Project DE-FE 0031940

Efficient, Reliable, and Cost-Effective Reversible Solid Oxide Cell Technology for Hydrogen and Electricity Production

and

Project DE-FE 0032107

Development of Novel 3D Cell Structure and Manufacturing Processes for Efficient, Durable and Redox Resistant Solid Oxide Electrolysis Cells

22nd Annual Solid Oxide Fuel Cell (SOFC) Project Review Meeting
November 16-18, 2021

DE-FE0031940

Project Overview

- Project: Efficient, Reliable, and Cost-Effective Reversible Solid Oxide Cell Technology for Hydrogen and Electricity Production (DE-FE0031940)

- Project Objective: Develop and demonstrate proposed reversible solid oxide cell (RSOC) technology with the three main specific objectives
  - (i) To validate design, materials and process of proposed technology for both hydrogen and electricity production
  - (ii) To demonstrate operation of the proposed technology at relevant conditions with improved performance, reliability and endurance
  - (iii) To confirm the cost effectiveness of the proposed technology via a techno-economic assessment of a selected application

- Period of Performance: 9/27/2020 – 9/26/2023

- DOE/NETL Project Manager: Ms. Sarah Michalik

- Project Team:
  - ❑ University of California San Diego (UCSD)
    - Dr. Nguyen Minh (PI), Dr. Eric Fullerton, Dr. Shirley Meng, Dr. Ping Liu
  - ❑ OxEon Energy, LLC (OxEon)
    - Dr. Elango Elangovan, Mr. Joe Hartvigsen

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RSOC Technology

- RSOC technology to be developed in this project has two key elements
  - A compact, versatile and low-cost stack architecture: arrays of cell modules in electrical parallel and series connection
  - Superior-performance, fuel-flexible reversible cells

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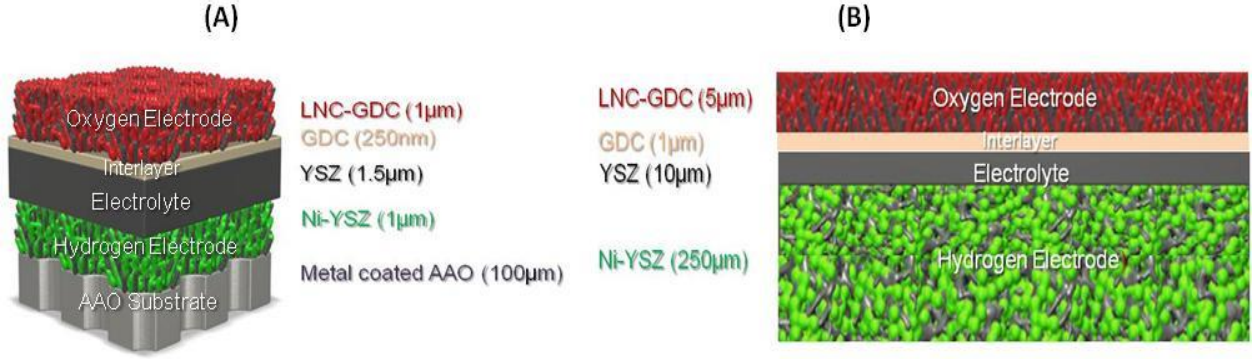
Cell Configurations

- Cell Structure: (A) Substrate supported thin-film (TF) reversible solid oxide cell (RSOC) (500˚-700˚C) and (B) Hydrogen electrode (HE) supported RSOC (700˚-800˚C)



- Cell and substrate materials:
  - Electrolyte : yttria stabilized zirconia (YSZ)
  - Hydrogen electrode: Ni-YSZ
  - Oxygen electrode: lanthanum nickel cobaltite (LNC)-gadolinium doped ceria (GDC)
  - Electrolyte/electrode interlayer: GDC
  - Substrate for TF-RSOCs: Metal-coated anodized aluminum oxide (AAO)

