Overview

- **Problems and Opportunities in SOEC Hydrogen Electrode Development**
  - **Problems**
    - Redox instability of Ni-YSZ
    - Nickel particle agglomeration/depletion
  - **Opportunities**
    - Redox-resistant hydrogen electrode support layer
    - High-performance and durable hydrogen electrode active layer

- **Develop and demonstrate highly efficient, durable, and redox-resistant SOECs with a focus on:**
  - **Cell Design**
    - Two layers of hydrogen electrode - a 3D hydrogen electrode support layer and an exsolved perovskite hydrogen electrode active layer
  - **Cell Manufacture**
    - Incorporating advanced inkjet printing and photonic sintering for the fabrication of the cell configuration

![Fig. 1 Proposed Cell Design](image1)

- **3D Hydrogen Electrode Support by additive manufacturing**
  - **3D Hydrogen Electrode Support Layer**
    - **Motivation**
      - 3D hydrogen electrode support for redox resistance
    - **Feature**
      - 3D networks of tetragonal zirconia (TZ) and Ni with controlled geometry and connectivity
    - **Printing**
      - Printing by ejection of drops of ceramic powder suspended in a liquid slurry
  - **Ink formulation, printing, and firing**
    - **Ink formulation**
      - Optimize We and Re for inkjet printability
    - **Structured Dual Ceramic Inkjet Printing**
      - Profilometry of printed structures to show height
      - Optimization of firing conditions

![Fig. 2 Reduction of Air-Sintered Hydrogen Electrode Support](image2)

- **3D Hydrogen Electrode Support by additive manufacturing**
  - **Exsolved Perovskite Hydrogen Electrode Active Layer**
    - **Ni-substituted perovskite and GDC**
      - When exposed to a reducing environment, Ni in the perovskite will exsolve to form fine particles embedded in the oxide skeleton.
      - High performance, enhanced stability, and redox resistance

![Fig. 3 Photonic Sintering](image3)

- **3D Hydrogen Electrode Support by additive manufacturing**
  - **3D Hydrogen Electrode Support by additive manufacturing**
    - **Inkjet Printing Process for Fabricating 3D Hydrogen Electrode Support Layer and Reduction of Air-Sintered Hydrogen Electrode Support**

![Fig. 4 Inkjet Printing Process for Fabricating 3D Hydrogen Electrode Support Layer and Reduction of Air-Sintered Hydrogen Electrode Support](image4)

- **3D Hydrogen Electrode Support by additive manufacturing**
  - **Optimization of firing conditions**
    - **Reynolds number vs. Weber number**
      - Where:
        - Re = Reynolds number
        - We = Weber number
        - μ = Viscosity (Pa·s)
        - ρ = Density (g/ml)
        - ν = Viscosity (cP)
        - d = Nozzle diameter (μm)

![Fig. 5 Weight of the binders by temperature](image5)

- **3D Hydrogen Electrode Support by additive manufacturing**
  - **Ink formulation, printing, and firing**
    - **Metal ion salts**
      - Sol synthesis
    - **Wet mixing**
      - 800°C 2nd Calcination
      - 1150°C 2nd Calcination

![Fig. 6 Reynolds number vs. Weber number of the selected inks](image6)

- **3D Hydrogen Electrode Support by additive manufacturing**
  - **Structured Dual Ceramic Inkjet Printing**
    - Profilometry of printed structures to show height
    - Optimization of firing conditions

![Fig. 7 3D-Printing strategy for the checkerboard pattern, and image and surface profilometry of the 3D-printed layer](image7)

- **3D Hydrogen Electrode Support by additive manufacturing**
  - **Embedded Structure Formed from Exsolution of Nickel Particle**
    - **Fig. 9 Embedded Structure Formed From Exsolution of Nickel Particle**

![Fig. 8 Pictures and surface profilometry of the 3D-printed Ni-YSZ support layers before and after firing](image8)

- **3D Hydrogen Electrode Support by additive manufacturing**
  - **Problems**
    - Heating of thin layers of material by <1 ms flashes of broad-spectrum light
    - 30 kJ/cm² energy
    - Projected reduction of sintering cycle from hours/days to seconds/minutes
    - Projected reduction in sintering process energy consumption by >90%

![Fig. 10 Synthesis Process](image10)

- **3D Hydrogen Electrode Support by additive manufacturing**
  - **Development**
    - High performance, enhanced stability, and redox resistance

![Fig. 11 XRD Patterns of Reduced LSCFN at different temperature with 50% H₂-50% H₂O](image11)

- **3D Hydrogen Electrode Support by additive manufacturing**
  - **Fig. 12 XRD Patterns of As-synthesized, Reduced, and Reoxidized LSCFN**

![Fig. 13 FESEM Images of Reduced and Reoxidized LSCFN](image12)