Next generation fuel cell materials (nextgenFCmat)

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1. Overview of project participants

Dr. Camilla Haavik
Dr. Per Martin Rørvik
Prof. Reine Wallenberg
PhD stud. Filip Lenrick
Dr. Nikolaos Bonanos
Dr. Sandrine Ricote
Dr. Theodor Schneller
PhD stud. David Griesche
2. Project budget

- Total and with an overview of external funding from other sources

<table>
<thead>
<tr>
<th>Partner</th>
<th>N-INNER funding</th>
<th>External funding</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>SINTEF</td>
<td>370 380</td>
<td>0</td>
<td>370 380</td>
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<tr>
<td>DTU</td>
<td>246 000</td>
<td>0</td>
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<tr>
<td>Lund</td>
<td>242 960</td>
<td>59 040</td>
<td>302 000</td>
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<tr>
<td>RWTH</td>
<td>219 196</td>
<td>0</td>
<td>219 196</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1 078 536</strong></td>
<td><strong>59 040</strong></td>
<td><strong>1 137 576</strong></td>
</tr>
</tbody>
</table>
3. Project organisation

- Project coordinator: Camilla Haavik (from September 2011 Per Martin Rørvik)
- 4 work packages
  - WP1: Thin film fabrication (RWTH, SINTEF, DTU)
  - WP2: Structural/microstructural characterization (advanced: LU, basic: all)
  - WP3: Electrochemical characterization and modelling (DTU, SINTEF, RWTH)
  - WP4: Project co-ordination (SINTEF) and dissemination (all)
- 5 face-to-face meetings held so far (Oslo, Risø, Lund, Grenoble, Aachen)
- Final meeting in June
- Telephone/Skype meetings in between
4. Project progress and possible deviations

• The project started July 1\textsuperscript{st}, 2010
  • Later start than planned due to funding issues
• The project ends June 31\textsuperscript{st}, 2013
  • RWTH: 31\textsuperscript{st} April (has applied for extension until June 31\textsuperscript{st})
  • Lund: has applied for extension due to PhD student start-up in 2011
• Two post docs started in 2010
• Two PhD students started in early 2011
  • Will finish in 2016
5. Scientific findings and uniqueness of the project

- Fuel cells are technology for efficient and clean conversion of chemical energy into electricity and heat

![Solid Oxide Fuel Cell (SOFC)](image1)

![Protonic Ceramic Fuel Cell (PCFC)](image2)
The main innovative elements of nextgenFCmat are:

1. The use of proton conducting ceramic electrolytes instead of the conventional oxygen ion-conducting ones
2. Fabrication of genuine thin films instead of thick films
3. The use of “gentle” fabrication methods for ceramic fuel cell materials

This will facilitate the development of fuel cells with low weight, compact design and low cost that can operate at low temperature.
Cathode microstructure and performance

• Study of how the cathode microstructure and interface towards the electrolyte phase affects the performance
  • Spray pyrolysis of cathode
  • Infiltration of cathode
• Choice of materials
  • BaCe$_{0.2}$Zr$_{0.7}$Y$_{0.1}$O$_3$ (BCZY27) is a good and stable proton conductor
  • La$_{0.58}$Sr$_{0.4}$Co$_{0.2}$Fe$_{0.8}$O$_3$ (LSCF) is a good oxide ion and electron conductor
• Published in *Journal of Power Sources* (S. Ricote *et al.*, 2012, vol. 209, p. 172-179)
**Infiltration:**
- Thickness cathode: 30-40 microns
- Porosity: 35 ± 2%
- Micro-scale pores

**Spray pyrolysis:**
- Thickness cathode: 2-5 microns
- Porosity: 37 ± 5%
- Nano-scale pores
Infiltration:

- Limited by oxygen ads./dissoc.

