Development of novel High Temperature and Pressure Alkaline Electrolysis Cells (HTP-AEC)

Adolphsen, Jens Quitzau; Gil, Vanesa; Sudireddy, Bhaskar Reddy; Chatzichristodoulou, Christodoulos

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Development of novel High Temperature and Pressure Alkaline Electrolysis Cells (HTP-AEC)

Jens Q Adolphsen (jenqui@dtu.dk); Vanesa Gil, Bhaskar R. Sudireddy and Christodoulos Chatzichristodoulou (ccha@dtu.dk)

Introduction

Background

- A HTP-AEC with gas diffusion electrodes (metal foams) and an aqueous KOH electrolyte immobilized in a mesoporous ceramic matrix structure has been developed at DTU Energy.

Very high current density and performance has been demonstrated with shirt button sized cells:

Record data from earlier work [1]:

\[
\text{Current Density} = 1.75 \text{ A/cm}^2, \text{ Voltage} = 1.75 \text{ V}
\]

Motivation

- High temperatures (200°C) increase the activity of the electrodes and the conductivity of the electrolyte significantly.
- A cell that allows for high efficiency and current density simultaneously using non-noble metals.

Challenges

- Corrosion issues at the oxygen electrode. Identification of more stable materials, which also show significantly higher catalytic activity towards the oxygen evolution reaction.
- Processing of cell layers with optimized microstructure using a low cost & scalable processing method.

The experiments

Electrode materials for the oxygen electrode

- Electrode materials (electrocatalysts) based on La, Ni and Fe for the oxygen evolution reaction (OER) have been identified and evaluated.
- The electrochemical activity of the materials has been tested at room temperature and pressure conditions in N₂-atmosphere using densely sintered pellets polished down to 1 µm roughness.
- The chemical stability of the powders, immersed in 45 wt% KOH, and heated in an autoclave to 220°C has been examined comparing XRD patterns before and after.

Three-electrode setup for electrochemical characterization

- Working electrode (pressed bars, Au current collector)
- Counter electrode (Pt mesh)
- Reference electrode (RHE from Gaskatel)

Results – chemical stability

LaNi₅ₓFeₓO₃ powder surface before and after ~20 h electrochemical testing.

XRD patterns of the as-received LaNiO₃ powder and the same powder after exposure to 45 wt% KOH at 220°C for 1 week. The symbols represent the following phases:

\[\text{LaNiO}_3, \text{LaO(OH)}, \text{La}_2\text{O}_3, \text{NiO(OH)}, \text{La}_2\text{NiO}_4\]

The calculated Tafel fit parameters (I = a + b log[i]) from the tafel plot together with the overpotential, \(\eta\), at 10 mA/cm². The state-of-the-art, IrOₓ, and two of the best performing non-noble oxygen evolution catalysts are also included as benchmarking.

<table>
<thead>
<tr>
<th>Material</th>
<th>b (V/decade)</th>
<th>a</th>
<th>R²</th>
<th>(\eta) (V) at 10 mA/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>PrBaCo₂O₅+x</td>
<td>-0.07</td>
<td>-</td>
<td>-</td>
<td>-0.38</td>
</tr>
<tr>
<td>LaNi₅ₓFeₓO₃ [2]</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.32</td>
</tr>
<tr>
<td>LaNi₅ₓFeₓO₃ [3]</td>
<td>-0.07</td>
<td>-</td>
<td>-</td>
<td>0.34</td>
</tr>
<tr>
<td>LaNi₅ₓFeₓO₃ [4]</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.33</td>
</tr>
<tr>
<td>LaNi₅ₓFeₓO₃ [5]</td>
<td>-0.07</td>
<td>-</td>
<td>-</td>
<td>0.30</td>
</tr>
<tr>
<td>LaNi₅ₓFeₓO₃ [6]</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.32</td>
</tr>
<tr>
<td>PrBaCo₂O₅+x [3]</td>
<td>-0.07</td>
<td>-</td>
<td>-</td>
<td>-0.38</td>
</tr>
</tbody>
</table>

Comparison of the 2nd set of chronopotentiometric tests performed at 10 mA/cm². LaNi₅ₓFeₓO₃ could not be sintered dense without decomposition so it is a multiphase of mainly LaNiO₃, NiO(OH) and La₂O₃.

The calculated Tafel fit parameters from the tafel plot together with the overpotential, \(\eta\), at 10 mA/cm². The state-of-the-art, IrOₓ, and two of the best performing non-noble oxygen evolution catalysts are also included as benchmarking.

Reference


Outlook

Processing of porous oxygen electrodes

Based on the electrochemical screening LaNi₅ₓFeₓO₃ is going to be used as oxygen evolution electrocatalyst. The microstructure of the oxygen electrode is going to be optimized using the processing method screen printing. An electrode with a bimodal porosity distribution is envisioned to allow for electrolyte infiltration (~10-100 µm pore sizes) and gas diffusion (2-10 µm pore sizes) of evolved oxygen.

Successful fabrication and electrochemical characterization of up-scaled cells (≥ 5 cm²) with the microstructurally optimized oxygen electrode is the expected outcome of the project.