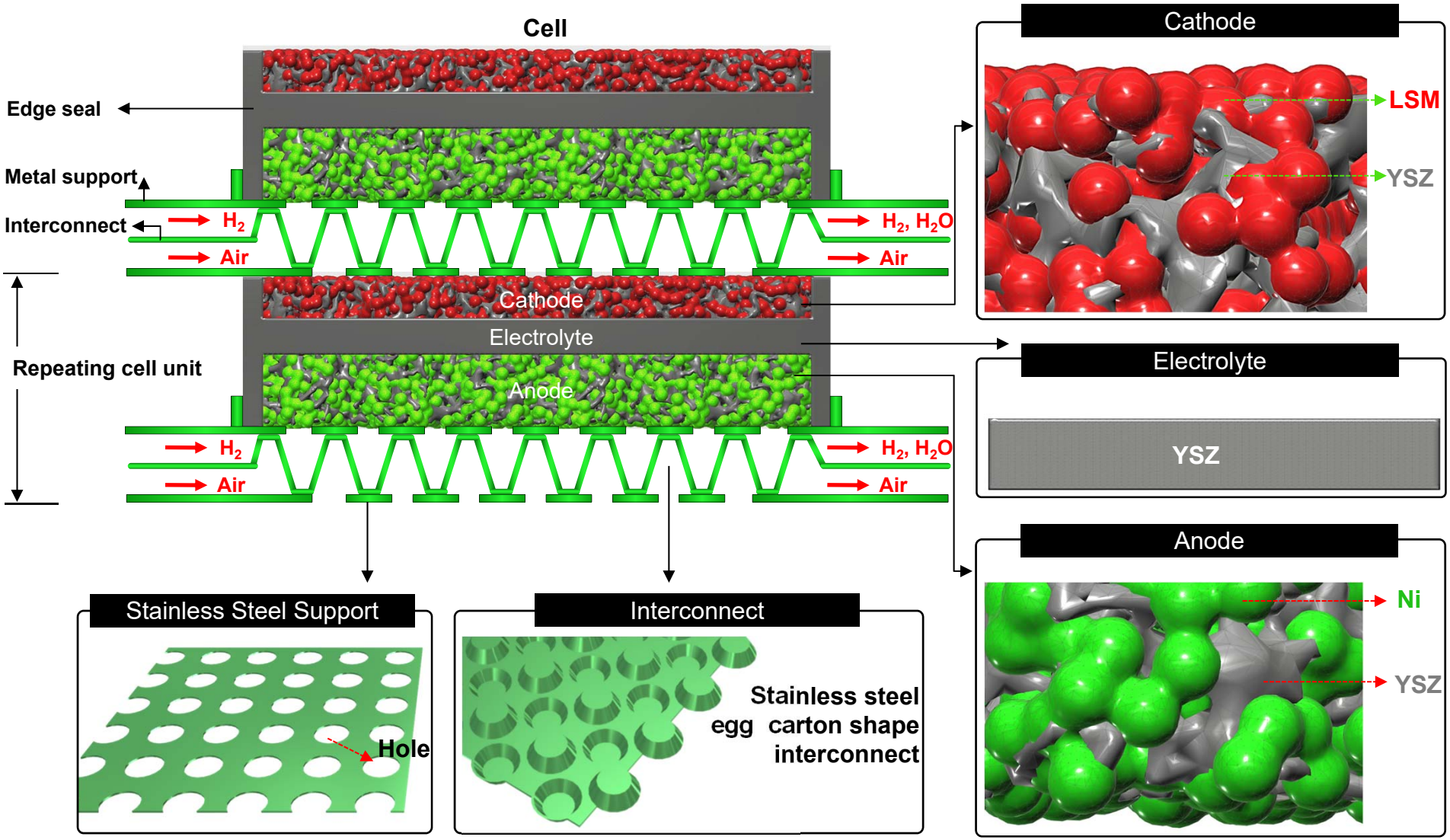
- DOE/NETL Project Manager: Dr. Patcharin Burke

- Project Team:
  - ❑ UCSD
    - *Center for Energy Research*: Dr. Nguyen Minh (PI), Dr. Yoon Ho Lee (Postdoctoral scholar), Dr. Tuyen Tran (Assistant Project scientist)
    - *Department of Electrical Engineering and Center for Memory and Recording Research*: Dr. Eric Fullerton, Haowen Ren (graduate student)
    - *Department of NanoEngineering*: Dr. Shirley Meng, Erik Wu (graduate student)
  - ❑ OxEon
    - Dr. S. Elangovan, Dr. J. Hartvigsen

STACK DESIGN CONCEPT

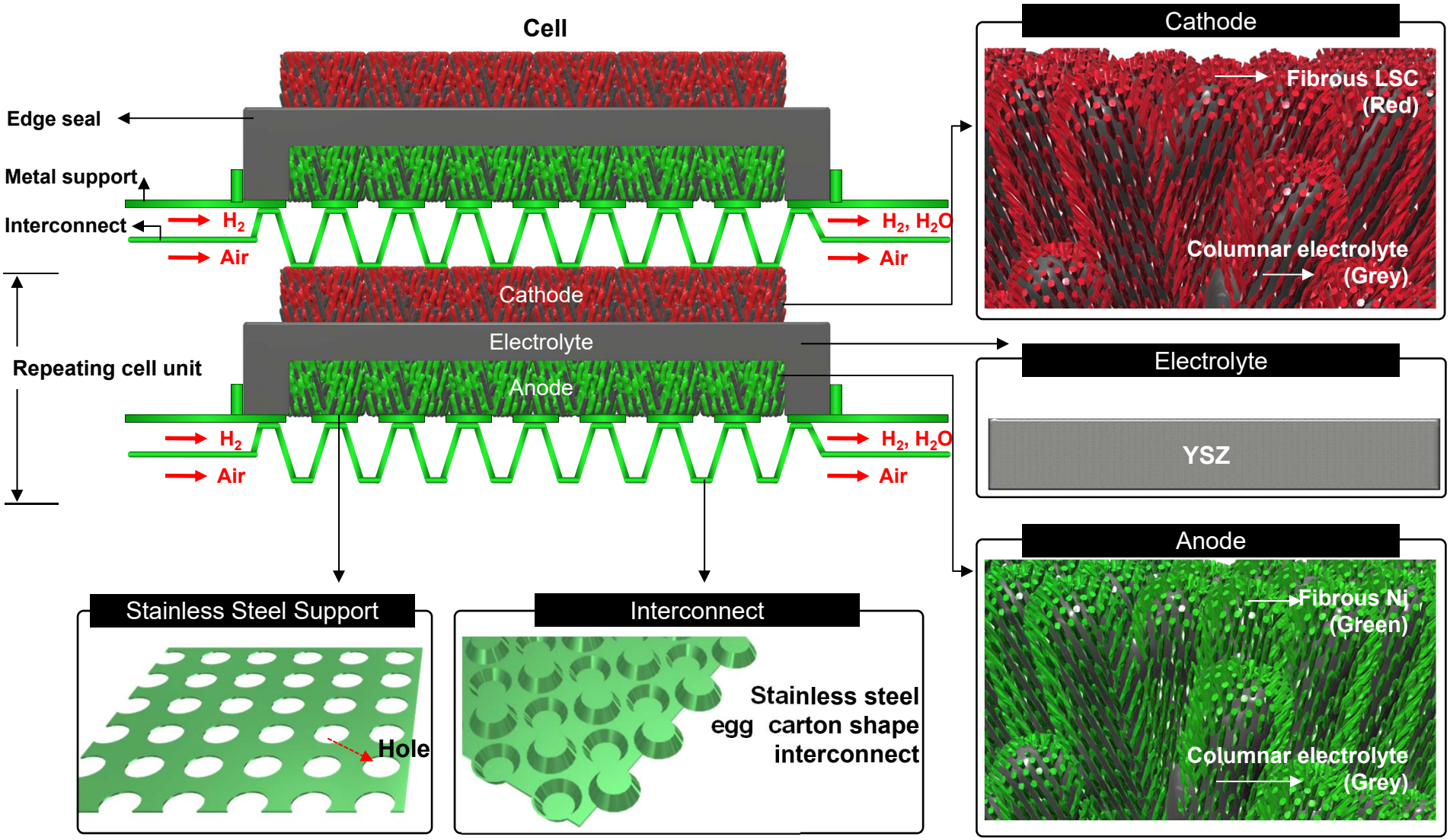
Stack Design

Incorporating Conventional Cells



Stack Design

Incorporating Metal-Supported Cells



Features of Stack Concept

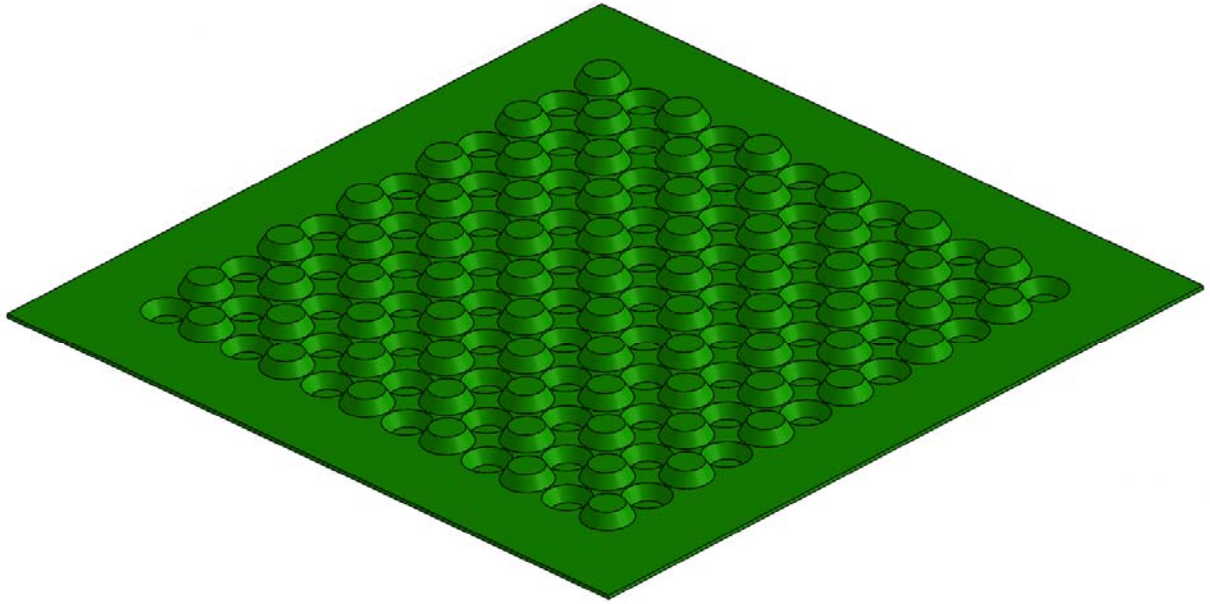
- Reduced weight and volume
- Flexibility in gas flow configuration
- Reduced stacking performance losses
- Improved sealing
- Versatility in incorporation of different types of cell construction

Current Project Technical Activities

- Prime surface interconnect design and fabrication development
- Metal-supported cell structure development
- Stack development

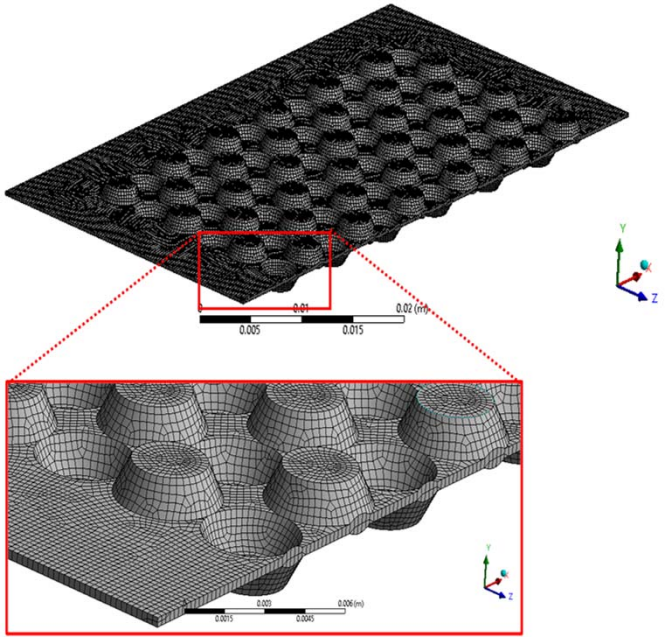
PRIME SURFACE INTERCONNECT DEVELOPMENT

Prime Surface Interconnect Design for Design Analysis and Formability Evaluation

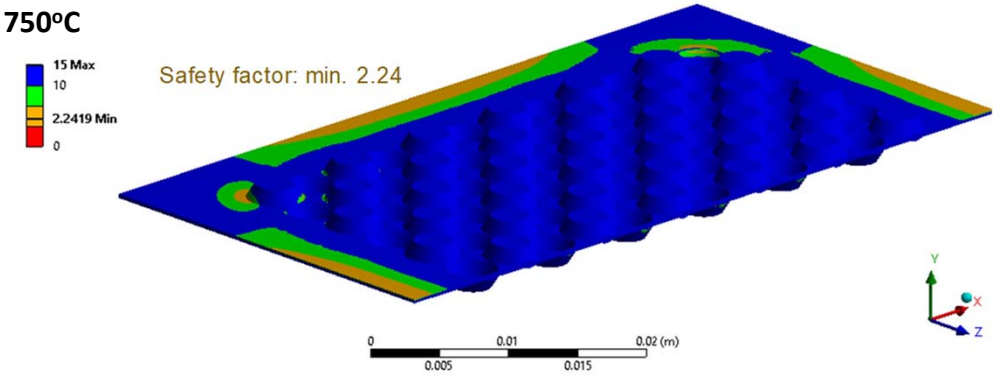


Dimension: Length x Width x Thickness	60mm x 60mm x 2.5mm
Thickness of the interconnect plate	0.3mm
Total height of the interconnect	2.5mm
Length of the interconnect	60mm
Width of the interconnect	60mm
Diameter of the cones at the base level	4mm
Cone angle	60 degrees
Mass of the interconnect	7.66 gram

