Proton Ceramic Fuel Cells and Steam Electrolyzers for Hydrogen

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Contribute to the creation of a sustainable and environmentally-friendly society by conducting fundamental research for the

- Advancement of low carbon emission and cost effective energy systems and improvement of energy efficiency
- Advancement of CO₂ capture and storage technology or its conversion to a useful product

Establish an international academic environment that fosters innovation through collaboration and interdisciplinary research (fusion)
We are looking in what would have to happen to achieve 80% reduction of CO$_2$. 

A Carbon Neutral Energy Vision for Japan
Proton conducting oxide

- Ceramic material
- Positively charged hydrogen (i.e. proton, $\text{H}^+$) is contained.
- $\text{H}^+$ is mobile at intermediate temp.

- Useful for energy conversion and related applications.
  - Fuel cells (SOFC)
  - Steam electrolysis (SOEC)
  - Hydrogen sensing
  - Hydrogen separation
Target values of SOEC

- Operating temp.: 600°C
- Energy efficiency: >90% (LHV) = electrolysis voltage ~ 1.4 V
- Current density: 0.5 A/cm²
- Electrolyte Conductivity > 10⁻² S/cm
  Stability in steam
- Electrode
  \( \eta_{\text{Anode}} + \eta_{\text{Cathode}} < 0.3 \) V
**Choice of electrolyte**

**Cerates: A CeO₃ (A=Ba, Sr)**
- High conductivity
- Low stability

**Zirconates: A ZrO₃ (A=Ba, Sr)**
- Lower conductivity
- High stability

Solid solution will be an answer for acceptable conductivity and stability.

**Electrical conductivity of Proton conductors**
Electrolyte: SZCY system

Conductivity isotherm in wet hydrogen*

XRD after CO\textsubscript{2} treatment at 600°C*. Upper: x=0, lower: x=0.4.
Thin film electrolyte cell

NiO/SZY541 cermet → Slurry coating of SZY541 → Post annealing in hydrogen

Screen printed

Backed
Electrolysis cell

Glass packing

Anode gas
1%O₂-Ar gas humidified at 81°C (50%H₂O)

Cathode gas
1%H₂-Ar gas humidified at 17°C

- Gas flow:
- Anode gas
- Cathode gas

- Electrode performance:
  - Current interruption method
  - H₂ evolution rate:
  - Gas chromatography

Pt wire × 2

ProboStat™
SOEC using SZCY541

Cathode: Ni/SZCY
Anode: (Sm,Sr)CoO$_3$
Temp. 600°C

Translation to
100%H$_2$ production:
1.4 V at 0.1 A/cm$^2$
Hydrogen production rate: Problem!

Problem:
- Part of the current flows electronically at high current density.

![Graph showing hydrogen production rate vs. current density](attachment:graph.png)

At 600°C, the hydrogen production rate increases with increasing current density. The graph shows a positive correlation between current density and hydrogen production rate for the material SZCY541+SSC55.
Reason for the low Faradaic efficiency

\[ \text{Anode: } V_{o} + \frac{1}{2}O_2 \xrightleftharpoons[K_f^1]{K_f^2} O_{o}^x + 2h^* \]  

\[ \text{H}_2\text{O} + 2h^* \xrightleftharpoons[K_f^2]{K_f^3} 2H^* + \frac{1}{2}O_2 \]  

\[ \text{H}_2\text{O} + V_{o}^x \xrightleftharpoons[K_f^3]{K_f^4} 2H^* + O_{o}^x \]  

\[ \text{H}_2 + 2h^* \xrightleftharpoons[K_f^4]{K_f^5} 2H^* \]  

\[ K_3 = K_1K_2, \quad K_4 = K_2K_w \]  

Electron hole in oxidative atmosphere

Insufficient anode performance will be the reason?
Surface proton conducting nanoparticles

Sulfated hydrous titania
Bar size: 4.5 mm X 4.2 mm X 14.3 mm
Tester result: 7570 Ω
Water-absorbing porous electrolyte cell

Conventional polyelectrolyte cell

Water-absorbing porous electrolyte water electrolysis

- Water transport: through electrolyte to electrode reaction part
- Gas diffusion layer: fully hydrophobic to provide smooth gas transport
- Possibility for reduction an electrode overpotential
Gas evolution during water electrolysis

Cell housing
- Collection of generated gases (H₂ / O₂)
- Gas evolution rate was compared with theoretical one by calculated Faraday’s law

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- Collection of generated gases (H₂ / O₂)
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Summary of this talk

Intermediate temperature proton-conducting oxide

Proton conducting acid modified nanoxides

Anode
\[ \text{H}_2\text{O} \xrightarrow{H^+} \text{H}_2 \]
\[ \text{O}_2 \xrightarrow{e^-} \]

Cathode

1%O\textsubscript{2}-Ar, anode | electrolyte | cathode, 1%H\textsubscript{2}-Ar

600\degree C

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<th>Voltage / V</th>
<th>Current density / mA cm\textsuperscript{-2}</th>
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1.2V@0.1A/cm\textsuperscript{2}

Room temp.