ASR 600ºC air, \( p_{H_2O} = 0.001 \text{atm} \):

\[ R_p = 0.63 \ \Omega \cdot \text{cm}^2 \]

Spray pyrolysis:

- Limited by charge transfer

ASR 600ºC air, \( p_{H_2O} = 0.001 \text{atm} \):

\[ R_p = 0.61 \ \Omega \cdot \text{cm}^2 \]

Performance of the cathode: highly dependent on the microstructure

Lowest values reported for LSCF
Improvement of cathode performance

- Infiltration of LaCoO₃ into BaCe₀.₂Zr₀.₇Y₀.₁O₃ backbone

- Results show that oxygen conduction is not necessary for the cathode process in a PCFC when infiltrating the cathode material

- Published in *Journal of Power Sources* (S. Ricote *et al.*, 2012, vol. 218, p. 313-319)
LaCoO$_3$ cathode: AC spectra

Spectrum in air, $p$H$_2$O=0.010 atm at 500ºC

$R_p=0.11$ and 0.39 $\Omega \cdot cm^2$ at 600 and 500ºC in air, $p$H$_2$O=0.01 atm

Lowest values reported so far
Electrolyte thin film – microstructure and interface

• By adjusting the deposition parameters thin electrolyte films with controlled thickness (100-600 nm) and microstructure were obtained
• The figures show a BZY film with epitaxial interface to the MgO substrate
• The film was monolithic and without grain boundaries

• Published in *ECS Transactions* (F. Lenrick *et al.*, 2012, vol. 45, p. 121-127)
6. Networks, co-operations, seminars and mobility

- Cooperation with other projects: only internally at the partner institutions
- No summer schools or international conferences have been arranged

- Mobility
  - Exchange of PhD students are planned (Lund ↔ Aachen)
7. Results

- **PhD degrees**
  - Two PhD students in progress, they will finish in 2016
- **MSc degrees**
  - 1 at Lund University
  - 2 at RWTH Aachen
- **BSc degrees**
  - 3 at RWTH Aachen
- **Academic publications**
  - 13 conference contributions (7 lectures, 6 posters)
  - 4 papers published
  - ~7 papers planned/in progress
8. Other publications / information activities (web, social media, television, daily press et cetera)

- A web site for the project has been established: [http://www.sintef.no/Projectweb/nextgenFCmat/](http://www.sintef.no/Projectweb/nextgenFCmat/)

- Lund: interview in local University paper to appear
- SINTEF: in contact with *International Innovation*
9. Patents

• None submitted
10. What did the N-INNER call do for the initiation of collaboration, research area and network, how will it move forward?

- The N-INNER call has been very useful in establishing collaboration between the North European partners and allowed us to do work we could not have done in FP7
- N-INNER is small but significant
- The project has been very fruitful in bringing together specialists in various fields working towards a common goal
- The consortium would like to continue the collaboration after the official project end
- The two PhD students are planned to finish in 2016 (three more years)
- New joint proposals will be prepared in appropriate calls
  - Structuring of cathode
  - Fabrication of full cell
  - Up-scaling to cm-scale (5×5 cm²)
Acknowledgements

• Partners

- DTU National Laboratory for Sustainable Energy
- RWTH Aachen University
- Lund University
- SINTEF

• Funding

- INER - ERA-Net
- Innovative Energy Research
- Danish Agency for Science Technology and Innovation
- The Research Council of Norway
- Swedish Energy Agency
- PTJ
Papers

• S. Ricote, N. Bonanos, A. Manerbino, W.G. Coors, *Conductivity study of dense BaCe\textsubscript{x}Zr\textsubscript{(0.9-x)}Y\textsubscript{0.1}O\textsubscript{(3-d)} prepared by solid state reactive sintering at 1500 °C*, International Journal of Hydrogen Energy, 2012, 37, 7954-7961

• S. Ricote, N. Bonanos, P.M. Rørvik, C. Haavik, *Microstructure and performance of La\textsubscript{0.58}Sr\textsubscript{0.4}Co\textsubscript{0.2}Fe\textsubscript{0.8}O\textsubscript{3-δ} cathodes deposited on BaCe\textsubscript{0.2}Zr\textsubscript{0.7}Y\textsubscript{0.1}O\textsubscript{3-δ} by infiltration and spray pyrolysis*, Journal of Power Sources, 2012, 209, 172-179

• S. Ricote, N. Bonanos, F. Lenrick, L.R. Wallenberg, *LaCoO\textsubscript{3}: promising cathode material for protonic ceramic fuel cells based on a BaCe\textsubscript{0.2}Zr\textsubscript{0.7}Y\textsubscript{0.1}O\textsubscript{3-d} electrolyte*, Journal of Power Sources, 2012, 218, 313-319.