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Cell Designs - Motivation

- Leverage on previous work on cells fabricated by sputtering
  - ***Record performance for sputtered cells in fuel cell mode at reduced temperatures*** (e.g., >3.0W/cm^2 at 650°C with hydrogen fuel)
- Proposed two types of cell configuration
  - Demonstrate the capability of the proposed stack design to ***incorporate different types of cell operating at different temperatures***
  - Use the more advanced ***HE-supported cell as a backup with regards to risk mitigation***
  - Leverage and apply the development of ***sputtered oxygen electrodes for TF cells to HE-supported cells to improve performance*** as compared with state-of-the-art
- Proposed LNC-GDC oxygen electrode
  - Suitable for ***operation in both fuel cell (SOFC) and electrolysis (SOEC) modes***
  - LNC ($La_{0.97}Ni_{0.5}Co_{0.5}O_{3-\delta}$) contains ***no strontium***, thus ***unwanted Sr segregation and interactions with volatile Cr species to form strontium chromium oxides are avoided***

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Project Activities

- Application Selection and System Design and Analysis
- Techno-Economic Assessment
- RSOC Cell Development
- RSOC Stack development
- Stack Operation Demonstration

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PROGRESS/ACCOMPLISHMENTS

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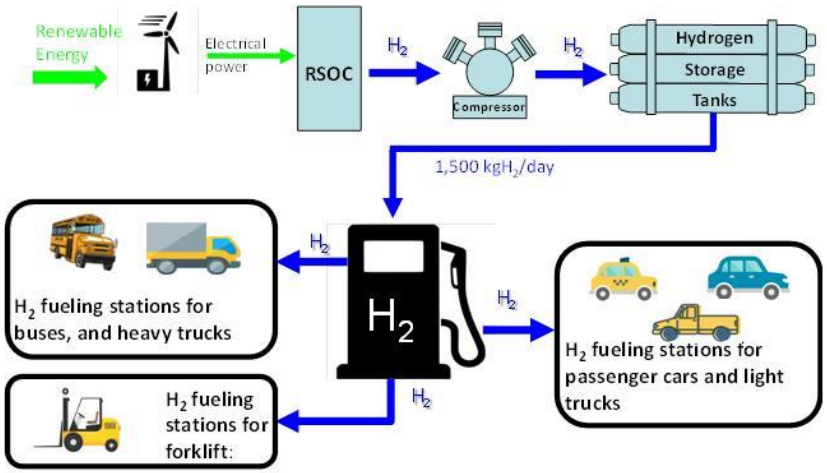
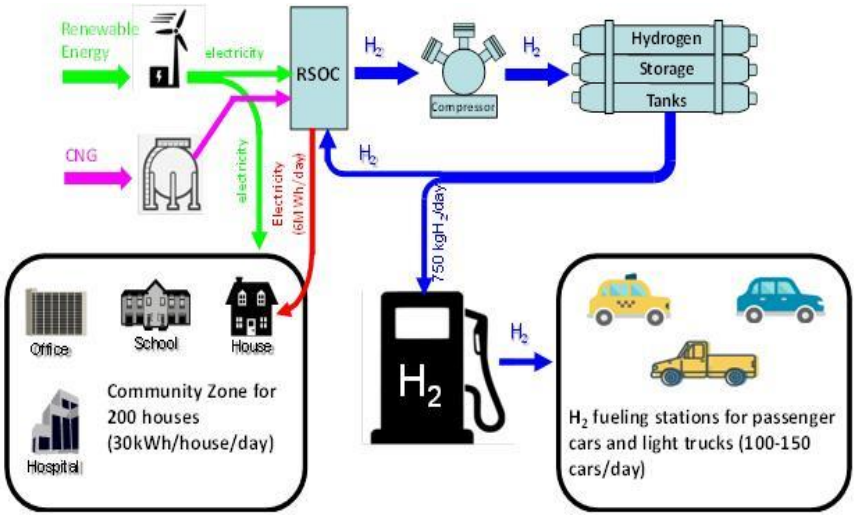
Application Selection

- Reversible solid oxide cell (RSOC) systems selected
  - Small-scale distributed RSOC systems
  - Hydrogen production: 1,500 kg H_2/day
  - Power generation: 480 kW (on natural gas)
- Applications selected
  - On-site hydrogen fueling stations
    - for passenger car, and light trucks
    - for school buses, passenger buses, and heavy trucks
    - for forklifts
  - Distributed hydrogen/power systems
    - Hydrogen/power systems for low population areas/small towns/offices/buildings
    - Hydrogen/power systems for remote areas



