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

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La Jolla, California

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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)
- **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. Eduard Ron (Postdoctoral scholar)
    - 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)
  - FuelCell Energy
    - Dr. Hossein Ghezel-Ayagh and Dr. Alireza Torabi
**Project Objective and R&D Work**

- **Objective**: Develop and evaluate a versatile stack configuration based on a prime-surface interconnect design for a broad range of power generation applications

- **R&D Work**: Involve R&D activities to demonstrate fabricability, operability and affordability of the stack design
STACK DESIGN CONCEPT
Stack Design
Incorporating Conventional Cells

Cell
Edge seal
Metal support
Interconnect
H₂
Air

Repeating cell unit

Electrolyte

Cathode
LSM
YSZ

Anode
Ni
YSZ

H₂O, H₂

Stainless steel support
Hole
Stainless steel egg carton shape interconnect
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
Prime-Surface Interconnect Design

- Notch
- Metal sheet with openings
- Metal sheet with egg carton shape
- Metal sheet with openings

Assembly

Cross Section

Fuel → AIR

Not in Scale
Stack Design

Incorporating Sintered Cells

Sintered Cell

Prime Surface Interconnect

Sintered Cell

Prime Surface Interconnect

Sintered Cell

Edge Seal

Sintered Cell

Anode

Electrolyte

Cathode

H₂, H₂O

Air

Notch

Not in Scale
Stack Design
Cross Flow Gas Manifolding

Notch

Opening for Gas Access to Cell

H₂

H₂O/H₂

Air

Not in Scale
Stack Design
Incorporating Metal-Supported Cells

Electrolyte seal
Metal support
Interconnect
Repeating cell unit

Anode
Columnar electrolyte scaffold
Ni nanoparticle
Doped electrolyte nanoparticle

Electrolyte
Dense electrolyte

Cathode
Columnar electrolyte scaffold
LSC nanoparticle
Doped electrolyte nanoparticle
Ag nanoparticle

Stainless steel support
Hole
Stainless steel egg carton shape interconnect
Project Technical Activities

- Prime surface interconnect design and fabrication development
- Metal-supported cell structure development
- Stack development
- Stack operation demonstration
- Stack cost assessment
PRIME SURFACE INTERCONNECT DEVELOPMENT
Preliminary Interconnect Design Assessment

- Flow distribution
- Mechanical loading
- Current collection
- Formability
Prime Surface Interconnect Design

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interconnect height</td>
<td>2.5mm</td>
</tr>
<tr>
<td>Interconnect sheet thickness</td>
<td>0.3mm</td>
</tr>
<tr>
<td>Cone angle</td>
<td>60°</td>
</tr>
<tr>
<td>Diameter of the cone</td>
<td>4mm</td>
</tr>
<tr>
<td>Mass of one sample (60 mm x 60 mm)</td>
<td>10.56 grams</td>
</tr>
</tbody>
</table>
Gas Flow Distribution Modeling

• Approach: FLUENT software, LES & URANS turbulence models

• Inlet boundary conditions:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet velocity</td>
<td>2 m/s</td>
</tr>
<tr>
<td>Temperature of the flow</td>
<td>800°C</td>
</tr>
<tr>
<td>Interconnect design</td>
<td>Egg carton shape</td>
</tr>
<tr>
<td>Fuel type</td>
<td>Hydrogen</td>
</tr>
</tbody>
</table>
Gas Flow Patterns

Plane near interconnect/cell interface

- Flow is uniform with areas of boundary layer detachment in the wakes of the hills

Plane in interconnect center

- Flow exhibits areas of acceleration
- Potentially that can be used for improved diffusion
Mechanical Loading Modeling

- Approach: ANSYS Mechanical software, modeling of loading within a stack
- Parameters:

<table>
<thead>
<tr>
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</tr>
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<tbody>
<tr>
<td>Temperature of the cell</td>
<td>800°C</td>
</tr>
<tr>
<td>Interconnect design</td>
<td>Egg carton shape</td>
</tr>
<tr>
<td>Cell type</td>
<td>Conventional anode-supported</td>
</tr>
<tr>
<td>Number of cells in the stack</td>
<td>100</td>
</tr>
<tr>
<td>Interconnect material</td>
<td>Ferritic stainless steel</td>
</tr>
</tbody>
</table>
The appeared stresses of 3.65MPa at the bottom cell are much lower than the yield strength of ferritic stainless steel (240MPa)
Current Collection Modeling

• Approach: Analytical calculations
• Parameters:

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Current Collection Losses

- Evaluation was performed for a simplified interconnect design and egg carton shape
- Egg-carton shape accounts for insignificant increase in the area-specific resistance as compared to that of a cell
- Negligible current density losses with egg carton shaped interconnects
Interconnect Formability

- Engineering drawing produced
- Hydroforming method of production chosen
- The interconnect manufacturer Borit™ contacted
- Positive feedback on its manufacturability received
Prime Surface Interconnect Design

