U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

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

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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

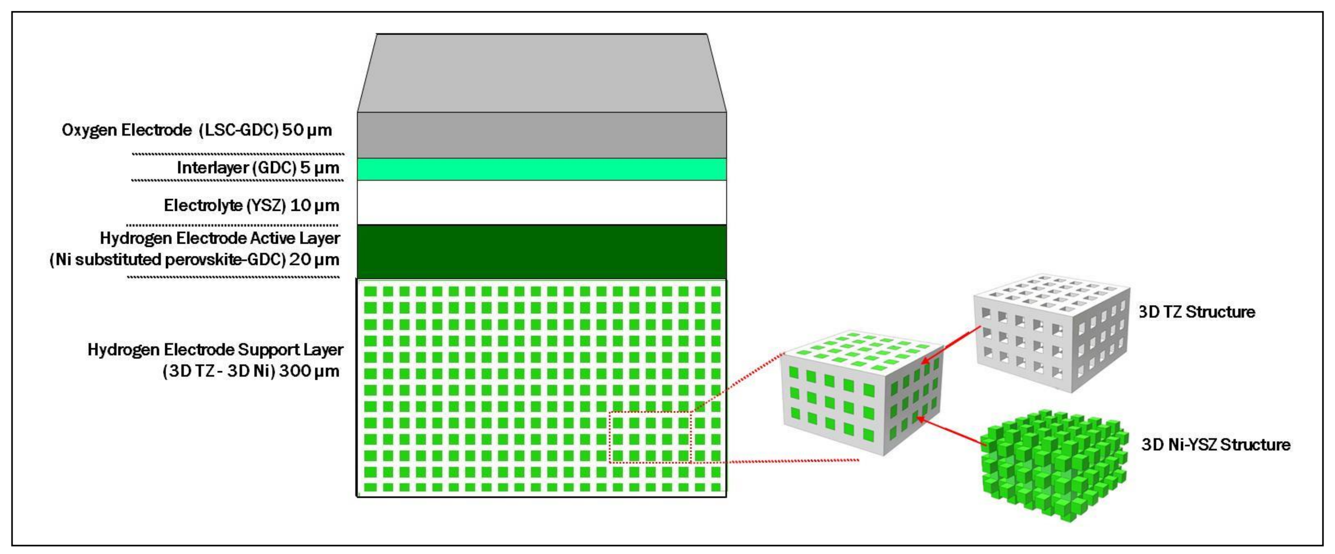

Fig. 1 Proposed Cell Design

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

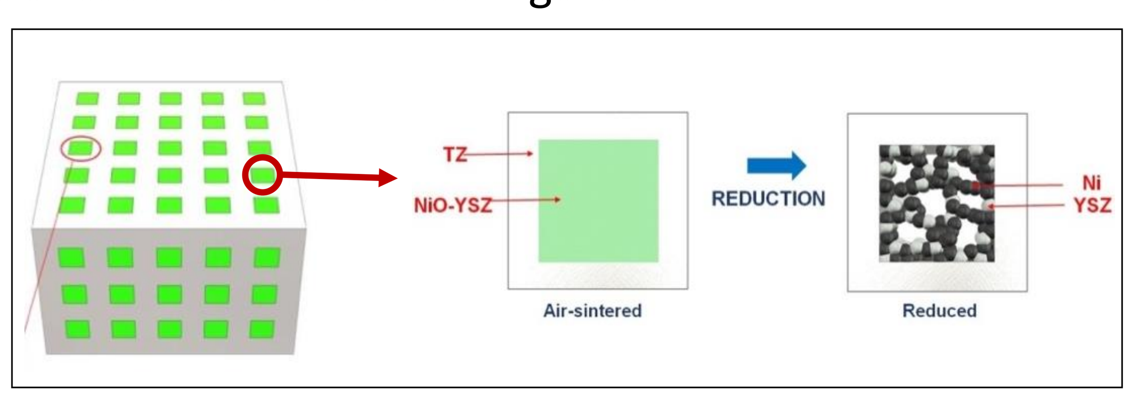

Fig. 2 Reduction of Air-Sintered Hydrogen Electrode Support

✓ Photonic sintering
- Heating of thin layers of material by <1 ms flashes of broad-spectrum light
- 30 kJ/cm^2 energy
- Projected reduction of sintering cycle from hours/days to seconds/minutes
- Projected reduction in sintering process energy consumption by >90%