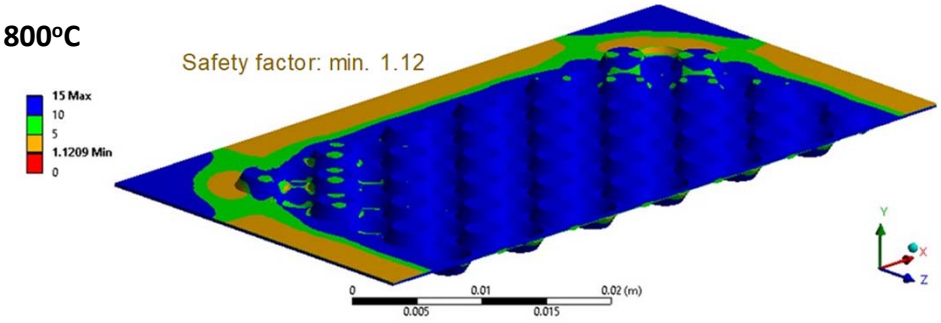
Mechanical Loading Analysis



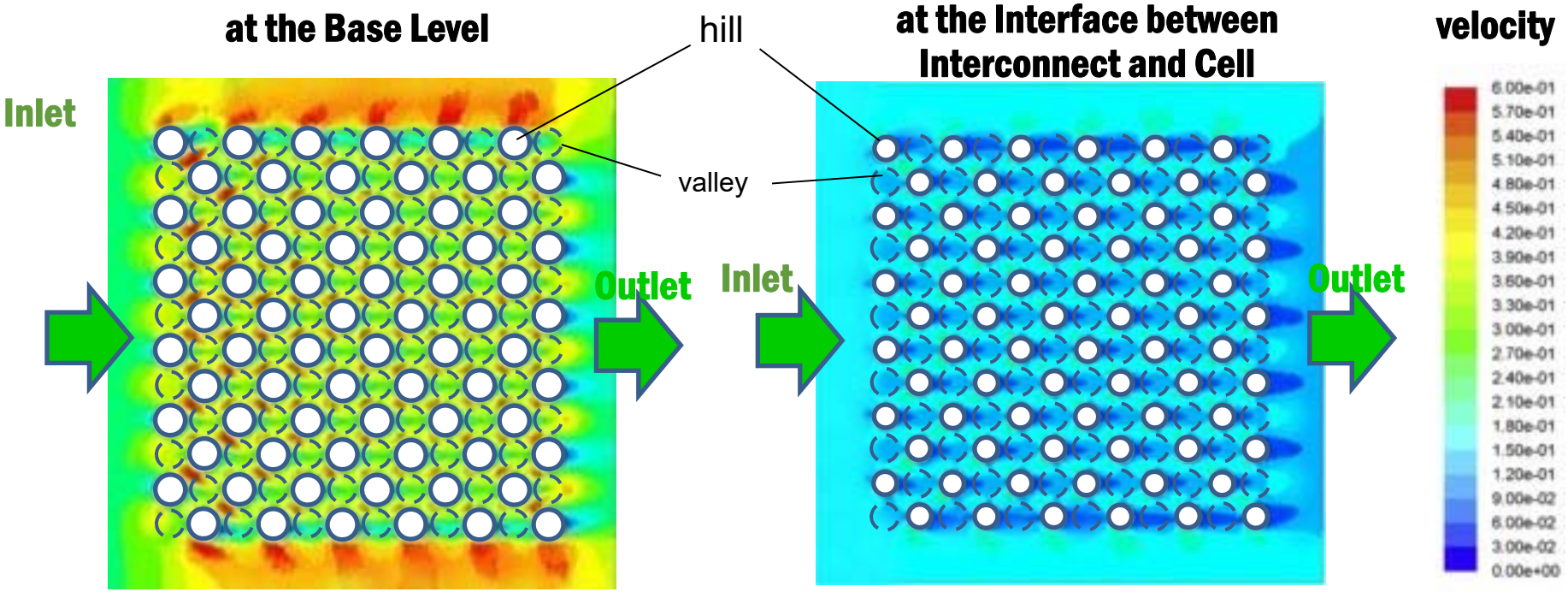
(a) **750°C**



(b) **800°C**



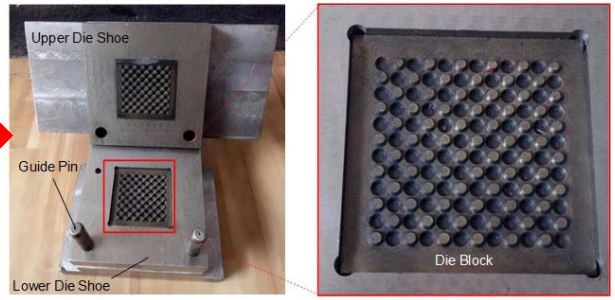
Gas Velocity Distribution Analysis

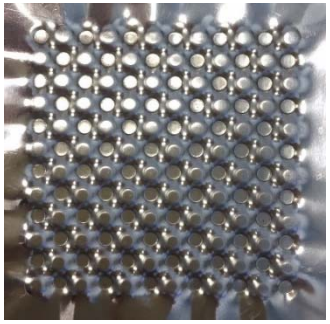


Inlet gas velocity = 0.3 m s^{-1}

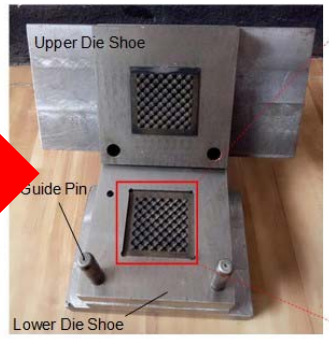
Interconnect Formability

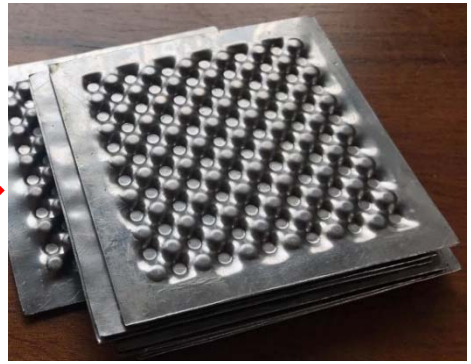
One-step stamping





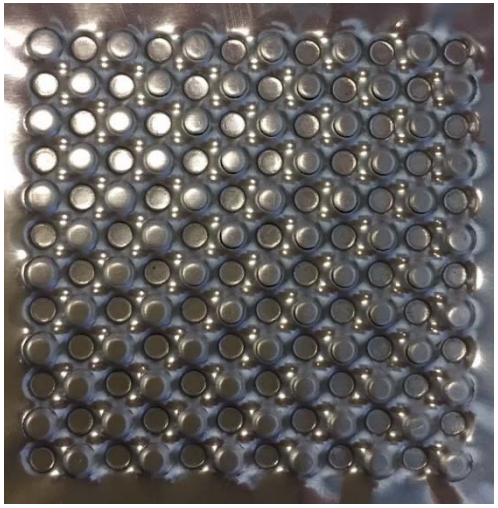
Two-step stamping

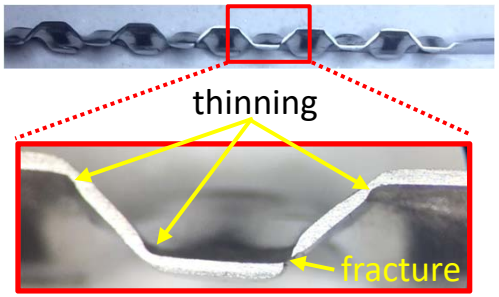




Stamped Interconnect

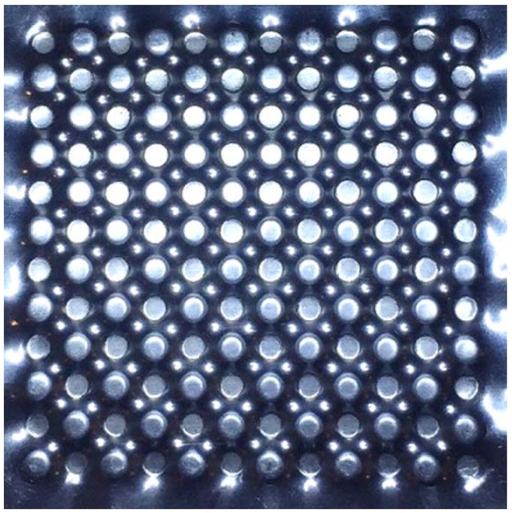
Interconnect with 2.5 mm in height

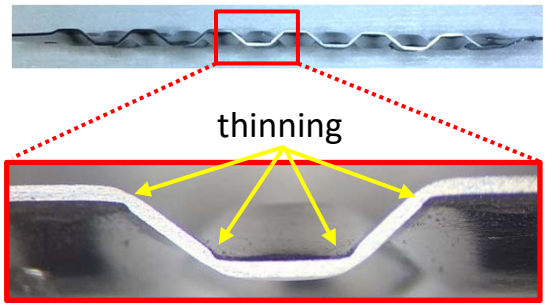




- Significant thinning
- Breakage at corners

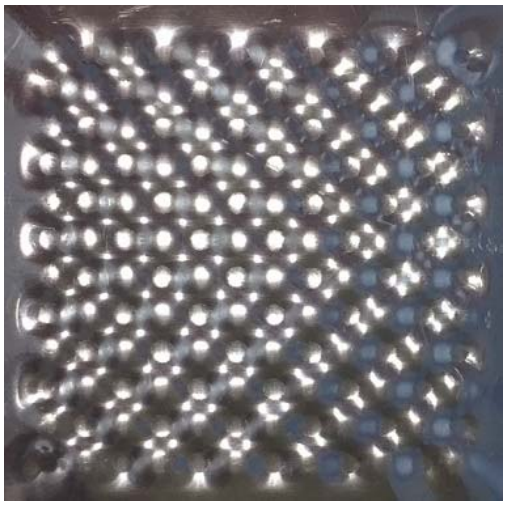
Interconnect with 2 mm in height

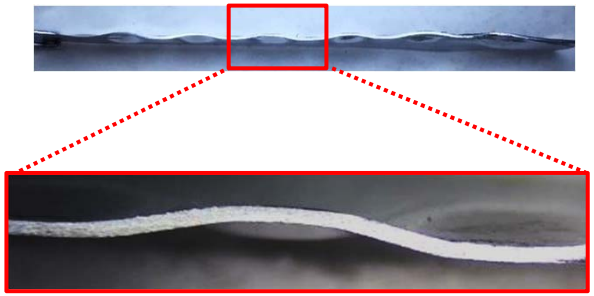




- Small thinning
- Well-formed egg-carton shape