On-site hydrogen fueling station



Distributed hydrogen/power system

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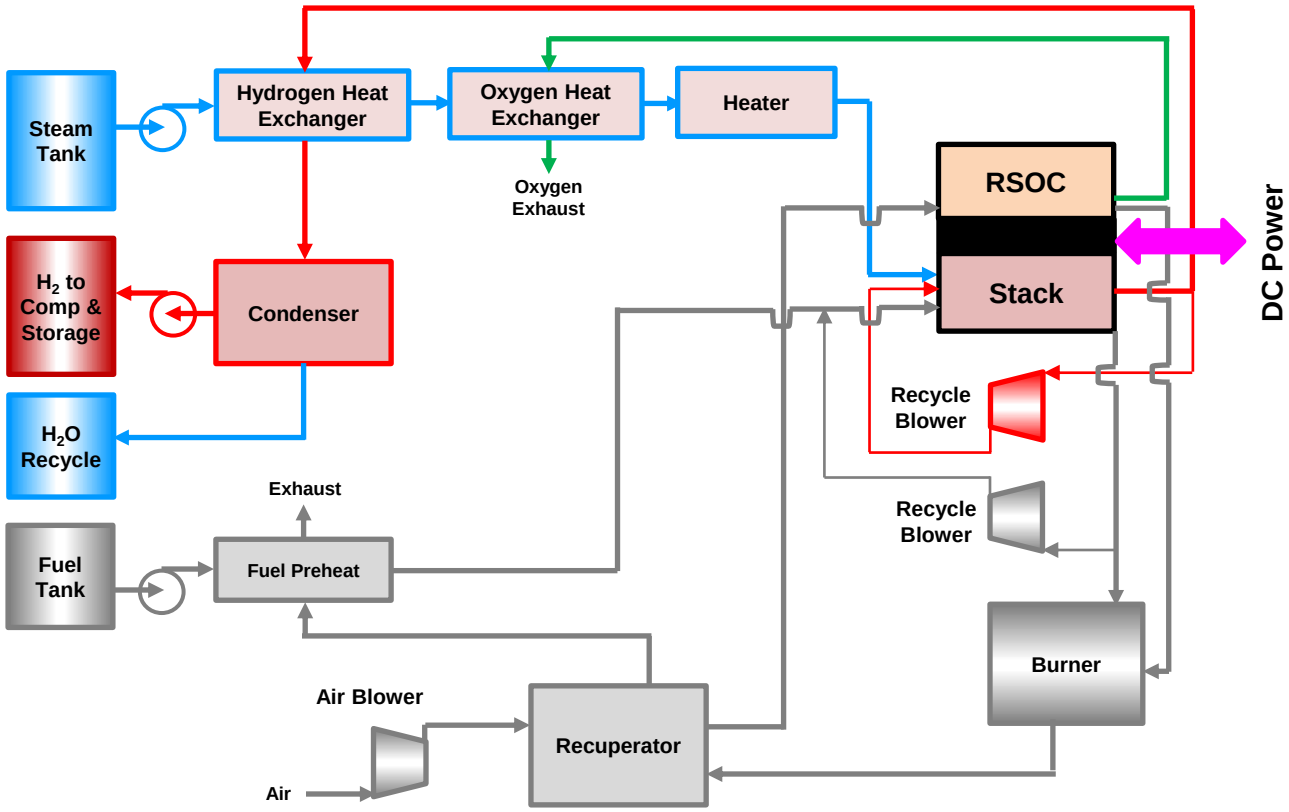
RSOC System Schematic