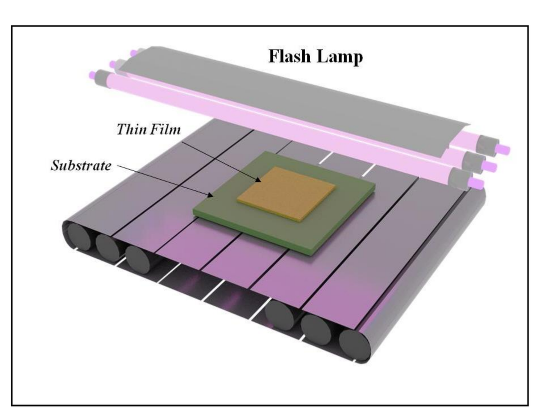

Fig. 3 Photonic Sintering

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 by ejection of drops of ceramic powder suspended in a liquid slurry

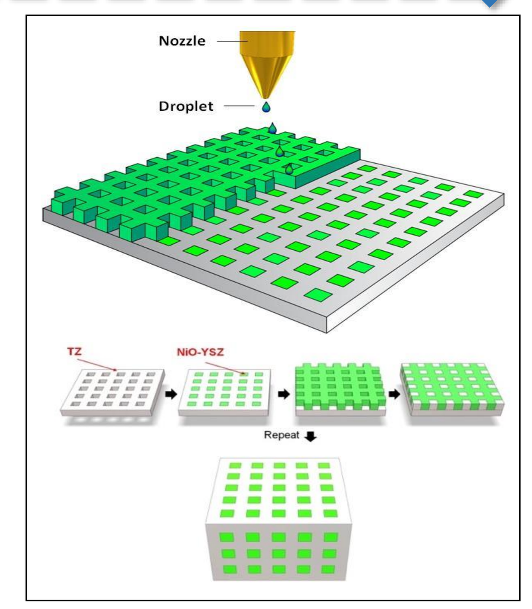

Fig. 4 Inkjet Printing Process for Fabricating 3D Hydrogen Electrode Support Layer and Reduction of Air-Sintered Hydrogen Electrode Support

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

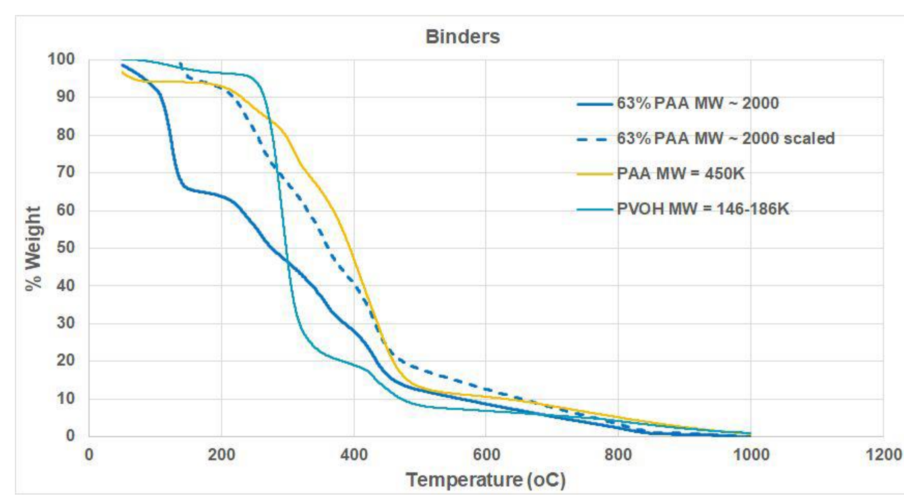

Fig. 5 Weight of the binders by temperature

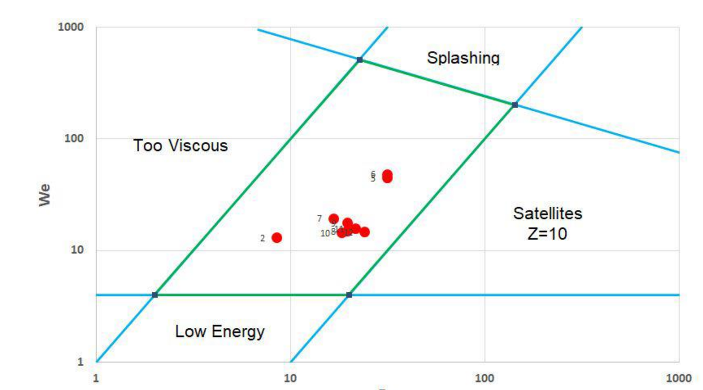

Fig. 6 Reynolds number vs. Weber number of the selected inks

$$Re = \frac{v\rho r}{\eta} \quad We = \frac{v^2 \rho r}{\gamma} \quad Z = \frac{(\gamma \rho r)^{1/2}}{\eta} = \frac{1}{Oh} = \frac{Re}{We^{1/2}}$$