Interconnect with 1 mm in height



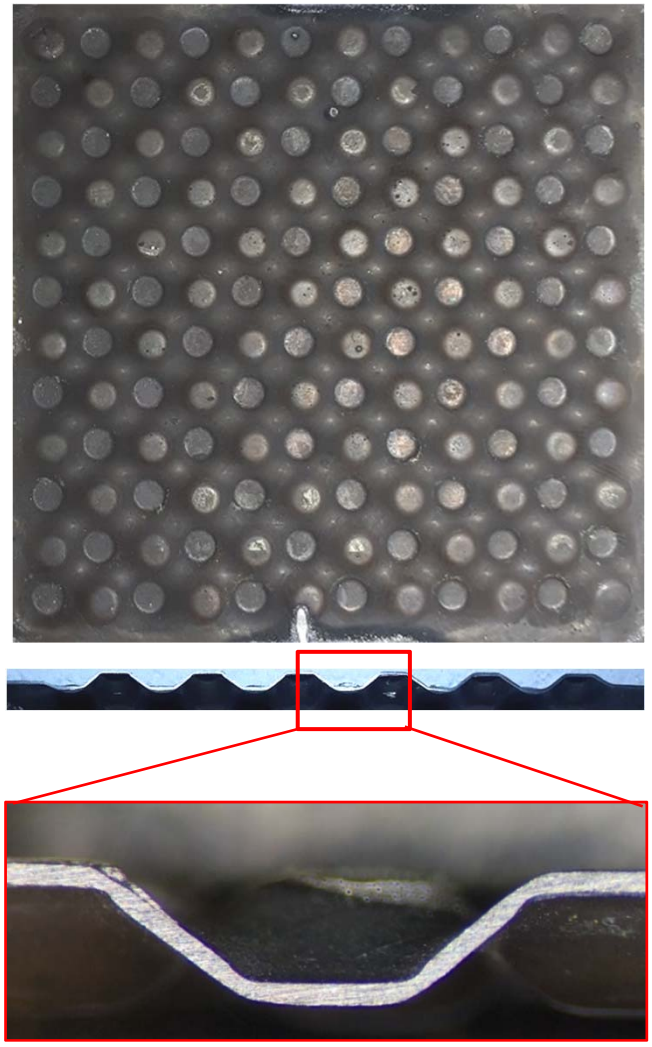


- No thinning
- Not well-formed egg-carton shape

Stamped Interconnect Characterization

Mechanical Load Test

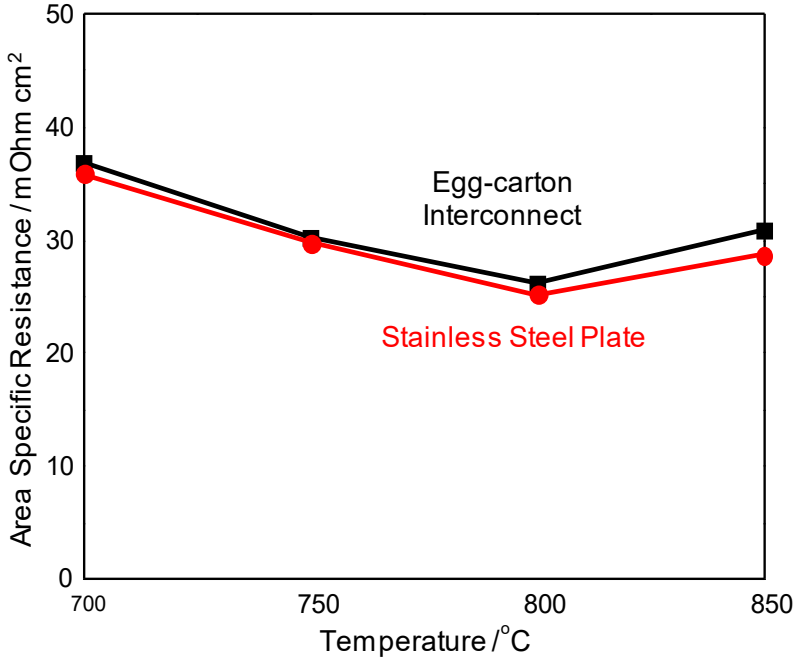
Interconnect after firing under load (3 lbs, equivalent to 100 cells and 100 interconnect) at 800°C for 200 hours



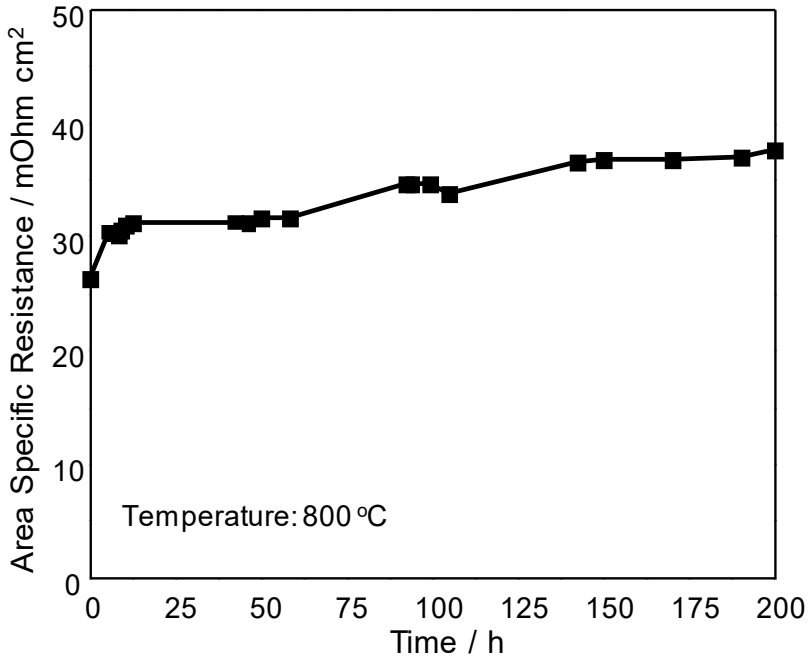
Stamped Interconnect Characterization

Area Specific Resistance Test

(a)

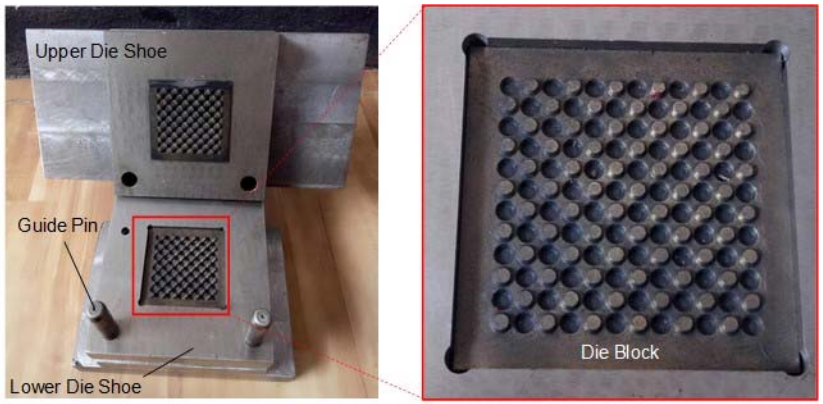


(b)

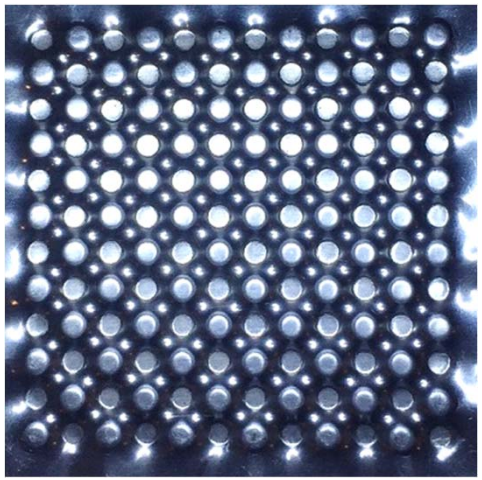


Stamped Interconnect Characterization

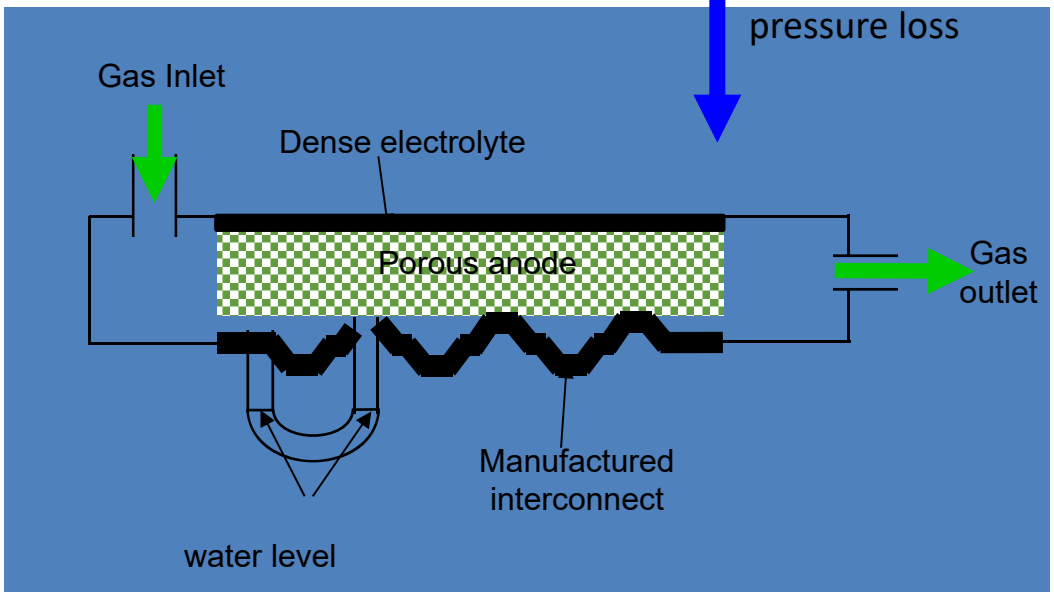
Pressure Loss Test



manufacturing



test for pressure loss

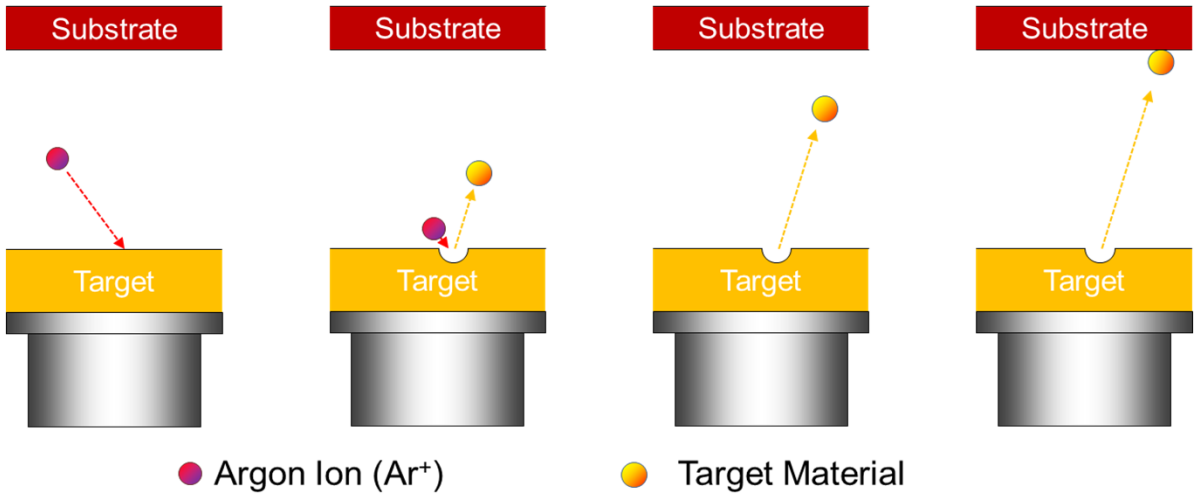


No large different in water level → no pressure loss

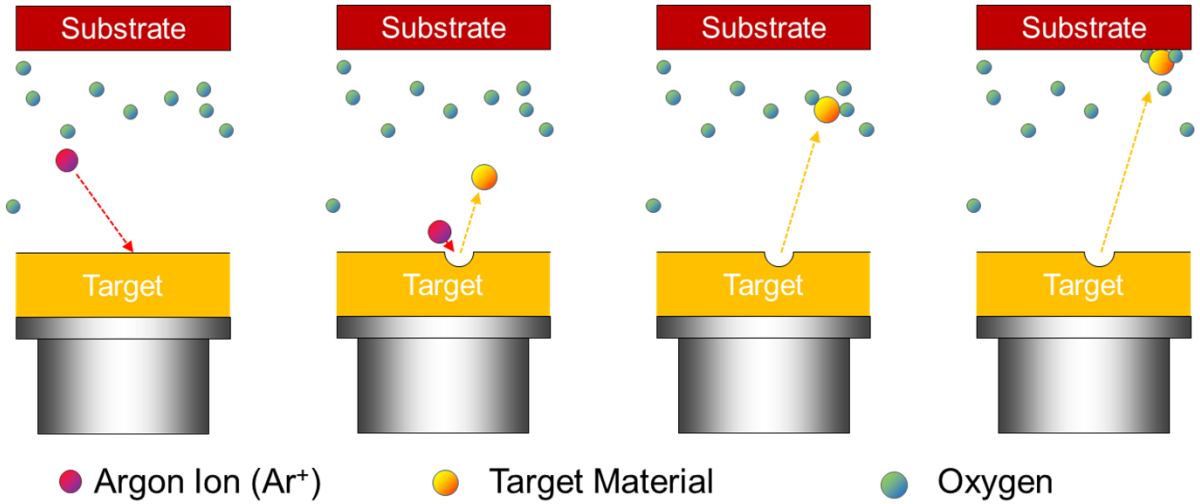
METAL-SUPPORTED CELL STRUCTURE DEVELOPMENT