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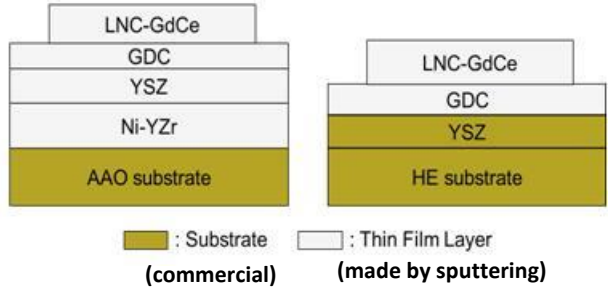
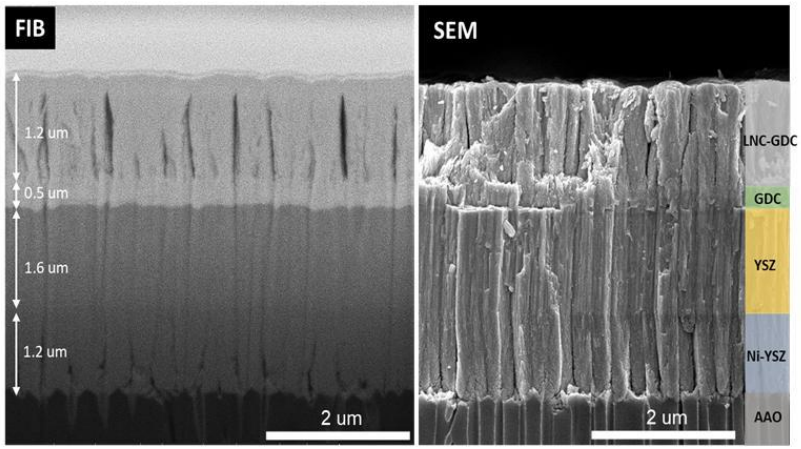
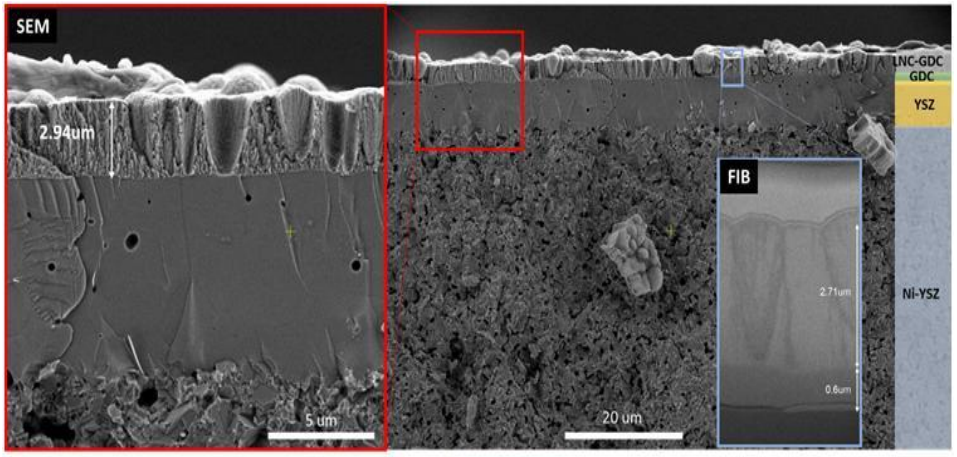
Cell Fabrication







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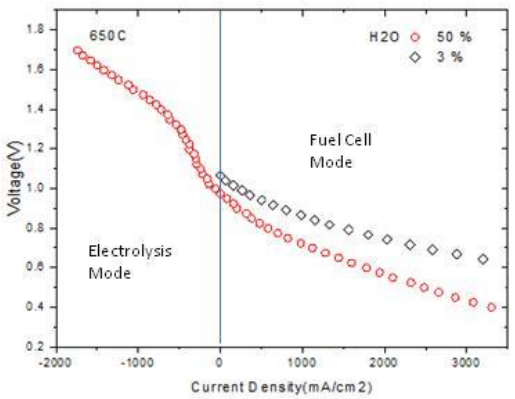
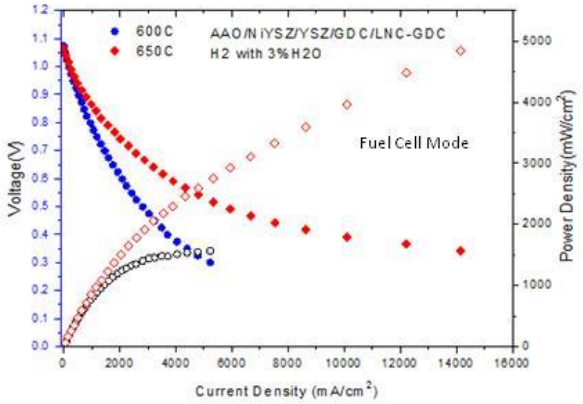
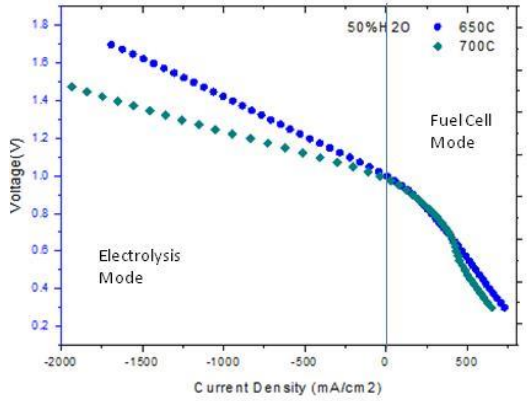
Cell Reversible Performance