Where:

Re	Reynolds number	η	Viscosity (cP)
We	Weber number	ρ	Density (g/ml)
Oh	Ohnesorge number	v	Velocity (m/s)
γ	Surface tension (mN/m)	r	Nozzle diameter (μm)

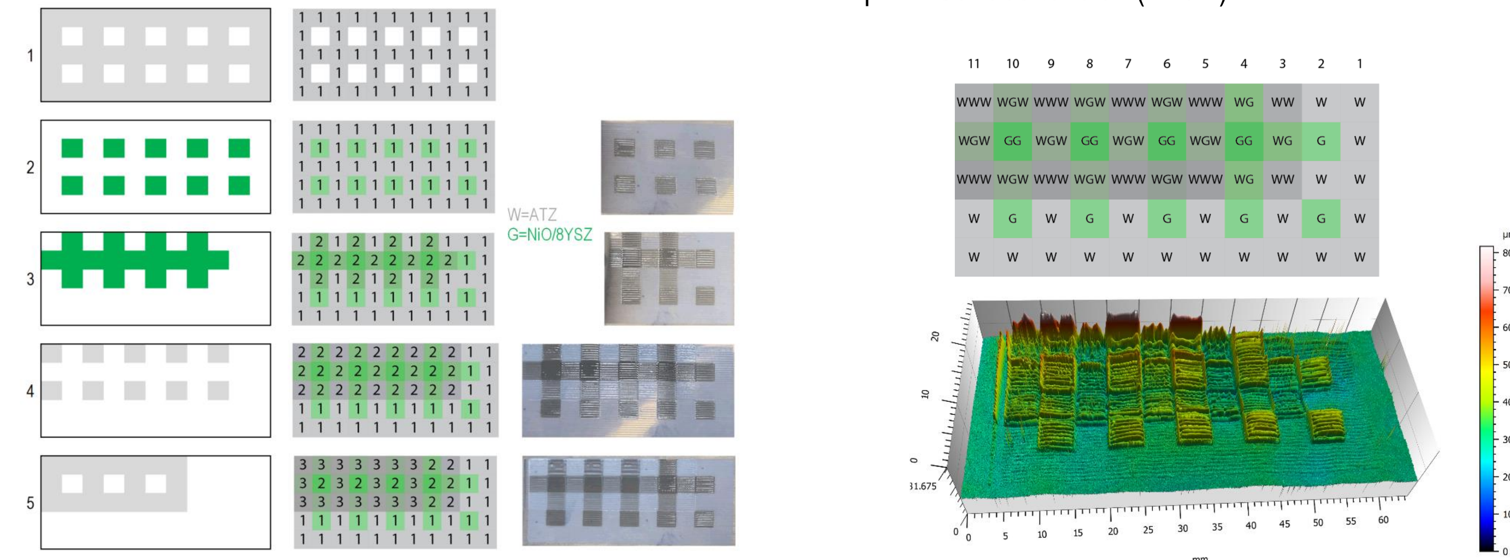

Fig. 7 3D-Printing strategy for the checkerboard pattern, and image and surface profilometry of the 3D-printed layer