Sputtering Process

Conventional

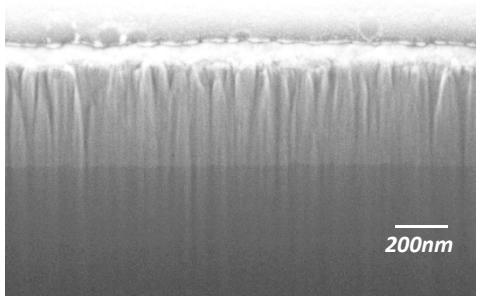


Reactive



Sputtering for SOFC Cell Fabrication

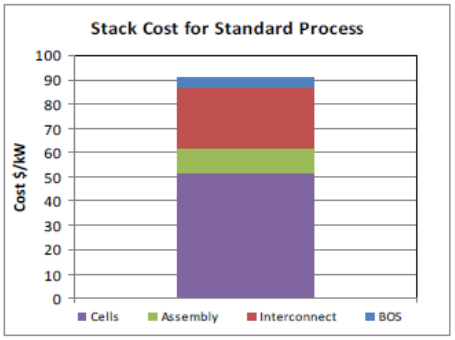
- Fabrication of dense and porous layers
- Scalability
- Potential cost effectiveness

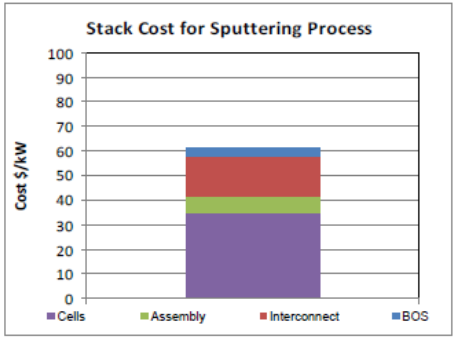


Nano-scale Dense YSZ layer

Goldstone Vacuum Sputter System
http://www.goldstone-group.com/

Sputtering Target by AZO Materials
http://www.azom.com/

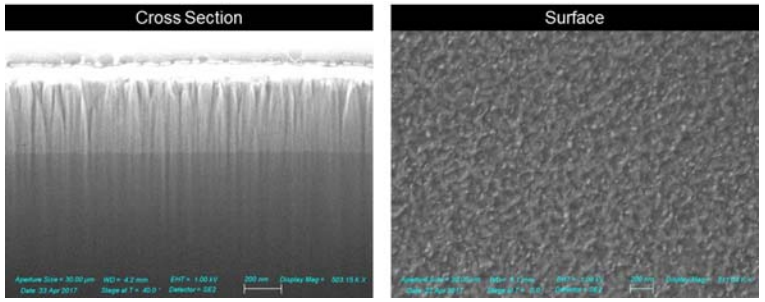




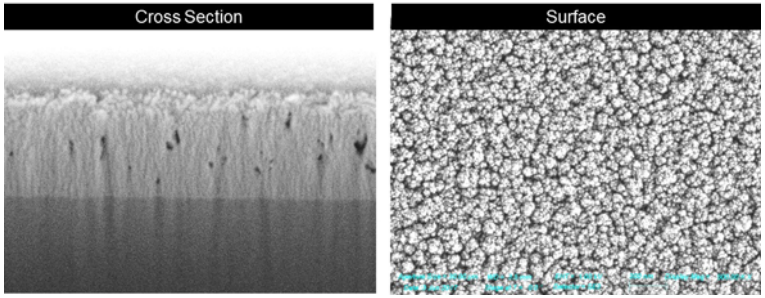
Weimar et al, PNNL Report PNNL-22732, 2013

Cell Components and Single Cells Fabricated by Sputtering (on Si wafers)