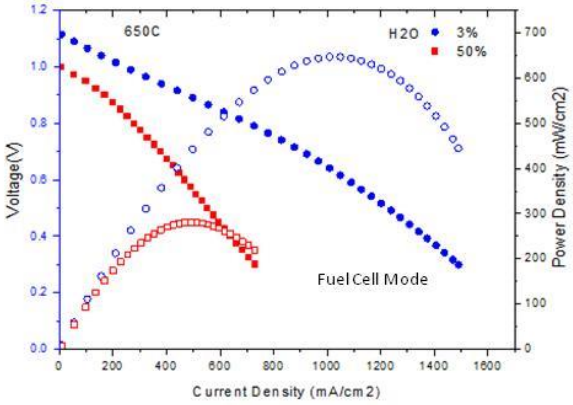
TF-RSOC Cell





HE-Supported RSOC Cell





Superior reversible performance for both thin film (TF) cell and hydrogen electrode (HE)-supported cell at reduced temperatures (≤ 700°C)

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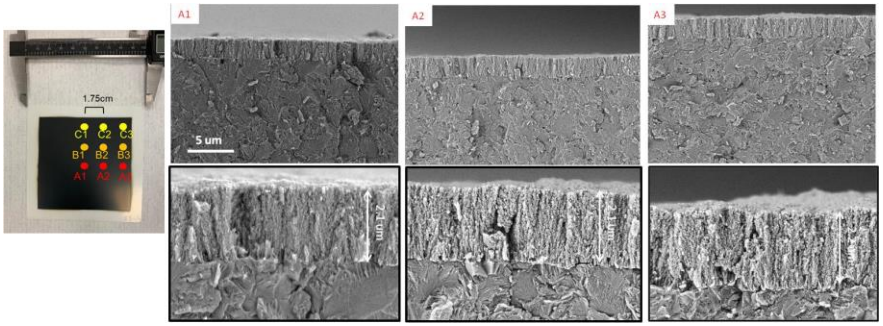
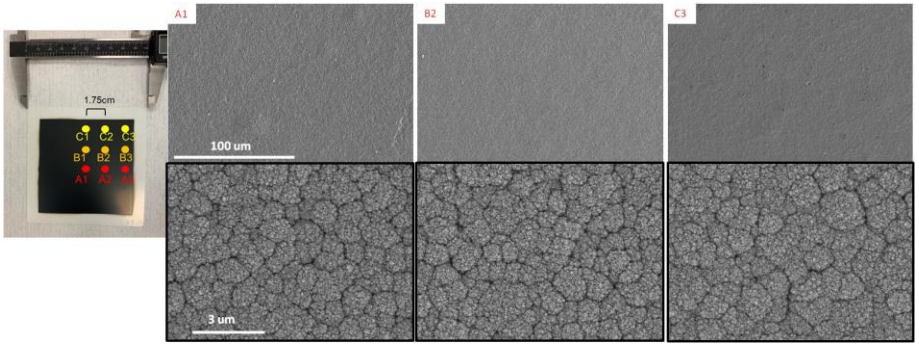
Scale-Up of Sputtering Process

Demonstration of cell fabrication on 10cm×10cm substrate

10cm×10cm cell



LNC-GDC oxygen electrode
(cross section)



LNC-GDC oxygen electrode
(as-deposit surface)

Demonstration of sputtering process scale-up

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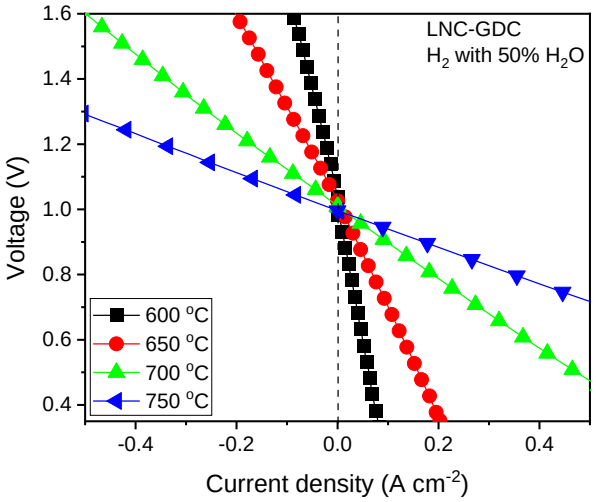
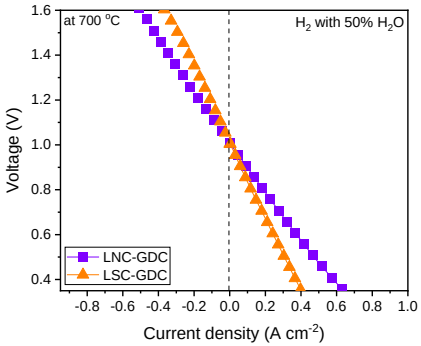
Evaluation of LNC-GDC Oxygen Electrode

