Advanced bipolar plates without flow channels, for PEM electrolysers operating at high pressure

Hydrogen Session – Bipolar plates for PEM fuel cells and electrolyzers

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TECHNOPORT RERC 2012
Trondheim, April 16 - 18, 2012

www.ise.fraunhofer.de
Merits and challenges of high pressure PEM water electrolysis

**Merits**
- Splitting of water into its constituent elements by use of electricity
- Storage of excess power from renewable energy sources
- Highly efficient with zero carbon footprint
- Reduced system cost for operation at high pressure

**Challenges**
- Commercialisability
- Improvement of cell and stack performance
- High capital, material and operational costs
- Short durability of components

→ Bipolar plate is the critical component for costs and life span improvements
# The multifunctional bipolar plate

<table>
<thead>
<tr>
<th>Functions</th>
<th>Required properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduction of electrical current from cell to cell</td>
<td>High electrical conductivity</td>
</tr>
<tr>
<td>Facilitation of heat management</td>
<td>Good thermal conductivity</td>
</tr>
</tbody>
</table>
| Flow distribution of reactant water and product gases          | • Highly impermeable to gases  
• Corrosion resistant on anode side  
• Hydrogen embrittlement resistant on cathode side  
• High electrochemical stability |
| Constitutes most part of the mass and volume of electrolyser   | • High mechanical stability  
• Low material and production costs  
• Availability                                        |
Bipolar plates development at Fraunhofer ISE

- **Conventional design**
  - Machined Ti plates, 50 cm² active area
  - Expensive

- **Gold coated design**
  - Injection molded PPS
  - 9 cm² active area
  - Highly durable but expensive

- **Low cost design**
  - Injection molded plate with inner Ti pin
  - 78 cm² active area
  - Low thermal management and low power density

- **Second generation low cost design**
  - Thin unmachined Ti plate
  - Better thermal management
  - Problems with gas tightness
Major bipolar plate challenges

- Strong corrosive conditions on the anode side due to:
  - Anodic polarisation
  - Operation at elevated temperatures
  - Presence of oxygen
- Hydrogen embrittlement of metals on the cathode side
- High material costs and manufacturing techniques

R&D focus

- Screening of candidate materials based on corrosion and hydrogen embrittlement resistance
- Comprehensive cost analysis model on material and production techniques
- Novel design concepts
- Develop and demonstrate PEM water electrolyser integrated with RES
- 75% efficiency (LHV)
- Hydrogen production cost ~ €5,000 / Nm$^3$h$^{-1}$
- Target lifetime of 40,000 h

Jan 2010 - Dec 2012
Co-ordination: SINTEF
Funding: Fuel Cells and Hydrogen JU
Total Budget: €3,353,549
www.nexpel.eu
Benchmark materials and Cost break down model

Cost model and assumptions
- Material costs based on offers from suppliers that guarantee real market prices
- Manufacturing costs from in-house experience and information from sub-contractors
- Cost model accounts for all steps in the production process
- Waste materials such as shavings are recycled and sold for a third of the original price
- Two stack design concepts (conventional and advanced) are considered

<table>
<thead>
<tr>
<th>Components</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bipolar plates</td>
<td>Titanium</td>
</tr>
<tr>
<td>Cell frame</td>
<td>PPS GF40</td>
</tr>
<tr>
<td>Anode catalyst</td>
<td>IrO₂</td>
</tr>
<tr>
<td>Anode loading</td>
<td>2 mg/cm²</td>
</tr>
<tr>
<td>Cathode catalyst</td>
<td>40 wt. % Pt on carbon</td>
</tr>
<tr>
<td>Cathode loading</td>
<td>1 mg/cm²</td>
</tr>
<tr>
<td>Membrane</td>
<td>Nafion 117</td>
</tr>
<tr>
<td>Anode current collector</td>
<td>Sintered Ti, expanded Ti mesh, Ti felt</td>
</tr>
<tr>
<td>Cathode current collector</td>
<td>Carbon paper, sintered Ti, expanded Ti mesh, Ti felt</td>
</tr>
</tbody>
</table>
Conventional Vs. Advanced design