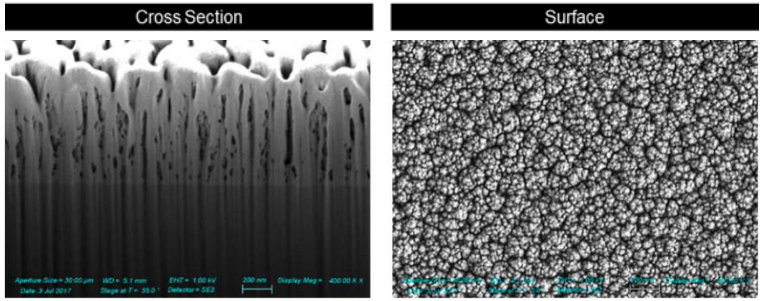
Dense YSZ Layer



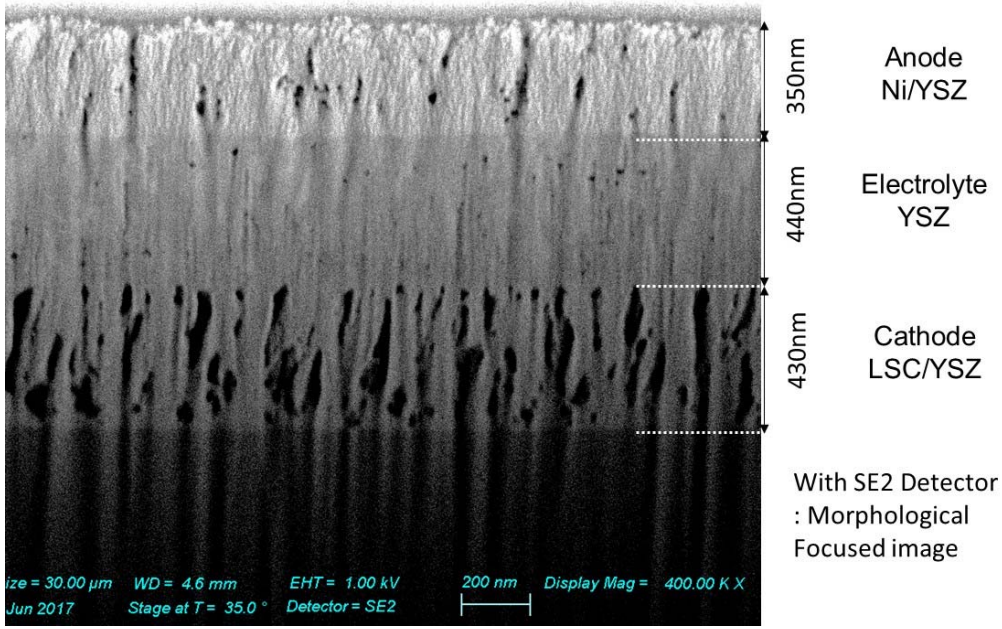
Porous Ni-YSZ Layer



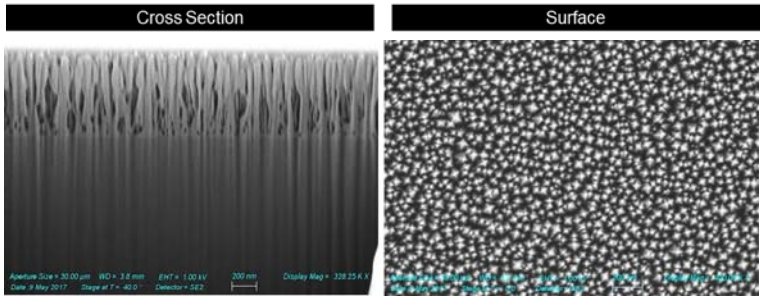
Porous LSCF-YSZ Layer



Single Cell

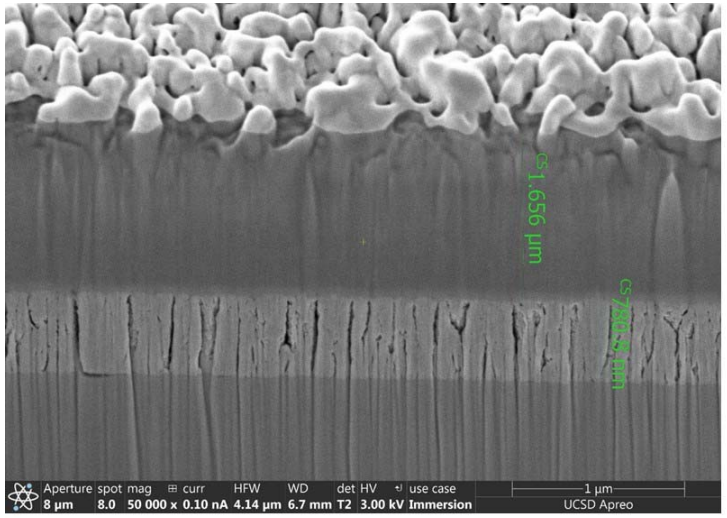


Porous LSC-YSZ Layer



Sputtered Single Cells

Stainless steel substrate



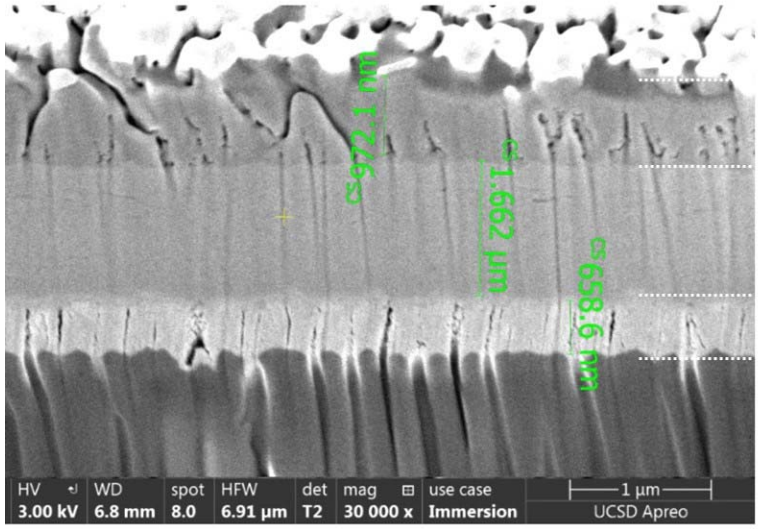
200nm Cathode Pt

1.6um Electrolyte YSZ

780nm Anode Ni

100um Substrate Stainless Steel

Anodized aluminum oxide (AAO) substrate



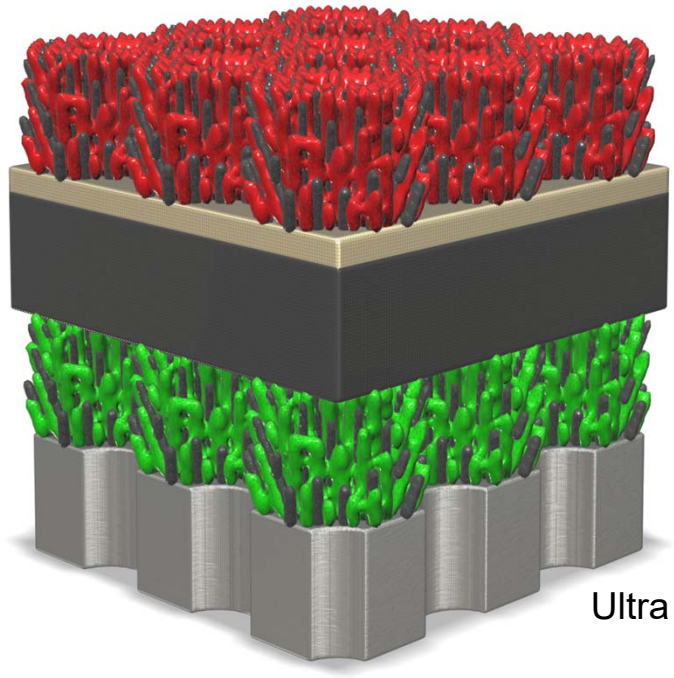
1um Cathode LSCF-YSZ

1.6um Electrolyte YSZ

650nm Anode Ni

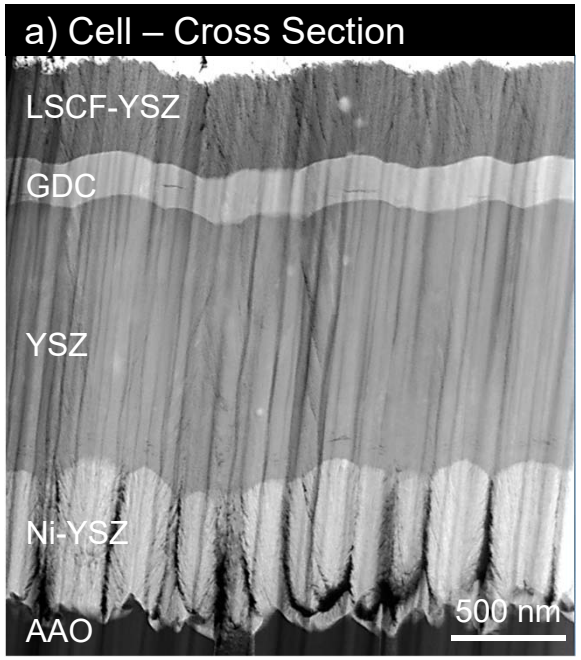
100um Substrate AAO

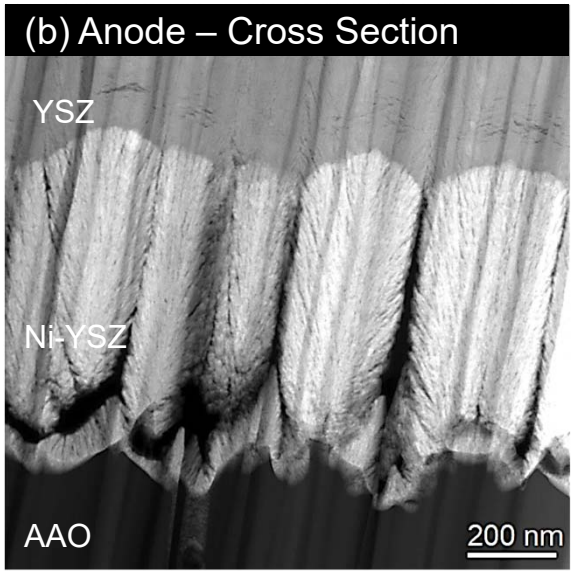
TEM Analysis of Cell Microstructure

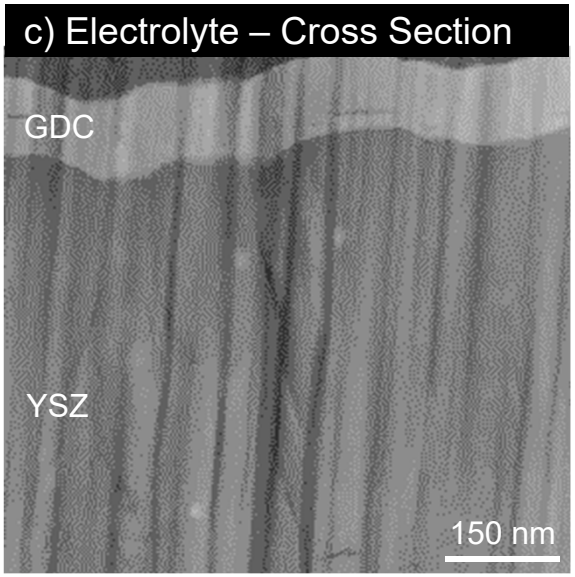


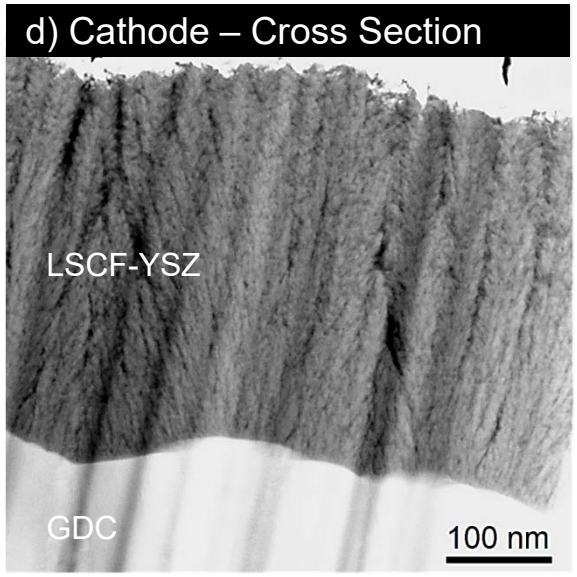
- **LSCF-YSZ (800nm)**
- **GDC (250nm)**
- **YSZ (1.4 um)**
- **Ni-YSZ (650nm)**
- **AAO (100um)**

Ultra Fine Nano Structured Electrodes
and Fully Dense Electrolyte



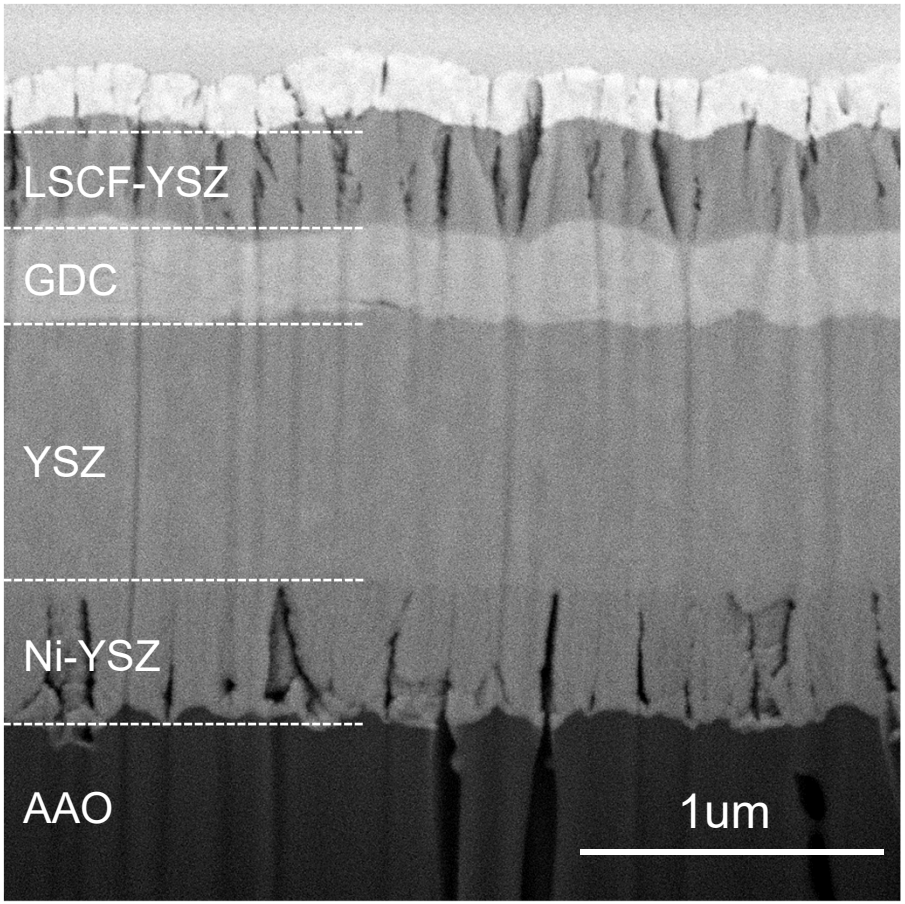


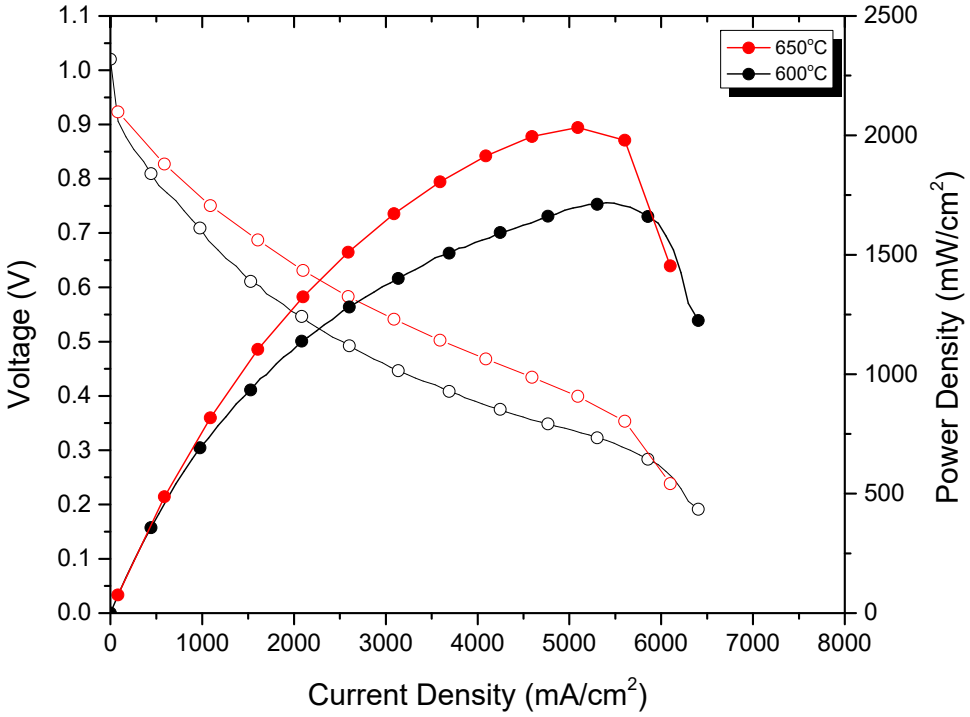




Cell Performance

LSCF-YSZ / GDC / YSZ / Ni-YSZ , Hydrogen Fuel

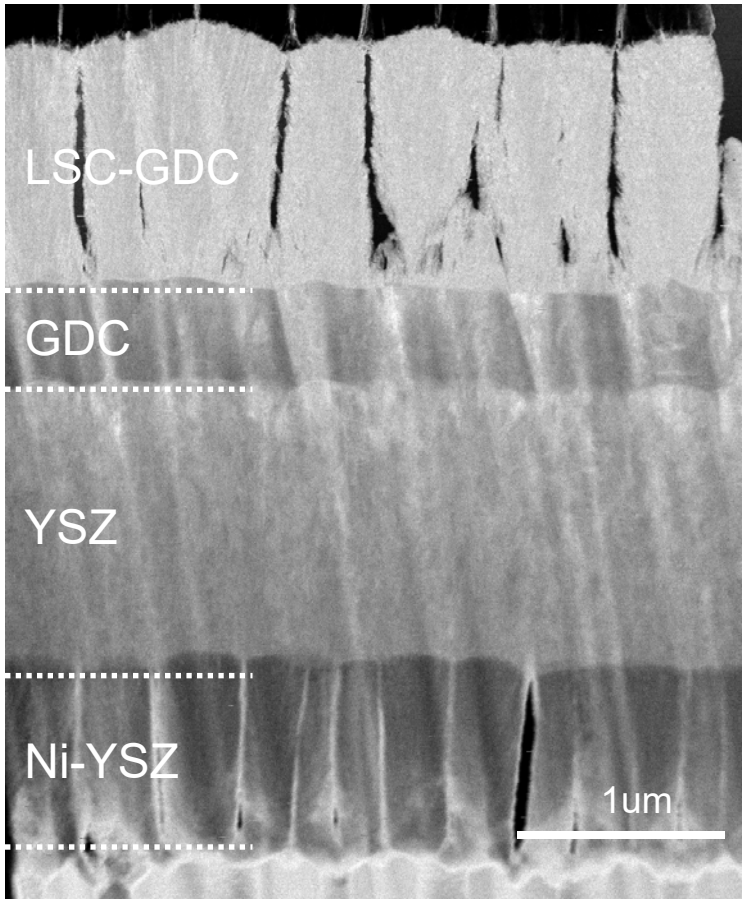


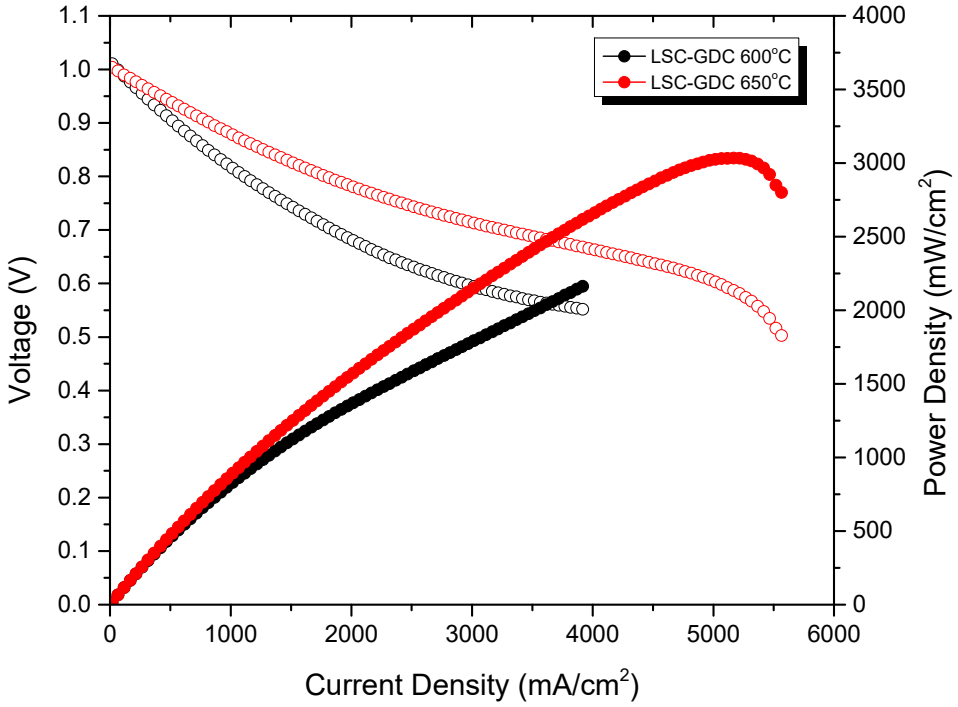


Best cell performance reported at these reduced temperatures (08/2018)

