Infiltrated cathode materials for microtubular solid oxide fuel cells

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Why SOFC?

**ADVANTAGES:**

- **Cheap catalysers**
  - Ni: 0.008 $/g
  - Pt: 42.8 $/g
- **Remarkable energetic efficiency:**
  > 60% electrical efficiency. Heat can be used, SOFC+Gas turbine cogeneration system
  > 80% energy efficiency
- **Fuel flexibility:** internal reforming allows the direct use of hydrocarbons: methane or syngas
- **Low pollutant emissions:** High T operation means low NOx

**DISADVANTAGES:**

- **High volume and weight**
- **High thermal inertia:** long start-up times
- **High temperature operation means ceramics and high temperature metals**
- **Aging problems and high cost**

* Market price: July 2013
**Microtubular (< 5 mm diameter)**

**Portable applications**

- ✔ Low T Seals: possibility of using HT silicon
- ✔ High volumetric Power Density 2.5W/cm³
- ✔ Excellent thermal shock resistance
- ✔ Fast start-up: less than 1 minute
- ✔ Light weight and small volume
- ✔ Life: at least 2000 hours

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**AIST (Japan)**
Portable applications: UAVs, batteries
Small devices: Power range 25 W-2 kW

Acumetrics (USA)
Ultra Electronics AMI (USA)
eZelleron (Germany)
Adelan (UK)

Field test and demonstration
Precursor CIP (cold isostatic pressing) fabrication

NiO/YSZ support: CIP

We also fabricate tubes by extrusion, as presented by H. Monzón et al. (keynote presentation)

R. Campana et al., J. Power Sources 2009
Thermal stability of the components not only under operation conditions BUT at sintering temperatures.
Infiltration

**Novel Tubular SOFC Design**

- YSZ porous support (<500 µm, >50% porosity)
- YSZ thin porous layer (<20 µm, >50% porosity)
- LSM or Nd$_2$NiO$_{4+δ}$ infiltration

Ni-SDC anode infiltration

Fuel in

Air in

AR Hanifi et al., J Electrochem Soc 2014
Infiltration of LSM

LSM cathode infiltration

**LSM** (LaSr$_{0.2}$Mn$_{0.8}$O$_3$)

- 2.949g lanthanum nitrate
- 0.359 strontium nitrate
- 2.230g manganese nitrate
- 0.3g Triton X-45
- 1.0g deionized water

Interface between infiltrated electrodes and electrolyte

Experimental setup

Gas lines: H2, N2, air

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

Heated lines

Computer

Potentiostat/Galvanostat/FRA
Standard cells fabricated at ICMA (LSM/YSZ by dip coating)

**Geometry**

<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**

$T = 850 \, ^\circ\text{C}$

850-900 mA/cm² at 0.7 V

600-700 mW/cm² at 0.7V
** LSM infiltration**

**Sample code LSM1**

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>
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<tr>
<td>Vol.% LSM</td>
<td>0</td>
<td>21.95</td>
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<tr>
<td>Open porosity of the TPL</td>
<td>50</td>
<td>39.3</td>
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</table>

**Sample code LSM2**

<table>
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<tr>
<td>TPL weight gain upon infiltration with LSM (%)</td>
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<td>37.5</td>
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<tr>
<td>Vol.% YSZ</td>
<td>100</td>
<td>64.74</td>
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<tr>
<td>Vol.% LSM</td>
<td>0</td>
<td>35.26</td>
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<tr>
<td>Open porosity of the TPL</td>
<td>50</td>
<td>33</td>
</tr>
</tbody>
</table>

Note that standard LSM/YSZ cathodes are 50/50 (in vol.%).
Electrochemical characterization

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

**LSM1 (infiltrated x2)**

- Voltage (V)
- Current density (mA cm\(^{-2}\))
- Power density (mW cm\(^{-2}\))

**LSM2 (infiltrated x4)**

- Voltage (V)
- Current density (mA cm\(^{-2}\))
- Power density (mW cm\(^{-2}\))

750 mW cm\(^{-2}\) for LSM1

850 mW cm\(^{-2}\) for LSM2
Microstructure

LSM1 (x2)  
LSM/YSZ (x2)

LSM2 (x4)  
LSM/YSZ (x4)

Ni/YSZ  
YSZ
Nd$_2$NiO$_{4+\delta}$ infiltration

Novel cells fabricated at ICMA & U. Alberta (Nd$_2$NiO$_{4+\delta}$ onto porous YSZ)

Interface between the YSZ electrolyte and porous YSZ infiltrated with the Nd-nickelate

Nd$_2$NiO$_{4+\delta}$ reacts with YSZ at typical sintering temperatures (above 1000 °C)

This reactivity is avoided by infiltration (calcination temperatures of 850 °C)

Laguna-Bercero et al. submitted to J. Mater Chem A
No microstructural evolution after the electrochemical experiments

Laguna-Bercero et al. submitted to J. Mater Chem A
Conclusions

-Anode supported mT-SOFC using LSM/YSZ and \( \text{Nd}_2\text{NiO}_{4+\delta} /\text{YSZ} \) cathodes prepared by infiltration were fabricated and characterized.

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

-At 850 °C and 0.7V:Standard cells (LSM/YSZ/pore 30/30/40): 0.6-0.7 Wcm\(^{-2}\)

  LSM infiltrated (LSM/YSZ/pore 13.32/52.6/39,3): 0.75 Wcm\(^{-2}\)
  LSM infiltrated (LSM/YSZ/pore 23.6/43.4/33): 0.85 Wcm\(^{-2}\)

  (composition in vol%)

  \( \text{Nd}_2\text{NiO}_{4+\delta} \) infiltrated: \( \sim 1 \) Wcm\(^{-2}\)

-Infiltrated LSM and \( \text{Nd}_2\text{NiO}_{4+\delta} \) electrodes seem to be stable after short-term operation conditions