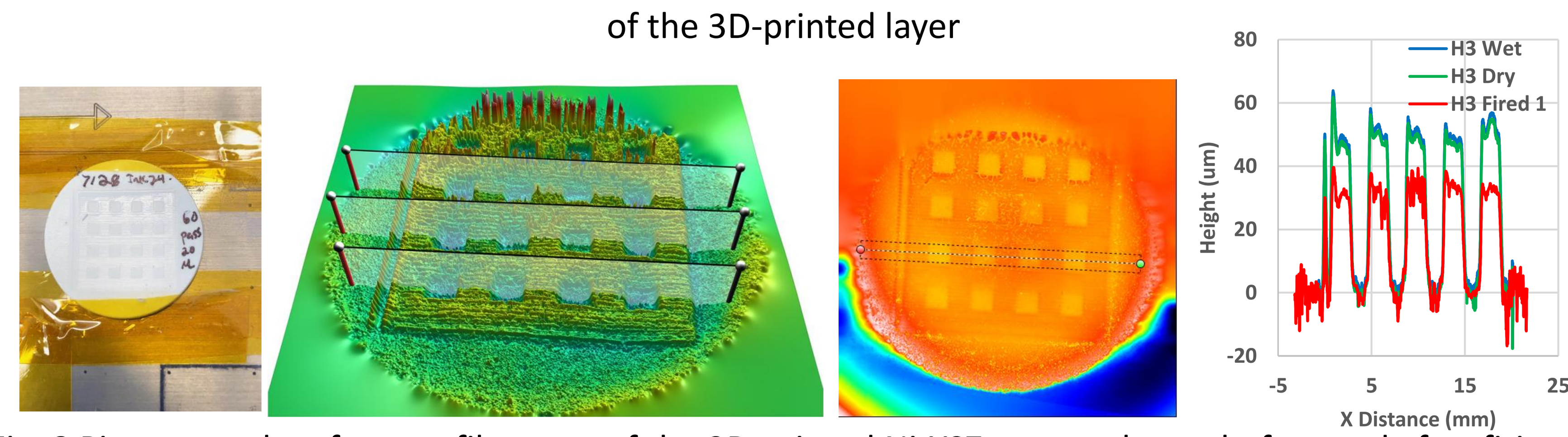

Fig. 8 Pictures and surface profilometry of the 3D-printed Ni-YSZ support layers before and after firing