Performance of RSOC cell*
with sputtered LNC-GDC oxygen electrode



Performance comparison
of RSOC cells* with
sputtered LNC-GDC and
sputtered LSC-GDC
oxygen electrodes

Voltage/current curves



Electrode area-specific resistance (ASR)

Temperature (°C)	LNC-GDC	LSC-GDC
	ASR (ohm cm^2)	ASR (ohm cm^2)
600	0.165	0.467
650	0.082	0.259
700	0.076	0.221

LNC-GDC oxygen electrode outperforms state-of-the-art LSC-GDC in both SOFC/SOEC modes at reduced temperatures

*Cells with YSZ electrolyte support , Ni-YSZ hydrogen electrode and GDC oxygen electrode/electrolyte interlayer

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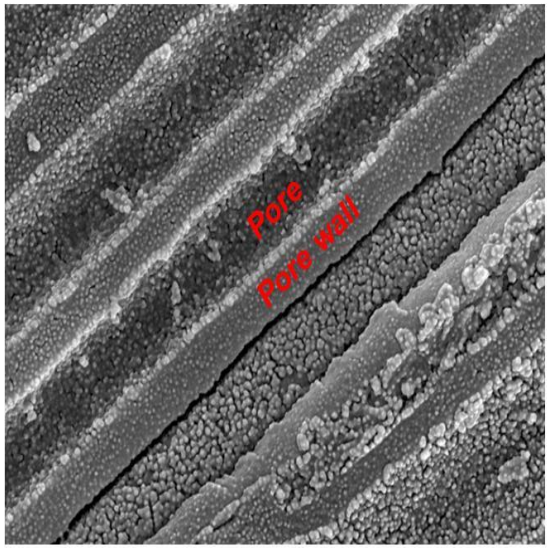
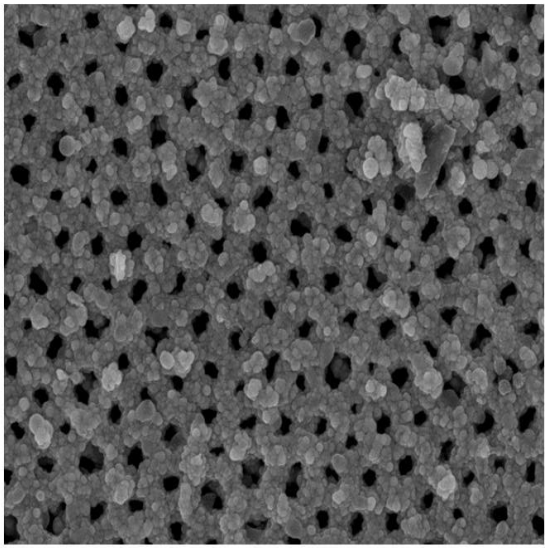
Nano-metal Coating of Anodized Aluminum Oxide (AAO) Substrate

Develop a nickel plating process for porous AAO substrates



Nickel-plated AAO, cross-section, pore middle
(pore size about 200 nm)



Nickel-plated AAO, top surface

Demonstration of nickel coating of AAO nano-porous structures

DE-FE0032107

Project Overview

- Project: Development of 3D Cell Structure and Manufacturing Processes for Highly Efficient, Durable and Redox Resistant Solid Oxide Electrolysis Cells (DE-FE0032107)

- Project Objective: Develop and demonstrate highly efficient, durable and redox resistant solid oxide electrolysis cells (SOECs) with a focus on
  (i) A cell design with the hydrogen electrode composed of two layers – a 3D hydrogen electrode support layer and an exsolved perovskite hydrogen electrode active layer
  (ii) A manufacturing scheme incorporating advanced inkjet printing and photonic sintering for fabrication of the cell configuration