Conventional Design:
- O-ring
- Current collector
- Bipolar plate
- Manifold
- MEA
- Flow field

Advanced Design:
- Current collector (multilayer)
- Bipolar plate (sheet or foil)
- Manifold
- MEA
- Aplied sealing
- Frame

Stack costs [€]

Produced stacks [-]

Costs per stack [€]

Produced stacks [-]
BiP Manufacturing costs break down

- Machining of Titanium bipolar plates is quite expensive
- Only slight cost reduction with increasing production rate
- Cost target of 2500 € / Nm³h⁻¹ cannot be met using machined bipolar plates
Corrosion screening of candidate bipolar plate materials

- Corrosion tests performed in a three electrodes electrochemical cell
- Hg/Hg$_2$SO$_4$ / K$_2$SO$_4$ (0,690 V vs. R.H.E) reference electrode
- 0,5M H$_2$SO$_4$ electrolyte
- pH 3,3
- Candidate materials tested
  - Grades of stainless steel
  - Tantalum coated stainless steel
  - Hastealloys
  - Various grades of Titanium
### Stainless steel grades

<table>
<thead>
<tr>
<th></th>
<th>Fe (Wt%)</th>
<th>Ni (Wt%)</th>
<th>Cr (Wt%)</th>
<th>Mo (Wt%)</th>
<th>Mn (Wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SS 316L</strong></td>
<td>0,68</td>
<td>0,11</td>
<td>0,17</td>
<td>0,02</td>
<td>0,02</td>
</tr>
<tr>
<td><strong>SS 904L</strong></td>
<td>0,49</td>
<td>0,26</td>
<td>0,21</td>
<td>0,02</td>
<td>0,01</td>
</tr>
<tr>
<td><strong>TCS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Low cost surface modification on 316L and 904L*

### Corrosion current at 2V vs. RHE (µA/cm²)

<table>
<thead>
<tr>
<th></th>
<th>316 L</th>
<th>316LTS C</th>
<th>904 L</th>
<th>904LTS C</th>
<th>Ti Gr2</th>
<th>DOE Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion current at 2V vs. RHE (µA/cm²)</td>
<td>96,1</td>
<td>88,2</td>
<td>42,4</td>
<td>31,8</td>
<td>10</td>
<td>&lt; 16</td>
</tr>
</tbody>
</table>
Tantalum coated stainless steel

- Tantalum coated by electrodeposition in ionic liquids
- A second sample of Ta coated SS316L was annealed at 500°C under air before testing

<table>
<thead>
<tr>
<th></th>
<th>316 L</th>
<th>316L+Ta</th>
<th>316L+Ta Annealed</th>
<th>Ti Gr2</th>
<th>DOE Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion current at 2V vs. RHE (µA/cm²)</td>
<td>63,4</td>
<td>41,8</td>
<td>99,6</td>
<td>10</td>
<td>&lt; 16</td>
</tr>
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![Graphs showing corrosion current vs. E (V vs. RHE)]
## Hastealloys

<table>
<thead>
<tr>
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<th>Fe (Wt%)</th>
<th>Ni (Wt%)</th>
<th>Cr (Wt%)</th>
<th>Mo (Wt%)</th>
<th>Mn (Wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cronifer 1925</td>
<td>0,47</td>
<td>0,25</td>
<td>0,19</td>
<td>0,06</td>
<td>0,01</td>
</tr>
<tr>
<td>Nicrofer 3127</td>
<td>0,32</td>
<td>0,31</td>
<td>0,27</td>
<td>0,06</td>
<td>0,02</td>
</tr>
<tr>
<td>Nicrofer 5923</td>
<td>0,01</td>
<td>0,59</td>
<td>0,23</td>
<td>0,16</td>
<td>-</td>
</tr>
</tbody>
</table>

