Novel Cathodes Prepared by Impregnation Procedures
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Technical Issues

- LSM / YSZ cathodes are widely used but exhibit only modest performance at 700°C and are impractical for operation at lower temperatures

- More conductive cathode materials are available but …
  - High temperature calcination necessary to sinter YSZ causes solid state reactions
  - Doped ceria interlayers often used to avoid solid state reactions are not always effective
  - Poor CTE match between these “improved” cathodes and YSZ can hurt cell lifetime
Approach

- Impregnate perovskite into a porous matrix of YSZ that has already been sintered to high temperatures

**YSZ+pore formers**

**YSZ**

**Anode**

**Electrolyte**

**Cathode**

**Lamination**

70°C, 8 MPa

**Firing**

1400 – 1550°C

**Impregnation & Calcination at 450 ~ 850°C**
R&D Objectives & Approach

YSZ Structure

Electrode I

electrolyte

Electrode II

X 500  35 um

X 2500  8 um

X 1000  20 um
R&D Objectives & Approach

Infiltrate with metal salts or perovskite nanoparticles

Porous YSZ

Correct phases are formed

40 wt% LSF-YSZ by impregnation

XRD after calcination to 850°C
Advantages

- Separate firing temperatures for YSZ and perovskite.
  - Avoids solid-state reactions between LSF & YSZ.
- Composite is non-random structure; perovskite coats pores.
  1. Electrical conductivity of LSM-YSZ

700°C in air, composites calcined at 1523 K.

2. CTE of LSCo-YSZ (CTE of LSCo is 23x10^{-6}/K)

<table>
<thead>
<tr>
<th>LSCo Weight Fraction in YSZ</th>
<th>0%</th>
<th>35%</th>
<th>45%</th>
<th>55%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTE (10^{-6}/K), 300 to 1073 K</td>
<td>10.3</td>
<td>11.7</td>
<td>12.6</td>
<td>12.6</td>
</tr>
</tbody>
</table>
Project Objectives

– Compare key performance attributes (power density / ASR, lifetime effects, cost) for the following three cathode systems:
  
  • Paste LSM
  • Impregnated LSM
  • Impregnated LSF

– Evaluate ways of improving impregnation process
  
  • Nanosized perovskite colloidal dispersion
  • Molten salt
Key Technical Risks

• Potential for long term operation to result in the formation of insulating phases leading to decreased performance

• Sintering of perovskite particles that reduces performance or requires significantly heavier loadings
Accomplishments

• Two 1000 hour tests of impregnated LSF working cells show nearly flat performance

• Symmetric cell tests for impregnated LSF-YSZ and LSCo-YSZ electrodes show phenomenal performance, as low as 0.1 Ωcm² and 0.03 Ωcm² at 700°C in air

• LSF-YSZ and LSCo-YSZ cathode supported cells tested, yielding similar performance to anode supported cells

• Impregnated anode supported LSM-YSZ cells tested show similar performance to that of conventional paste LSM-YSZ cells

• Molten salt impregnation of LSM shown to reduce infiltration steps by factor 2
Phase I Project Plan

Task 1 – Cost Analysis
- Cost models for paste LSM, infiltrated LSM and infiltrated LSF

Task 2 – Characterize Baseline Design
- Long run testing and material characterization of paste and impregnated cells

Task 3 – Improvement of Design
- Evaluate higher perovskite loadings and / or use of mixed perovskites
- Long run testing and material characterization of paste and impregnated cells

Task 4 – LSM Nanoparticle Proof of Concept
- Synthesis of nanoparticle LSM colloidal dispersion
- Working cell testing of impregnated nanoparticle LSM cells
Results to Date

Symmetric cell testing of LSF-YSZ AND LSCo-YSZ

Good agreement with fuel cell data!
Results to Date

Long run tests of infiltrated LSF-YSZ working cells at 700°C

Anode: Cu-CeO₂ / 8YSZ
Electrolyte: 45 - 60 μm 8YSZ
Cathode: LSF / YSZ
Fuel: H₂ (3% H₂O)
Results to Date

- Impregnation of LSM in YSZ using
  - Nano-particles (•)
  - Aqueous solutions (•)
  - Molten salts (two steps) (•)

Cathodes calcined at 1050°C
Anode: Co-CeO2
Electrolyte: 60 μm
Cathode: LSM-YSZ
Fuel: H2 (3%H2O)

700°C, H2 (3%H2O)
Results to Date

Cathode Supported Cells

Electrode I: 60 μm
Electrolyte: 60 μm
Electrode II: 600 μm
Cathode: LSF-YSZ
Anode: Cu-Ceria-YSZ

700°C, H₂ (3%H₂O)

Anode-supported cell
Cathode-supported cell
Applicability to SOFC Commercialization

- Method may allow the use of more conductive cathode materials that, in turn, permit lower temperature operation and/or higher power density and lower system cost.
- Ability to produce high performance cathode supported cells.
- Fabrication of impregnated cathodes is compatible with most types of SOFCs currently used by industrial teams.
Next Steps

• Develop cost models
• Material characterization of long run cells
• Evaluate increased perovskite loading
• Evaluate improved impregnation methods
Thank You

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