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

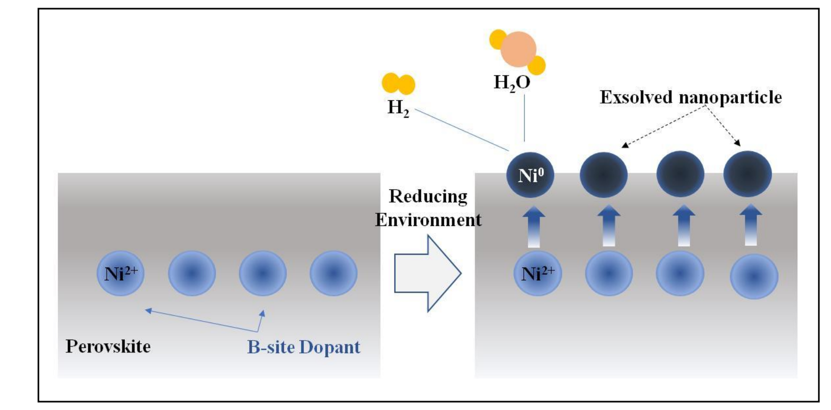

Fig. 9 Embedded Structure Formed from Exsolution of Nickel Particle

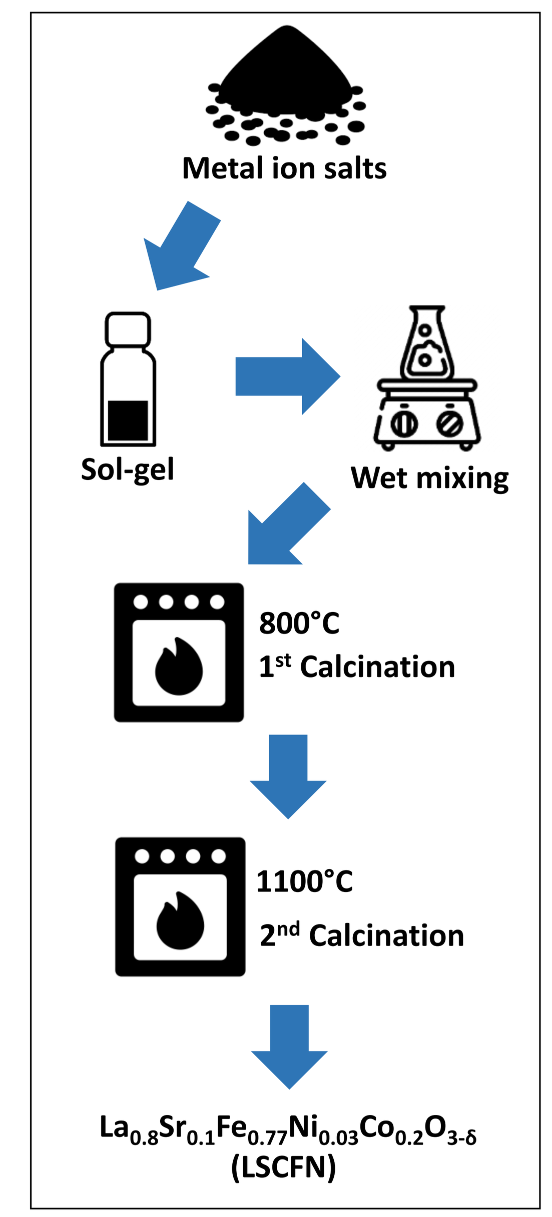

Fig. 10 Synthesis Process for LSCFN

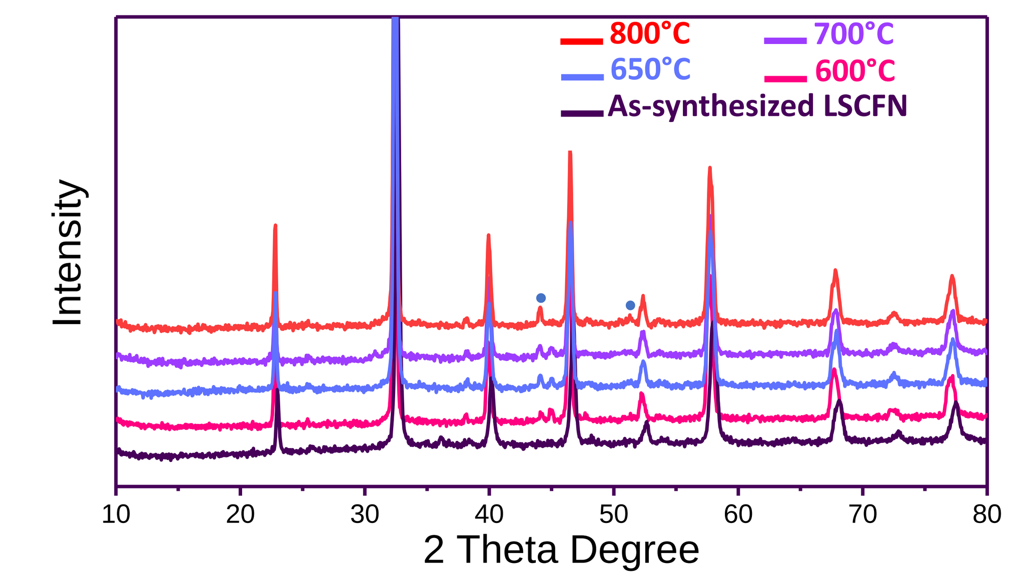

Fig. 11 XRD Patterns of Reduced LSCFN at different temperature with 50% H_2-50% H_2O