Cell Performance

LSC-GDC / GDC / YSZ / Ni-YSZ , Hydrogen Fuel

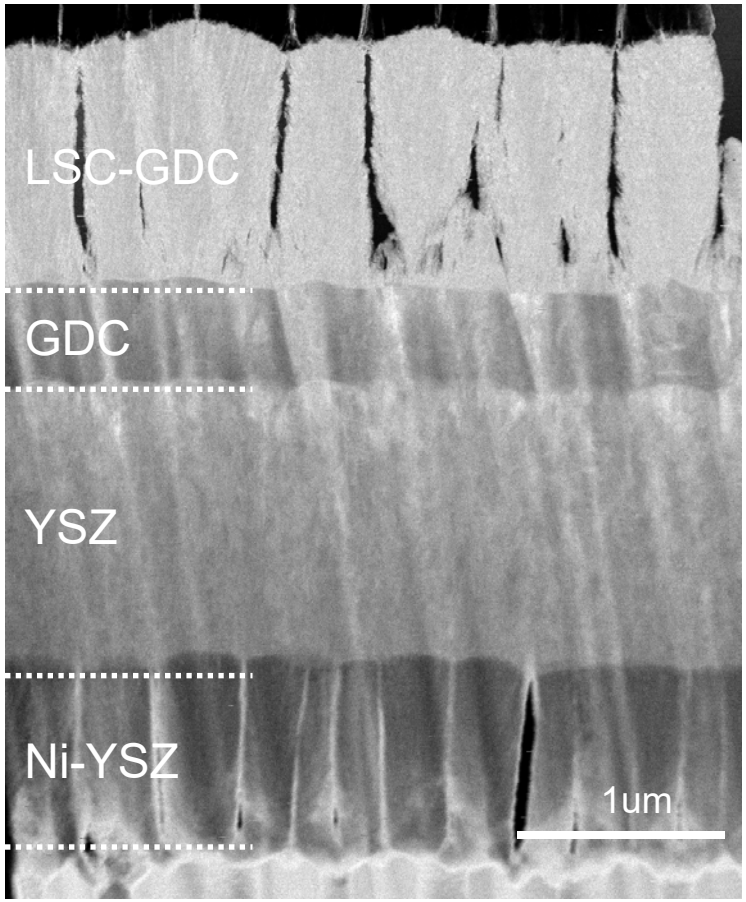


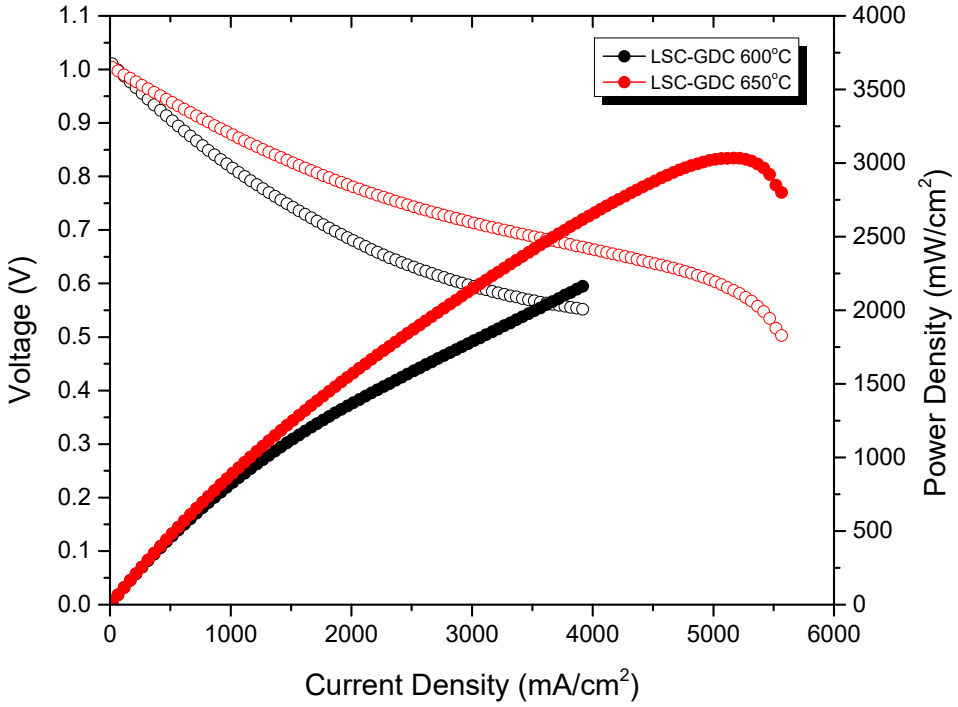


Best cell performance reported at these reduced temperatures (03/2019)

Cell Performance

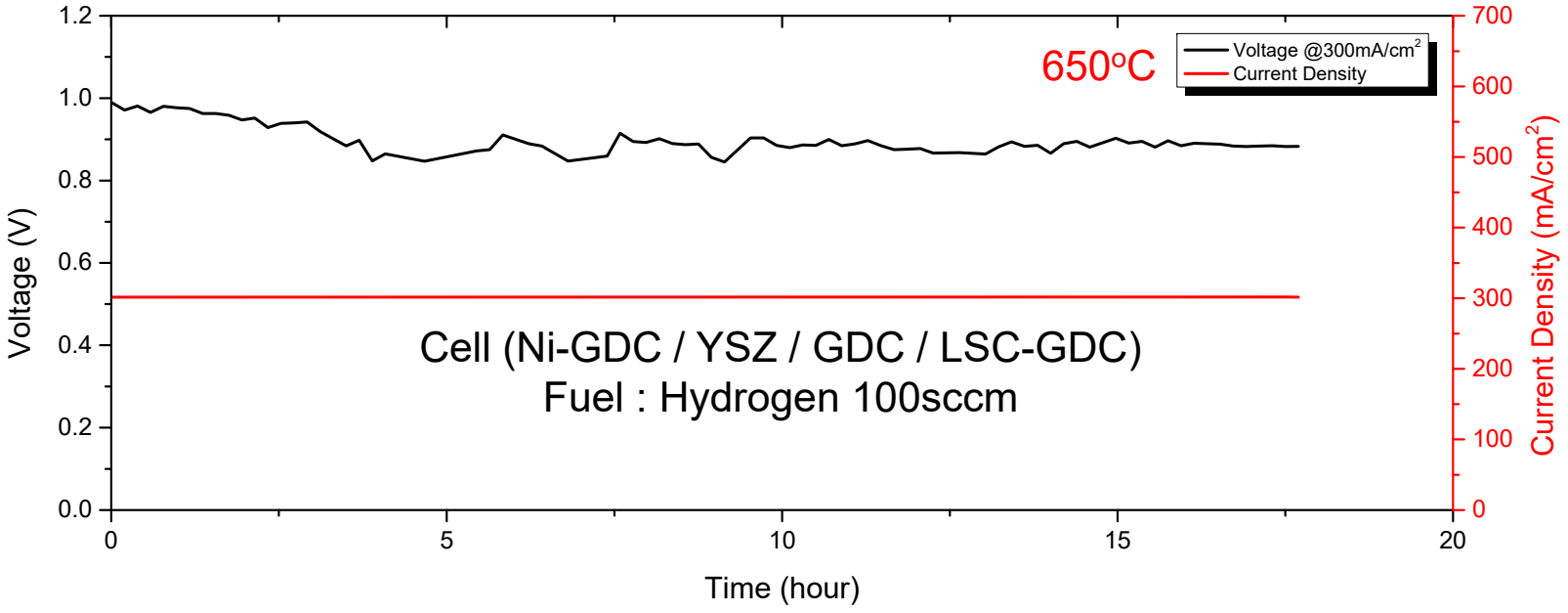
LSC-GDC / GDC / YSZ / Ni-YSZ , Hydrogen Fuel

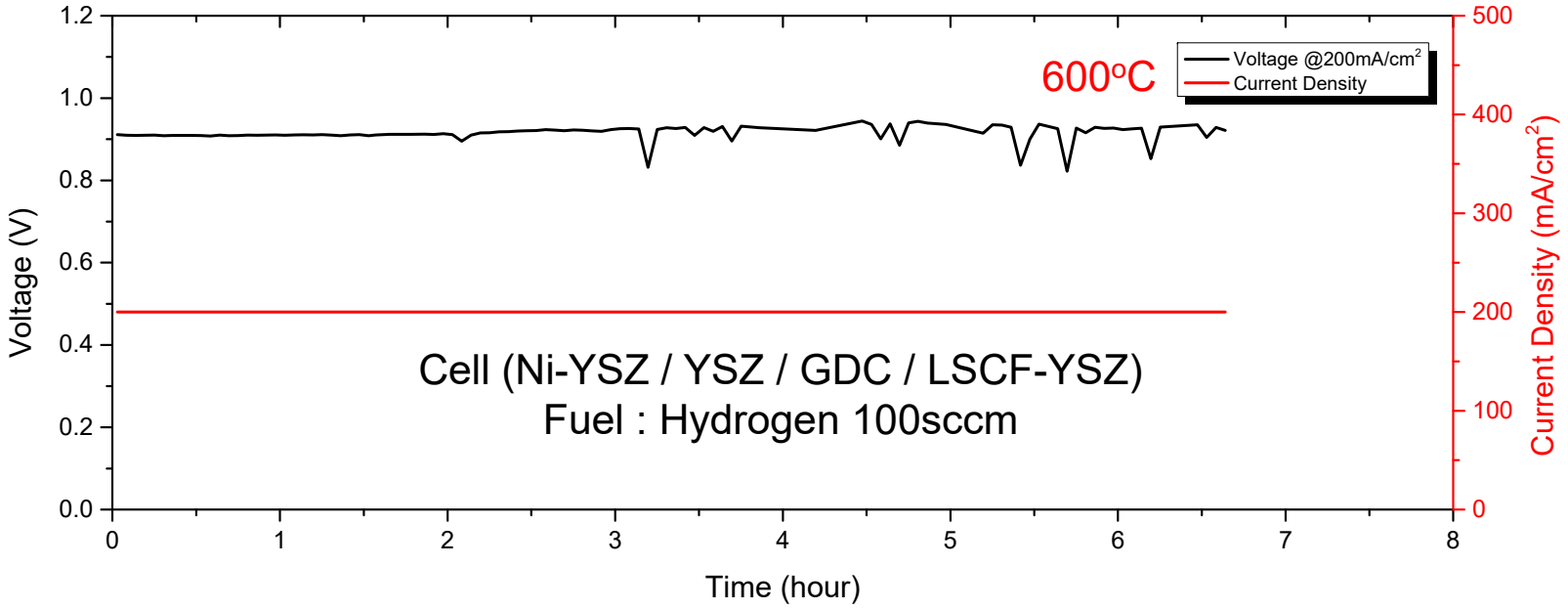




Best cell performance reported at these reduced temperatures (03/2019)