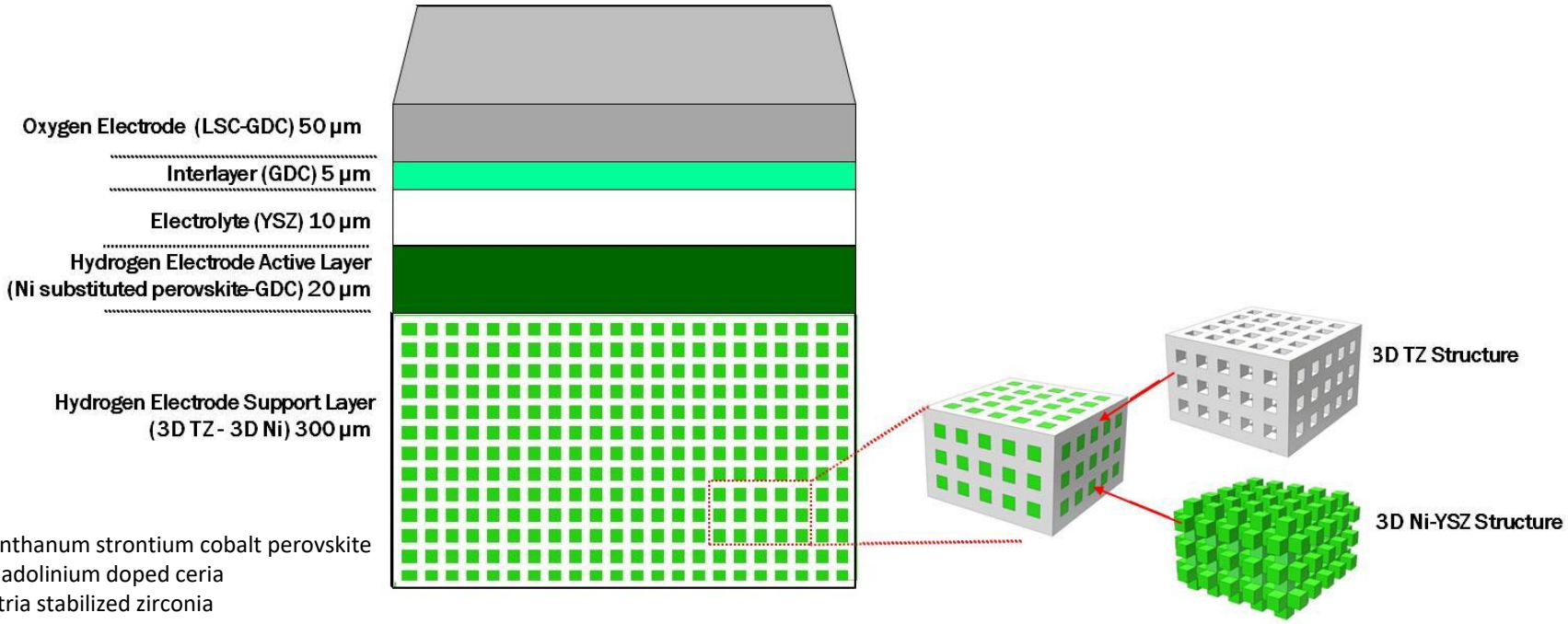
- Period of Performance: 10/01/2021 – 9/30/2023

- DOE/NETL Project Manager: Ms. Sarah Michalik

- Project Team:
  - ❑ University of California San Diego (UCSD)
    - Dr. Nguyen Minh (PI)
  - ❑ RocCera LLC (RocCera)
    - Dr. Sam Ghosh, Mr. Arkady Malakhov
  - ❑ Rochester Institute of Technology (RIT)
    - Dr. Denis Cormier
  - ❑ Oak Ridge National Laboratory (ORNL)
    - Dr. Edgar Lara-Curzio

Cell Design

- Design features:
  - Hydrogen electrode supported configuration
  - Unique hydrogen electrode concept – a support layer with 3D structural geometry coupled with an exsolved perovskite active layer
- Motivation:
  - 3D hydrogen electrode support for redox resistance
  - Exsolved perovskite hydrogen electrode active layer (high performance, improved stability, redox resistance)



LSC: Lanthanum strontium cobalt perovskite
GDC: Gadolinium doped ceria
YSZ: Yttria stabilized zirconia
TZ: Tetragonal zirconia

