The effect of LSM-YSZ infiltrated electrodes on the performance of microtubular solid oxide fuel cells

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Typical operation temperature: 500 - 1000°C

**ADVANTAGES:**

- Cheap catalysts*: Ni: 0.008 $/g
  Pt: 42.8 $/g
- High efficiency: >60% electrical efficiency
  SOFC-Gas turbine system > 80% energy efficiency
- Fuel flexibility: internal reforming
  direct use of methane or syngas
- Use of waste heat

**DISADVANTAGES:**

- High start-up times
- Mechanical stability
- Chemical compatibility

* Market price: July 2013
Why microtubular?

Microtubular SOFCs for portable applications
(< 5 mm diameter)

- Seals
- Power Density
- Thermal shock resistance
- Fast start-up

Applications:
- APU
- Portable
Fabrication steps

Elements

Synthesis of Nanopowders.

Accommodation of commercial powders

Anode Support fabrication

Electrolyte Deposition

Co-sinterization

Cathode deposition

Current collectors

Cell

LSCF painting 40 µm

LSCF Dip 20 µm 1000 ºC (2h)

GDC-LSCF dip 20 µm / 1050 ºC (2h)

GDC dip 4-7 µm 1400 ºC

YSZ WPS ~15 µm 1400 ºC

Ni-YSZ 400 µm 950 ºC

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Ni-YSZ 400 µm 950 ºC
NiO/YSZ support: CIP

- Commercial Powder
  - NiO
  - YSZ
  - Pore Former
  - Acetone

- Double milling
- Suitable NiO
- NiO-YSZ, 0.63 NiO+0.37 YSZ (wt%)

- Homogenization (ultrasonic mixing, mechanical agitation)

- Anode Powder
  - Cold Isostatic Pressed (200MPa)
  - Electrolyte Spray coating

- 1350°C sintering; NiO-YSZ, 150 mm length, 400µm thickness, 3.2 mm diameter

- NiO-YSZ, 150 mm length, 400µm thickness, 3.2 mm diameter
Electrolyte deposition

Thermal stability of the components not only under operation conditions BUT at sintering temperatures

- 1500°C
- DL/L0
- 0 500 1000 1500 2000
- Temperature [°C]
- Anode support
- YSZ coarse
- YSZ fine

Anode

Electrolyte

Cathode
Novel Tubular SOFC Design

*YSZ porous support (\(<500 \mu m, \geq 50\%\) porosity)*

*YSZ thin porous layer (\(<50 \mu m, \geq 50\%\) porosity)*

**Ni-SDC anode infiltration**

**Fuel in**

**Air in**

**LSM cathode infiltration**
Infiltration of LSM

LSM cathode infiltration

Sample A

TPL: Thin porous layer of YSZ coated on electrolyte for cathode infiltration

<table>
<thead>
<tr>
<th>Cell details</th>
<th>Before infiltration</th>
<th>After infiltration</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPL weight gain upon infiltration with LSM (%)</td>
<td>-</td>
<td>23.66</td>
</tr>
<tr>
<td>Vol.% YSZ</td>
<td>100</td>
<td>78.05</td>
</tr>
<tr>
<td>Vol.% LSM</td>
<td>0</td>
<td>21.95</td>
</tr>
<tr>
<td>Open porosity of the TPL</td>
<td>50</td>
<td>39.3</td>
</tr>
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</table>

Sample B

Infiltration of LSM $\times 4$ into a thin porous layer

<table>
<thead>
<tr>
<th>Cell details</th>
<th>Before infiltration</th>
<th>After infiltration</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPL weight gain upon infiltration with LSM (%)</td>
<td>-</td>
<td>37.5</td>
</tr>
<tr>
<td>Vol.% YSZ</td>
<td>100</td>
<td>64.74</td>
</tr>
<tr>
<td>Vol.% LSM</td>
<td>0</td>
<td>35.26</td>
</tr>
<tr>
<td>Open porosity of the TPL</td>
<td>50</td>
<td>33</td>
</tr>
</tbody>
</table>
Experimental setup

