Fabrication and Characterization of Metal-supported Solid Oxide Electrolysis Cells

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Content

Introduction

Materials & Processing of the metal supported solid oxide cells

Characterization and electrochemical investigation

Conclusion
Advantages of High Temperature Electrolysis

(1) High conversion efficiency
(2) Integration of the heat for conversion
(3) Simultaneous reduction of $H_2O/CO_2$ in co-electrolysis mode

Challenges of High Temperature Electrolysis with SOEC

(1) Developments of specific architectures and materials for steam and $H_2O+CO_2$ co-electrolysis
(2) Improvement of performance and durability
(3) Integration of the heat and pressurized operation
Advantages of Metal Supported Cells

Metal supported Cell (MSC):
• High robustness
• High resistance against thermal and redox cycling
• Good integration into interconnects (bipolar plates) via brazing or welding
• Low cost of metal support and cell materials (thin layers)
• High electronic and thermal conductivity
• Fast start-up, etc.

➢ To replace expensive ceramics by metals
➢ Reversible operation
Objectives

Development of metal supported SOCs for HTE application

Optimization of electrodes and functional layers for SOEC operation

Improvement power density and durability of the cells

Characterization and testing of metal supported SOECs
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Material Selection

- Improving mechanical stability and reduce materials costs
  - Commercial porous substrates made of ferritic steel
- Enhancing redox stability at the anode
  - Perovskite based anode materials (LST)
- Ensuring the electrolyte with good gas tightness and electrical property
  - Multi-layered thin film
- Avoiding High T sintering and reducing atmosphere
  - low T (max. 1000 °C) processing in air
Processing Route

- Low T processing route (< 1000°C)
- Manufacturing process in air
- Air electrode in-situ sintered during operation

Pretreatment of metal substrates

Substrate

Fuel Electrode Screen printing

Electrolyte deposition

Dip-coating + PVD (T<1000°C)

Firing air 1000°C

Infiltration of catalytic Nickel (5-10 wt%)
Firing air

Air Electrode Screen printing

Electrochemical Testing

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Architecture of the Metal Supported SOC

Porous metal substrate

Cathode: \( \text{La}_{0.58}\text{Sr}_{0.4}\text{Co}_{0.2}\text{Fe}_{0.8}\text{O}_{3-\delta} \) (LSCF)

GDC layer: \( \text{Ce}_{0.8}\text{Gd}_{0.2}\text{O}_{2-\delta} \) (CGO)

3x YSZ layers

Anode: \( \text{La}_{0.1}\text{Sr}_{0.9}\text{TiO}_{2-\delta} \) (LST) - GDC composite with Ni catalysts

Single cell 100mmx90mm
Porous Substrate & Dense Thin-film Electrolyte

- a. Porous Metal
- b. Anode: LST+GDC
- c. YSZ
- d. GDC

- a. Porous Metal
- b. Anode: LST+GDC+Ni
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Electrochemical Performance / SOFC

T = 750°C, 96% H₂ + 4% H₂O (H₂ electrode), air (O₂ electrode), flow rate of 2.0 slpm on both sides

- OCV\text{ASC} = 1074 mV while OCV\text{MSC} = 953 mV (defects and sealing issues)
- no activation part observed in the i-V curve of the MSC ⇒ the MSC works directly at a minimum resistance in FC mode
- no mass transport limitation observed in the i-V curve of the MSC

![Graph showing i-V curve with MSC and ASC compared.]

MSC

ASC

0.448 W/cm²

1.085 W/cm²

0.7 V
Electrochemical Performance / SOFC

T = 750°C, 96% H₂ + 4% H₂O (H₂ electrode), air (O₂ electrode), flow rate of 2.0 slpm on both sides, EIS spectra recorded at 0 A/cm², 0.0625 A/cm², 0.375 A/cm² and 0.625 A/cm².

- **Rₚ decreases** from 294 to 128 mΩ.cm² ➔ All main electrochemical processes are being activated with the current increase

- **Rₚ remains constant** (165 to 176 mΩ.cm²) ➔ consistent with i-V characteristics
Electrochemical Performance / SOEC

T = 750°C, 80% H₂O + 20% H₂ (H₂ electrode), air (O₂ electrode), flow rate of 2.0 slpm on both sides.

- OCVASC = 890 mV while OCVMSC = 840 mV

- 0.75 A / cm²

!!! Pinhole defects !!!

1.151 V / -863 mW/cm²
1.086 V / -815 mW/cm²

Contrary to FC mode, the i-V curve of the MSC shows an activation part at lower currents.
Electrochemical Performance / SOEC

EIS in Electrolysis operation at 0 A/cm², -0.0625 A/cm², -0.375 A/cm² and -0.625 A/cm². T = 750° C, 80% H₂O + 20% H₂ (H₂ electrode), air (O₂ electrode), flow rate of 2.0 slpm on both sides.

- **Rp INCREASES with current increase in Electrolysis mode**
  - mainly the high frequency impedance involved, the ASC needs to be activated in Electrolysis mode before optimum performances can be achieved

- **Rp DECREASES with the current increase in Electrolysis mode** from ~225 to ~145 mΩ.cm²
  - decrease of the all impedance diagram, the main electrochemical processes are activated with current
Cross section SEM of Cells Tested for over 2500h

- Anode supported cell
- Metal supported cell, no Ni infiltration / no current load
- No Ni depletion / significant Ni coarsening in AFL
- Electrolyte with good mechanical stability
- Pores are rarely found in the thin-film electrolyte layer after SOEC operation
- Delamination of LSCF Air electrode
Defects in thin-film electrolyte

Cr depletion region
Chromia scale and nickel particle in MSC

Internal interface: thin chromia scale and fine nickel particles

High H$_2$/CO content

External Interface: thick chromia scale and coarsened nickel particles

High H$_2$O/CO$_2$ content
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Metal supported cells (ferritic steel) with LST based anode materials delivered fair performance despite low nickel content (< 10 wt%)

At 750°C in SOFC mode:
OCV of 953 mV, power density of 448 mW/cm² @640mA/cm² & 0.7 V

At 750°C in SOEC mode:
OCV of 840 mV, power density of -863 mW/cm² @-0.75 A/cm² & -1.15V

Low OCV related to defects in thin-film electrolyte and sealing issues

Degradation and delamination issue at the air electrode

Results on cycling and co-electrolysis are still under investigation
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Thanks for your attention!

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