**Graphs:**

- Corrosion current at 2V vs. RHE (µA/cm²)

<table>
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<tr>
<th></th>
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<th>3127</th>
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# Titanium grades

<table>
<thead>
<tr>
<th></th>
<th>C (Wt%)</th>
<th>Fe (Wt%)</th>
<th>H (Wt%)</th>
<th>N (Wt%)</th>
<th>O (Wt%)</th>
<th>Pd (Wt%)</th>
<th>Mo (Wt%)</th>
<th>Ni (Wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 1</td>
<td>0,1</td>
<td>0,5</td>
<td>0,015</td>
<td>0,05</td>
<td>0,4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Grade 2</td>
<td>0,1</td>
<td>0,3</td>
<td>0,015</td>
<td>0,05</td>
<td>0,35</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Grade 7</td>
<td>0,1</td>
<td>0,3</td>
<td>0,015</td>
<td>0,05</td>
<td>0,35</td>
<td>0,2</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Grade 12</td>
<td>0,1</td>
<td>0,3</td>
<td>0,015</td>
<td>0,05</td>
<td>0,35</td>
<td>-</td>
<td>0,3</td>
<td>0,8</td>
</tr>
</tbody>
</table>

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<tbody>
<tr>
<td>Corrosion current at 2V vs. RHE (µA/cm²)</td>
</tr>
<tr>
<td>Grade 1</td>
</tr>
<tr>
<td>15,4</td>
</tr>
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</table>
SEM and EDAX analysis for Ti Gr.2

As received

Polished
Trade-off

- Basically, all titanium grades meet the corrosion resistance target!
- Material cost become major trade-off criterion
- Availability also taken into consideration
- Concerns about the possibility of nickel leaching into electrolyser water and to the environment
- Likelihood of leaching not studied
- Titanium grade 2 is chosen as the preferred material for used as bipolar plate, due to corrosion resistance and relatively low cost
- Bipolar plates without machined channels

<table>
<thead>
<tr>
<th>Approximate material cost ratio*</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM Grade</td>
</tr>
<tr>
<td>Unalloyed Ti</td>
</tr>
<tr>
<td>Ti-0,3Mo-0,8Ni</td>
</tr>
<tr>
<td>Ti-0,15Pd</td>
</tr>
<tr>
<td>Ti-0,06Pd</td>
</tr>
<tr>
<td>Ti-0,1Ru</td>
</tr>
<tr>
<td>Ti-3Al-2,5V</td>
</tr>
<tr>
<td>Ti-3Al-2,5V-0,05Pd</td>
</tr>
<tr>
<td>Ti-3Al-2,5V-0,1Ru</td>
</tr>
<tr>
<td>Ti-6Al-4V</td>
</tr>
<tr>
<td>Ti-6Al-4V-0,05Pd</td>
</tr>
<tr>
<td>Ti-6Al-4V-0,1Ru</td>
</tr>
</tbody>
</table>

*Source: R.W Schutz et al. 1996
Performance of conventional Vs. advanced design

- Laboratory test cells, both 25 cm² active area
- Sintered Ti Gr.2 discs as current collectors
- Fumatech EF-40 (230µm) MEA
- Increased electronic conduction
- Higher contact surface area

80°C, EF-40, 1 bar
Ti Sintered disc as Current Collector
Outlook

- *In-situ* tests with short stacks, 5 cells and then 10 cells
  - 150 cm² cell active area
  - 1,8 V nominal cell voltage
  - 1 A/cm² current density
  - Up to 30 bar operating pressure

- Characterisation after up to 1000 hours of operation

- Concerns about hydrogen embrittlement of titanium

- Questions about titanium self ignition

- Further investigation on other coating configurations and surface modifications
Thank you for your attention !!

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