Preliminary Assessment Summary

• No flow maldistribution
• Stress estimated at interconnects well below yield strength of stainless steels
• Interconnect current collection without significant losses
• Formability possible with hydroforming
METAL-SUPPORTED CELL STRUCTURE FABRICATION
Sputtering Process

Conventional

![Conventional Sputtering Process Diagram]

- Argon Ion ($\text{Ar}^+$)
- Target Material

Reactive

![Reactive Sputtering Process Diagram]

- Argon Ion ($\text{Ar}^+$)
- Target Material
- Oxygen
Sputtering for SOFC Cell Fabrication

• Fabrication of dense and porous layers

• Scalability

• Potential cost effectiveness

Weimar et al, PNNL Report PNNL-22732, 2013
Fabrication of Dense YSZ Layers

**Structure & Condition**

<table>
<thead>
<tr>
<th>Target</th>
<th>Y/Zr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>5mtorr</td>
</tr>
<tr>
<td>Gas Flow</td>
<td>50sccm of Ar</td>
</tr>
<tr>
<td>Power</td>
<td>200W</td>
</tr>
<tr>
<td>T-S Distance</td>
<td>70mm</td>
</tr>
<tr>
<td>Time</td>
<td>7200sec</td>
</tr>
</tbody>
</table>

**Cross Section**

**Surface**

Aperture Size = 30.00 μm
Date: 23 Apr 2017
WD = 4.2 mm
Stage at T = 40.0°
EHT = 1.00 kV
Detector = SE2
Display Mag = 503.15 K X

Aperture Size = 30.00 μm
Date: 22 Apr 2017
WD = 3.1 mm
Stage at T = 0.0°
EHT = 1.00 kV
Detector = SE2
Display Mag = 331.04 K X
Fabrication of Porous YSZ Structures

Structure & Condition

- Target: Y/Zr
- Pressure: 30mtorr
- Gas Flow: 50sccm of Ar
- Power: 200W
- T-S Distance: 120mm
- Time: 7200sec

Si wafer

Cross Section

Surface
# Fabrication of Porous Ni-YSZ Layers

## Structure & Condition

<table>
<thead>
<tr>
<th></th>
<th>Y/Zr</th>
<th>YSZ</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Target</strong></td>
<td>Y/Zr</td>
<td>YSZ</td>
<td>Ni</td>
</tr>
<tr>
<td><strong>Pressure</strong></td>
<td>30mtorr</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gas Flow</strong></td>
<td>50sccm of Ar</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>25W</td>
<td>200W</td>
<td>100W</td>
</tr>
<tr>
<td><strong>T-S Distance</strong></td>
<td>120mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td>7200sec</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Si wafer**

## Cross Section

- EHT = 1.00 kV
- Display Mag = 300 nm
- Image at T = 35.0 °
- Detector = SE2

## Surface
# Fabrication of Porous LSC-YSZ Layers

## Structure & Condition

<table>
<thead>
<tr>
<th>Target</th>
<th>Y/Zr</th>
<th>LSC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>30mtorr</td>
<td></td>
</tr>
<tr>
<td>Gas Flow</td>
<td>50sccm of Ar</td>
<td></td>
</tr>
<tr>
<td>Power</td>
<td>50W</td>
<td>200W</td>
</tr>
<tr>
<td>T-S Distance</td>
<td>120mm</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td>7200sec</td>
<td></td>
</tr>
</tbody>
</table>

[Image of Si wafer with LSC-YSZ layers]

[Image of micrograph showing the fabricated layers]
EDX Mapping of Deposited LSC-YSZ Layer
Fabrication of SOFC Cell

Anode
Ni/YSZ

Electrolyte
YSZ

Cathode
LSC/YSZ

With SE2 Detector
: Morphological
Focused image
Fabrication of SOFC Cell

- Cathode: LSC/YSZ
- Electrolyte: YSZ
- Anode: Ni/YSZ

With InLens Detector:
- Material: Focused image
- (Bright: Conductor, Dark: Insulator)
Metal-Supported Cell Development
Preliminary Fabrication Results Summary

• Fabrication feasibility demonstration by sputtering
  – Dense YSZ electrolyte layers
  – Porous YSZ structures
  – Porous Ni-YSZ layers
  – Porous LSC-YSZ layers
  – Single cell structures

• Uniform layer thickness and excellent interfaces between layers

• Electrode porosity improvements required
Near-Term Future Work

• Prime surface interconnect development
  – Initiate and evaluate hydroforming of egg carton shaped interconnect and characterize fabricated samples
  – Modify and optimize design

• Metal-supported cell structure development
  – Modify and optimize sputtering process and characterize fabricated samples
  – Fabricate and characterize single cells
  – Fabricate cell components and single cells on metal supports

• Stack development
  – Initiate assembling of stacks incorporating prime surface interconnects and sintered cells
Acknowledgments

• DOE/NETL SOFC project management, especially Dr. Patchcharin Burke
• UCSD/FCE SOFC project team