Gas lines: H₂, N₂, air

Fuel Cell bench:
- Mass flow control
- Humidifiers
- TC control

Heated lines

Computer

Potentiostat/Galvanostat/FRA

Microtubular furnace

Pt wires

Alumina tube

Quartz tube

Ni foam

low temperature sealing

air
Standard cells fabricated at ICMA (LSM/YSZ by dip coating)
30% of LSM

T = 850 °C
850-900 mA/cm² at 0.7 V
600-700 mW/cm² at 0.7 V

<table>
<thead>
<tr>
<th>Geometry</th>
<th>I (mA/cm² at 0.7V)</th>
<th>Labs</th>
</tr>
</thead>
<tbody>
<tr>
<td>m-tube</td>
<td>800</td>
<td>ours</td>
</tr>
<tr>
<td>m-tube</td>
<td>150</td>
<td>Sammes</td>
</tr>
<tr>
<td>m-tube</td>
<td>900</td>
<td>Ding &amp; Liu</td>
</tr>
<tr>
<td>m-tube</td>
<td>800</td>
<td>Kim et al.</td>
</tr>
<tr>
<td>Planar</td>
<td>1160</td>
<td>Basu et al.</td>
</tr>
<tr>
<td>Planar</td>
<td>1000</td>
<td>Souza</td>
</tr>
</tbody>
</table>

Competitive power output
Electrochemical characterization

Novel cells fabricated at ICMA & U. Alberta (LSM infiltration x2: 13.3% onto porous YSZ)

SAMPLE A

![Graph showing voltage and current density for different samples with power density and current density axes.](image-url)
EIS characterization

SAMPLE A

<table>
<thead>
<tr>
<th>Temp (°C)</th>
<th>$R_{\text{ohm}}$($\Omega \text{cm}^2$)</th>
<th>$R_1$($\Omega \text{cm}^2$) Anode act.</th>
<th>$R_2$($\Omega \text{cm}^2$) Anode dif.</th>
<th>$R_3$($\Omega \text{cm}^2$) Cathode act.</th>
<th>ASR($\Omega \text{cm}^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>700</td>
<td>0.17(1)</td>
<td>0.18(1)</td>
<td>0.23(1)</td>
<td>0.80(1)</td>
<td>1.38(4)</td>
</tr>
<tr>
<td>750</td>
<td>0.12(1)</td>
<td>0.12(1)</td>
<td>0.21(4)</td>
<td>0.66(1)</td>
<td>1.10(7)</td>
</tr>
<tr>
<td>800</td>
<td>0.10(1)</td>
<td>0.07(1)</td>
<td>0.20(2)</td>
<td>0.38(1)</td>
<td>0.75(5)</td>
</tr>
<tr>
<td>850</td>
<td>0.09(1)</td>
<td>0.05(1)</td>
<td>0.18(3)</td>
<td>0.36(1)</td>
<td>0.69(6)</td>
</tr>
</tbody>
</table>
Novel cells fabricated at ICMA & U. Alberta (LSM infiltration x4: 23.6% onto porous YSZ)

**SAMPLE B**
### EIS Characterization

#### Table

<table>
<thead>
<tr>
<th>Temp (°C)</th>
<th>$R_{\text{ohm}}$ (Ωcm$^2$) Elect+contact</th>
<th>$R_1$ (Ωcm$^2$) Anode act.</th>
<th>$R_2$ (Ωcm$^2$) Anode dif.</th>
<th>$R_3$ (Ωcm$^2$) Cathode act.</th>
<th>ASR (Ωcm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>700</td>
<td>0.15(2)</td>
<td>0.30(59)</td>
<td>0.17(10)</td>
<td>0.58(56)</td>
<td>1.19(9)</td>
</tr>
<tr>
<td>750</td>
<td>0.11(5)</td>
<td>0.03(10)</td>
<td>0.17(25)</td>
<td>0.45(48)</td>
<td>0.76(8)</td>
</tr>
<tr>
<td>800</td>
<td>0.10(7)</td>
<td>0.06(14)</td>
<td>0.20(13)</td>
<td>0.21(15)</td>
<td>0.58(5)</td>
</tr>
<tr>
<td>850</td>
<td>0.09(10)</td>
<td>0.07(10)</td>
<td>0.18(9)</td>
<td>0.17(3)</td>
<td>0.51(3)</td>
</tr>
</tbody>
</table>
Infiltration of $\text{Nd}_2\text{NiO}_{4+\delta}$ salt precursors into YSZ porous cathode matrix

*Publication submitted*
Conclusions

-Anode supported mT-SOFC using LSM/YSZ cathodes prepared by infiltration were fabricated and characterized.

- Cells with LSM infiltrated cathodes present better performance than analogue cells fabricated by dip-coating, using less amount of LSM electronic phase.

- At 850 °C and 0.7V: Standard cells (LSM/YSZ/pore 30/30/40): 600-700 mWcm⁻²
  LSM infiltrated (LSM/YSZ/pore 13,32/52,6/39,3): 750 mWcm⁻²
  LSM infiltrated (LSM/YSZ/pore 23,6/43,4/33): 850 mWcm⁻²
  (composition in vol%)

- Infiltrated LSM electrodes seem to be stable after short-term operation conditions