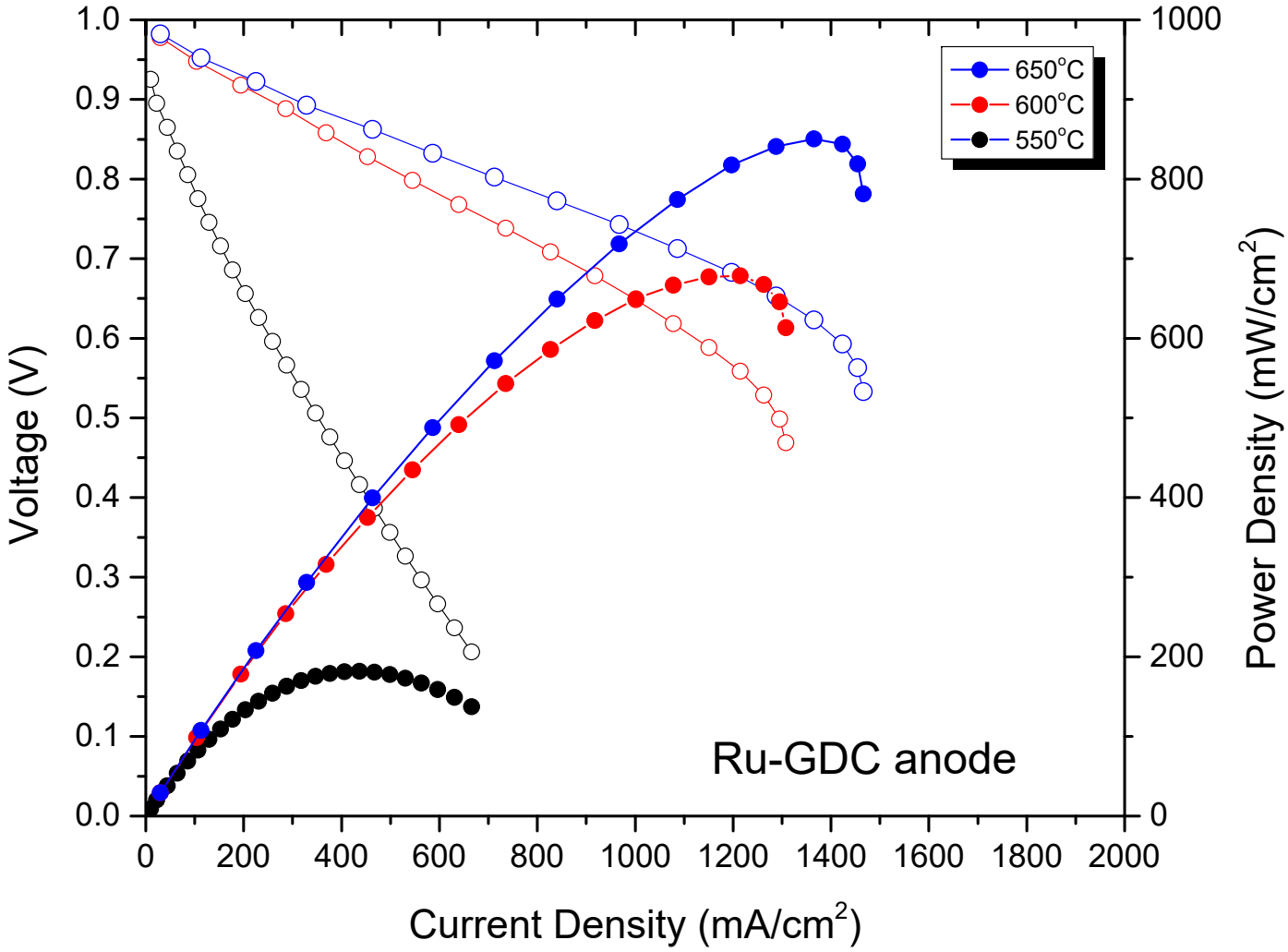
Cell Performance Stability





Cell Performance

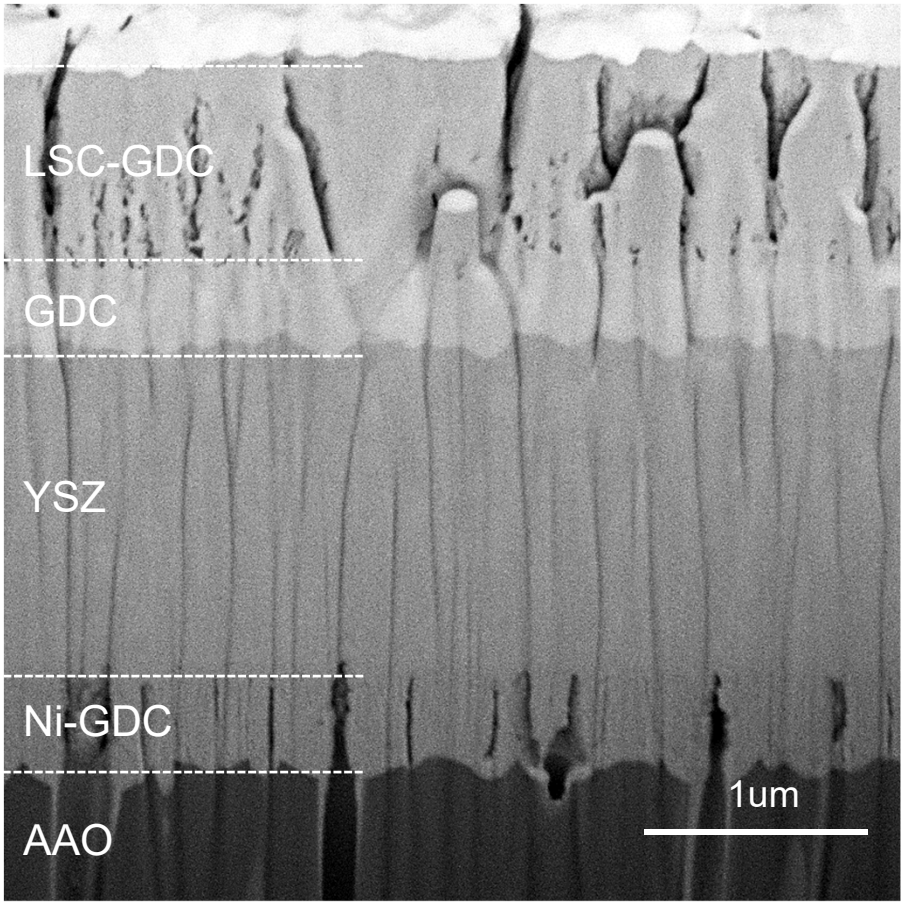
LSCF-YSZ/GDC/YSZ/Ru-GDC, Ethanol Fuel

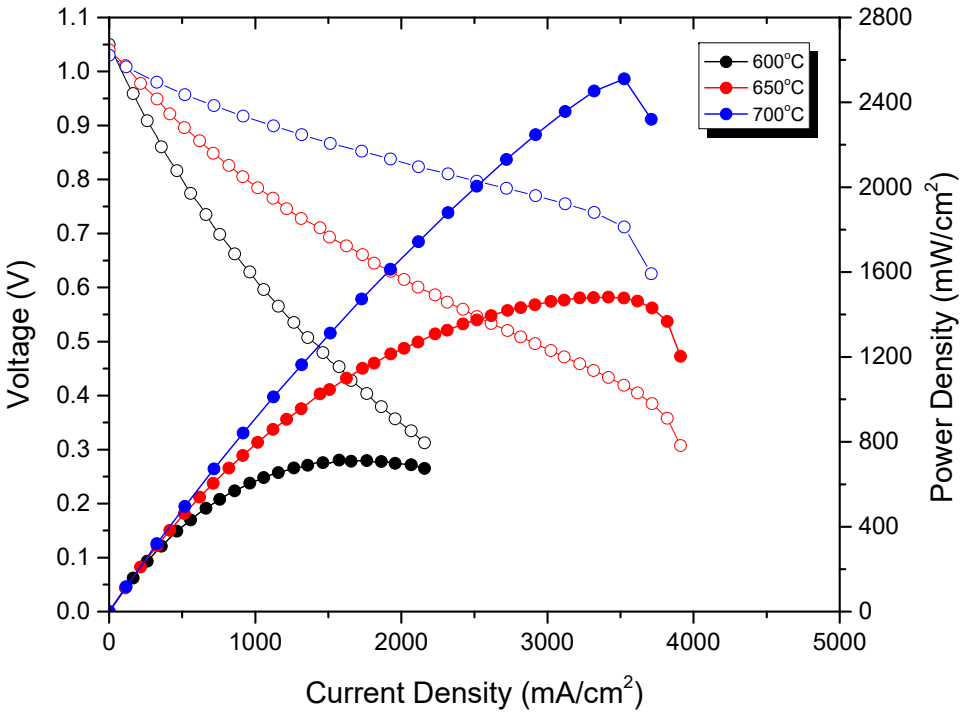


Pure Ethanol 70°C , 75sccm of Helium bubble

Cell Performance on Dry Methane

LSC-GDC/GDC/YSZ/Ni-GDC, Dry Methane



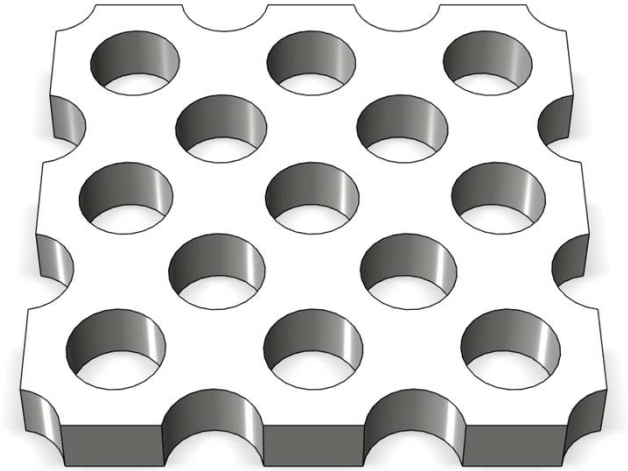


Pure Dry Methane 100sccm

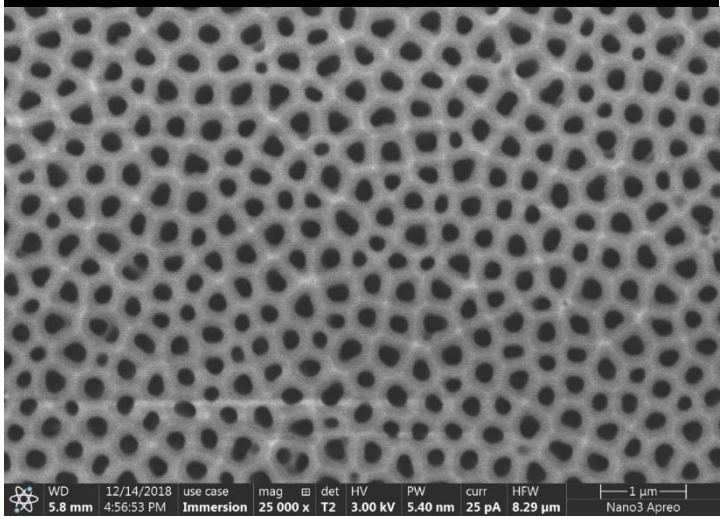
Best cell performance on dry methane reported at these reduced temperatures

Metal Coated AAOs

Porous Anodized Metal Oxide Substrate



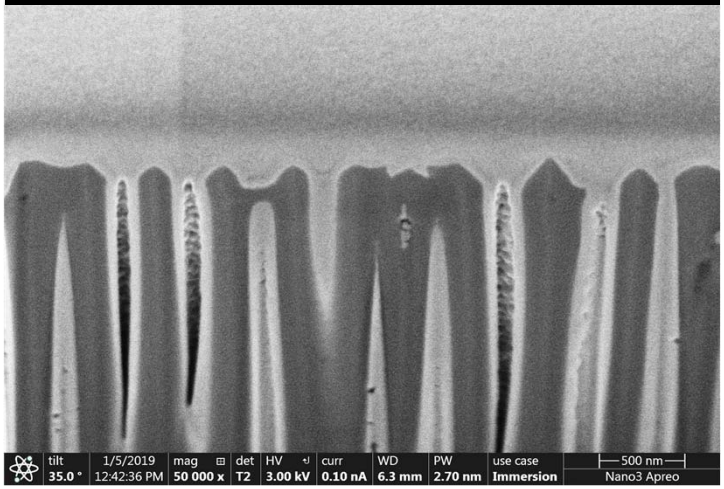
Surface image of porous substrate (AAO)