• F. Lenrick, D. Griesche, J.-W. Kim, T. Schneller, L.R. Wallenberg, *Electron microscopy study of single crystal BaZr\textsubscript{0.9}Y\textsubscript{0.1}O\textsubscript{3-x} films prepared by chemical solution deposition*, ECS Transactions, 2012, 45, 121-127.
Presentations

• P.M. Rørvik and C. Haavik, *Low‐temperature deposition of La$_{0.6}$Sr$_{0.4}$Fe$_{0.8}$Co$_{0.2}$O$_{3-d}$ thin film cathodes* [Poster], 7th Petite Workshop on the Defect Chemical Nature of Energy Materials, Storaas, Norway, March 14-17, 2011

• S. Ricote, N. Bonanos, R. Haugsrud, *Conductivity measurements on BaCe$_{(0.9-x)}$Zr$_x$Y$_{0.1}$O$_{(3-d)}$ prepared using NiO as sintering aid* [Poster], 7th Petite Workshop on the Defect Chemical Nature of Energy Materials, Storaas, Norway, March 14-17, 2011

• P.M. Rørvik, Y. Larring, C. Haavik, *Cathode performance of spray pyrolysis‐deposited La$_{1-x}$Sr$_x$Fe$_{1-y-z}$Co$_y$Ni$_z$O$_{3-d}$ thin films for micro‐solid oxide fuel cells* [Lecture], 18th International Conference on Solid State Ionics, Warsaw, Poland, July 3-8, 2011


Presentations continued

- F. Lenrick, D. Griesche, J.-W. Kim, T. Schneller, L.R. Wallenberg, *Electron microscopy study of single crystal BaZr_{0.9}Y_{0.1}O_{3-\delta} films prepared by chemical solution deposition* [Lecture], The 8th International Symposium on Ionic and Mixed Conducting Ceramics, 221st Electrochemical Society Meeting, Seattle, USA, May 6-11, 2012
- S. Ricote, N. Bonanos, P.M. Rørvik, C. Haavik, *Performance of La_{0.58}Sr_{0.4}Co_{0.2}Fe_{0.8}O_{3-d} and LaCoO_{3} cathodes deposited on BaCe_{0.2}Zr_{0.7}Y_{0.1}O_{3-d} by infiltration and spray pyrolysis* [Lecture], E-MRS Spring meeting, Strasbourg, France, May 14-18, 2012
- P. M. Rørvik, F. Lenrick, Y. Larring, L. R. Wallenberg, C. Haavik, *Cathode performance of spray pyrolysis-deposited La_{0.58}Sr_{0.4}Fe_{0.8}Co_{0.2}O_{3-d} and La_{0.58}Sr_{0.4}Fe_{0.8}Ni_{0.2}O_{3-d}* [Lecture], Electroceramics XIII, Enschede, Netherlands, June 24-27, 2012
Presentations continued

- P. M. Rørvik, F. Lenrick, L. R. Wallenberg, C. Haavik, *Chemical solution deposition of La₂₈ₓW₄₊ₓO₅₄+d thin films* [Poster], Solid State Protonic Conductors 16, Grenoble, France, September 10-14, 2012
- S. Ricote, N. Bonanos, P. M. Rørvik, C. Haavik, F. Lenrick, L. R. Wallenberg, *Performance of La₀.5₈Sr₀.₄Co₀.₂Fe₀.₈O₃-d and LaCoO₃ cathodes deposited by infiltration and spray pyrolysis on BaCe₀.2Zr₀.7Y₀.1O₃-d* [Lecture], Solid State Protonic Conductors 16, Grenoble, France, September 10-14, 2012