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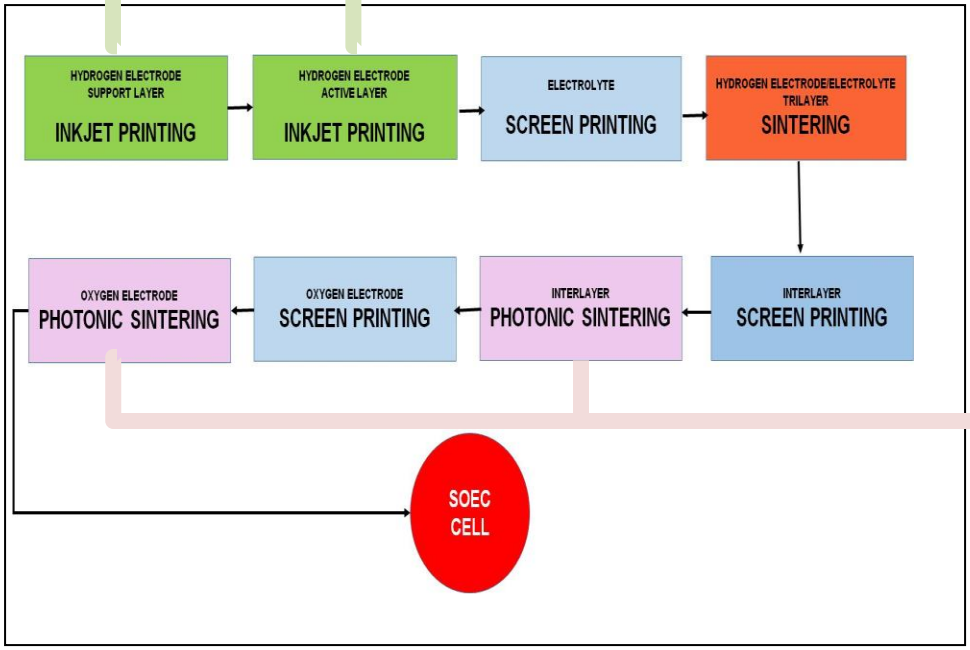
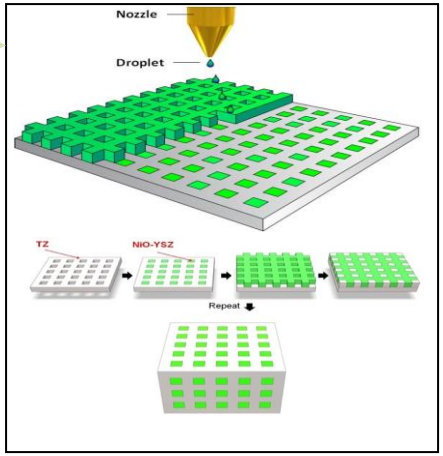
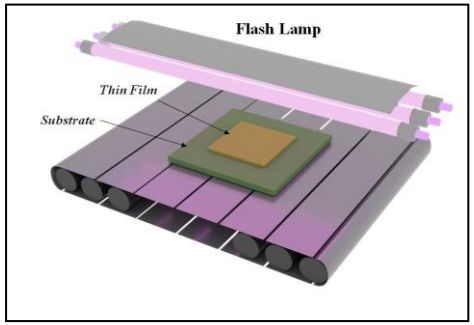
Fabrication Process

- Similar to but different from the conventional process in two areas:
  - Ink jet printing (instead of tape casting) for the 3D hydrogen electrode support
  - Photonic sintering (instead of conventional firing) for the interlayer and oxygen electrode







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Project Activities

- Fabrication Development of 3D Hydrogen Electrode Support, Hydrogen Electrode Active Layer and Electrolyte by Cofiring
- Fabrication Development of Interlayer and Oxygen Electrode by Photonic Sintering
- Characterization and Evaluation of Electrodes and Cells
- Demonstration of Cell Performance, Redox Resistance and Durability

DE-FE32107

PROGRESS/ACCOMPLISHMENTS

DE-FE0032107

Progress

- Project start date of October 1st 2021
- Work plan developed and technical activities initiated

Acknowledgments

- DOE/NETL SOFC project management, especially Ms. Sarah Michalik
- UCSD SOFC/SOEC project team
- OxEon, RIT, RocCera and ORNL team members