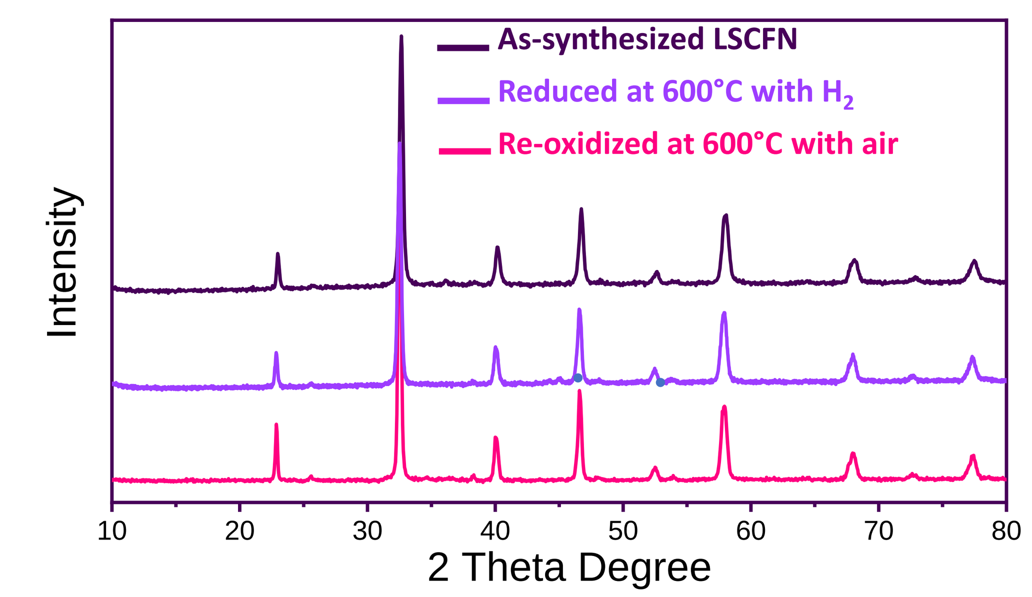

Fig. 12 XRD Patterns of As-synthesized, Reduced, and Reoxidized LSCFN

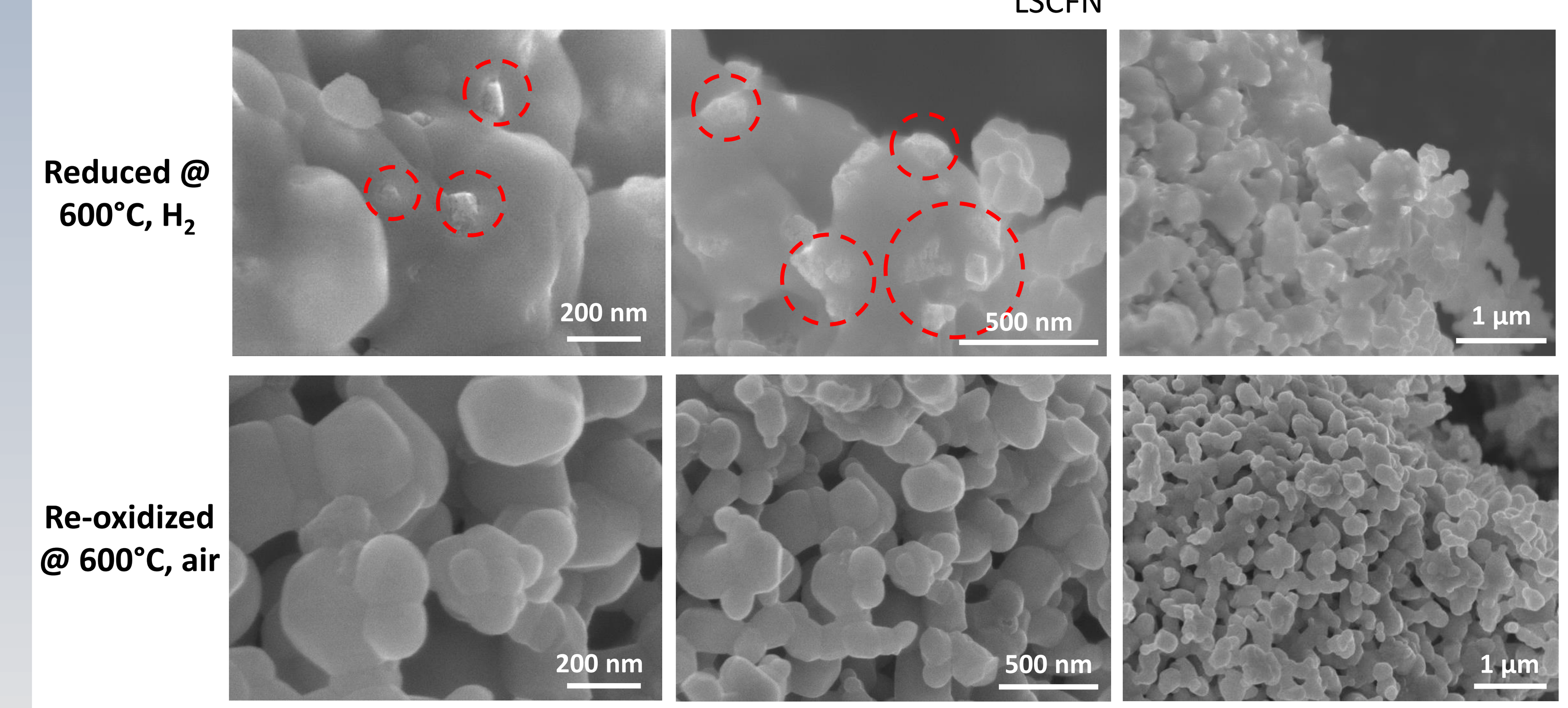

Fig. 13 FESEM Images of Reduced and Reoxidized LSCFN