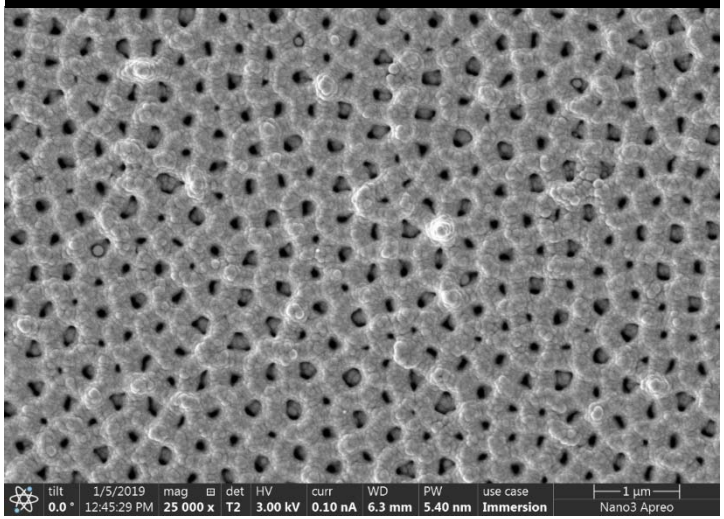
Metal Coating

Metal Coated Porous Anodized Metal Oxide Substrate

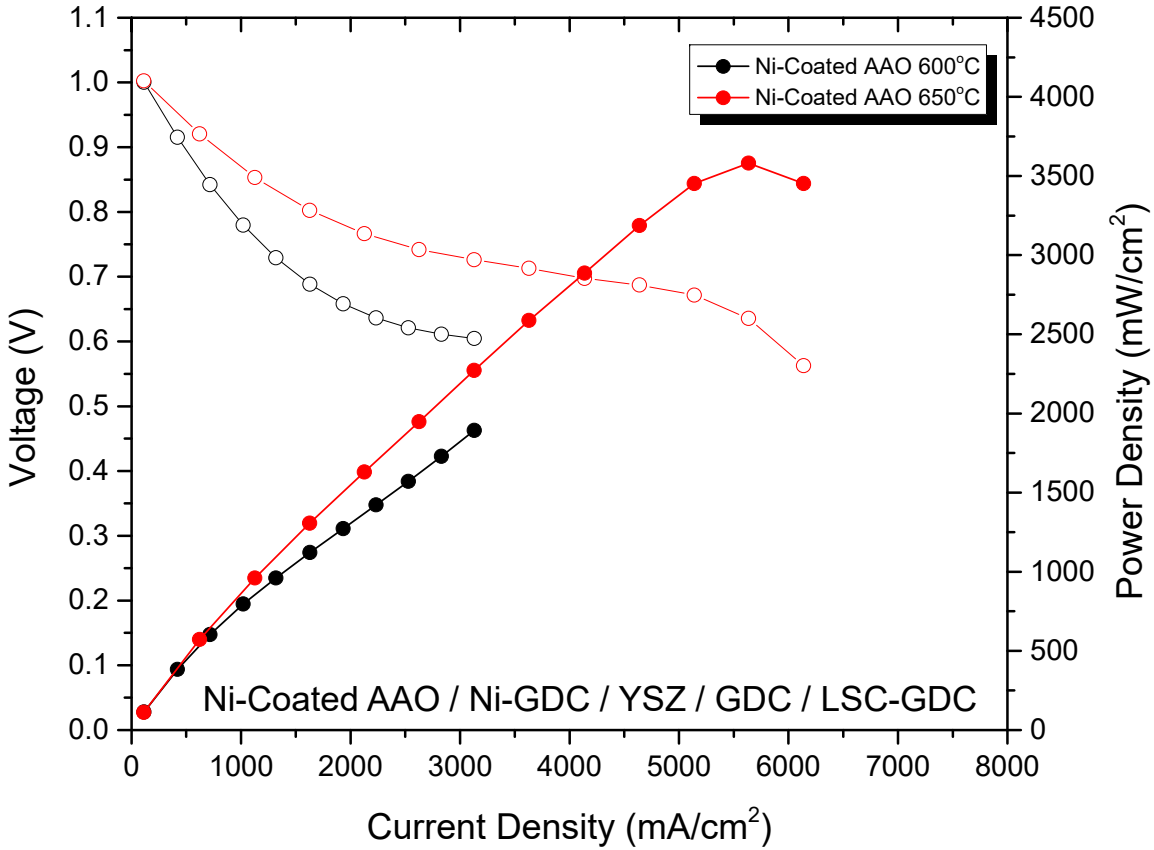
Cross sectional image of Metal-Coated AAO



Surface image of Metal-Coated AAO



Performance of Sputtered Cell on Ni-Coated AAO Substrate

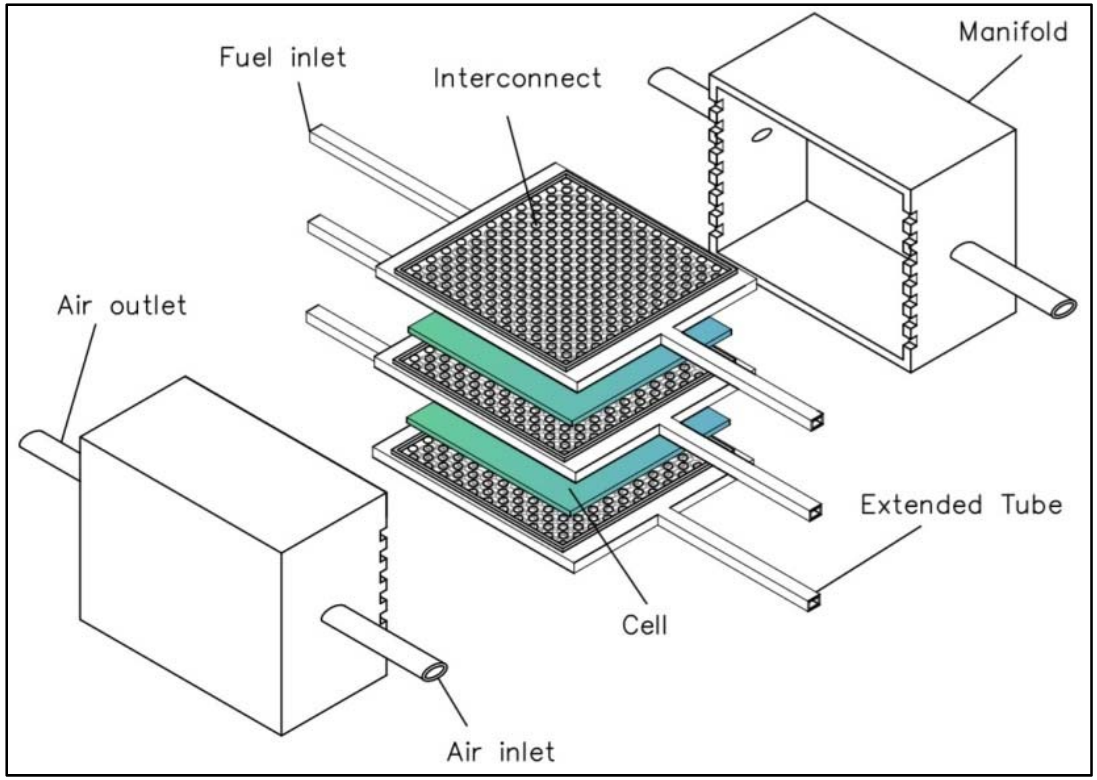


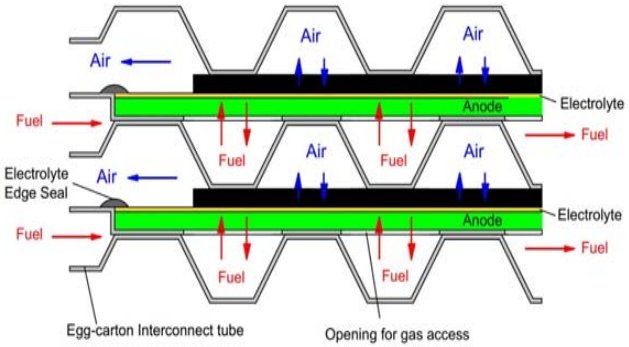
	600°C	650°C
Un Coated AAO Cell	2.1W/cm² (Peak Power Density)	3.0W/cm² (Peak Power Density)
Ni Coated AAO Cell	**1.9W/cm² (Peak Power Density)**	**3.5W/cm² (Peak Power Density)**

Pure hydrogen fuel (80sccm)

STACK DEVELOPMENT

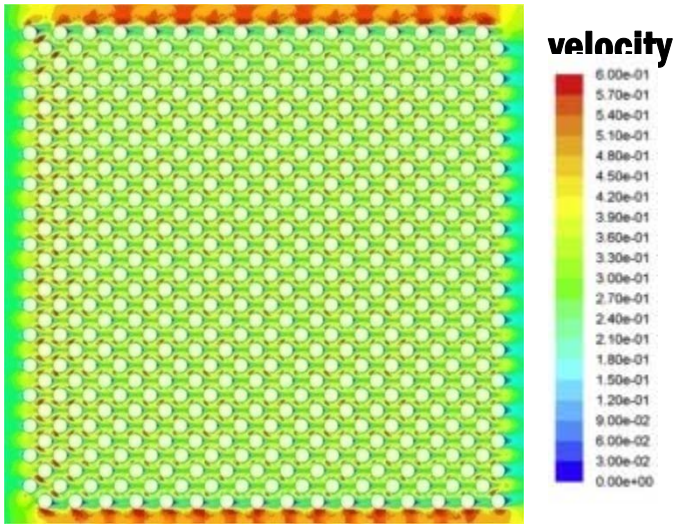
Design Concepts for kW Stacks





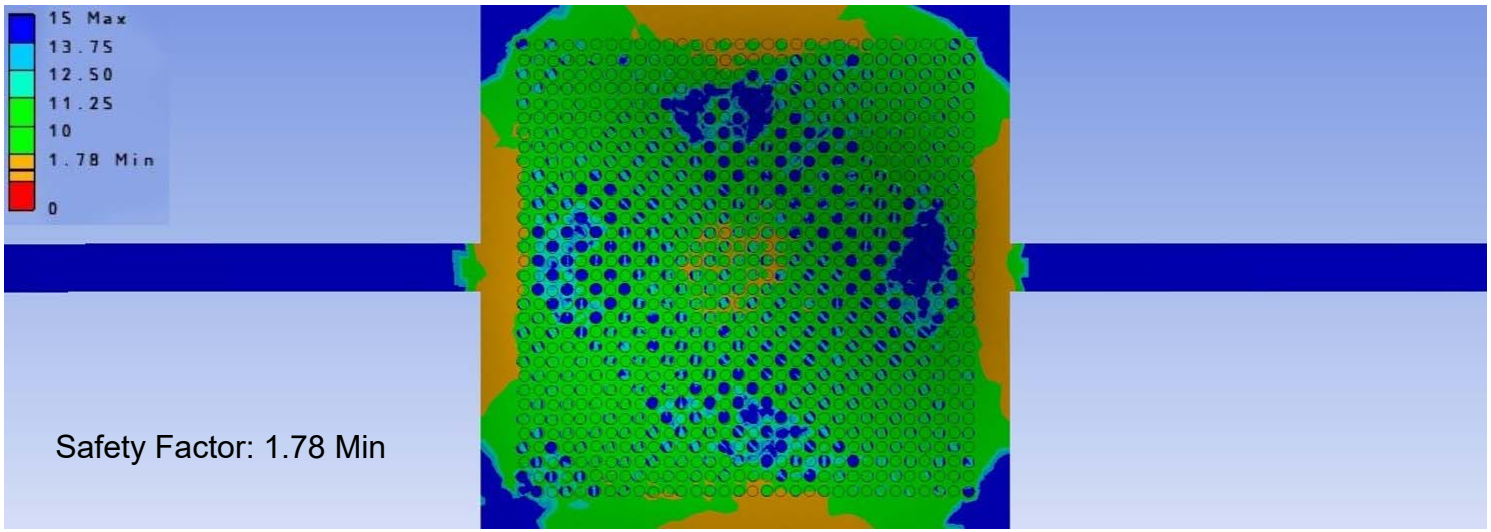
Preliminary Design Assessment

Flow Distribution and Mechanical Loading



Inlet gas velocity = 0.3m s^{-1}

- The flow distribution in the fuel channel of the interconnect is uniform.
- Egg-carton interconnect is strong enough for SOFC stack (under mechanical load of 50 cell-interconnect repeat unit with sintered cell size of 20 x 20 cm^2).



Safety Factor: 1.78 Min

Summary of Key Accomplishments

- Preliminary prime surface interconnect design
- Forming process for prime surface interconnects
- Sputtering process for fabrication of cell components
- Fabrication of thin-film cell structures with required characteristics on various types of substrates
- Demonstration of exceptional cell power densities on different fuels and best cell performance at reduced temperatures for YSZ based SOFCs (**power densities at 650^{o}C of ~3.5W/cm^{2} on hydrogen and ~1.5W/cm^{2} on dry methane**)
- Preliminary design for kW class stacks

Acknowledgments

- DOE/NETL SOFC project management, especially Dr. Patcharin Burke
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