Progress in Electrode Engineering of Solid Oxide Fuel Cells at NETL

Research & Innovation Center

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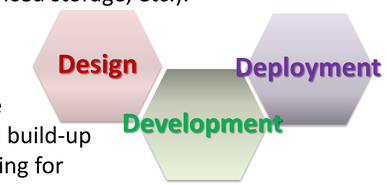
NETL's Electrode Engineering

- **Enhancement of electrode performance and longevity** through materials and microstructure engineering, while addressing coupled program criteria which are reducing stack costs, reduction in cell overpotential, and increase in thermo-mechanical/chemical stability.
- Utilization of technological improvements **to drive down operational costs by lowering operating temperature**, improve performance when operated reversibly, coupling with other advanced energy technologies (e.g. micro-turbines, renewables, advanced storage, etc.).

- **Approach**
  - **Design** of materials and microstructure
  - **Development** thru advanced electrode build-up
  - **Deployment** of the electrode engineering for industrial systems

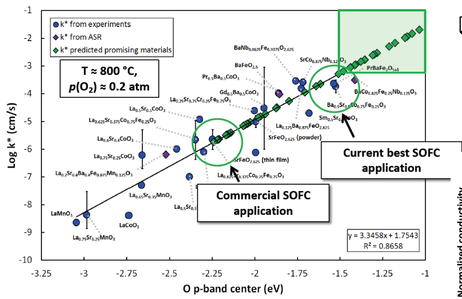


Design

1. Computation-guided cathode materials discovery

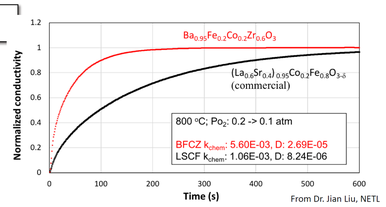
PI: Jian Liu/Beomtak Na(NETL), Dane Morgan/Ryan Jacobs(UW Madison)

- Calculating ORR activity: O*p*-band center descriptor
  - Y.L. Lee et al., *Energy and Environmental Science* (2011)
- Calculating stability: Phase analysis with Pymatgen
  - S.P. Ong et al., *Computational Materials Science* (2013)



Surface exchange coeff. Vs. *O p* band center
- R. Jacobs et al., *Adv. Energy Mater.* (2018)

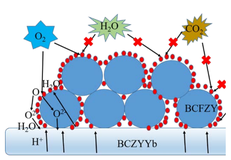
- ECR measurement on the calculated **$Ba(Fe_{0.2}Co_{0.2}Zr_{0.6})O_3$** resulted in 5x higher k_{chem} and 3x higher D_{chem} than LSCF



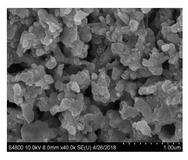
From Dr. Jian Liu, NETL

2. Electrode Design for Proton Ceramic Fuel Cells

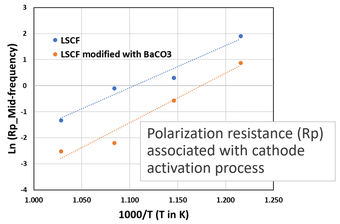
PI: Kyle Brinkman (Clemson Univ.)



Cathode infiltration in Proton SOFCs



LSCF electrode infiltrated with $BaCO_3$

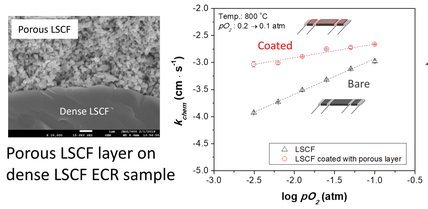


- The ASR of the **$BaCO_3$-infiltrated LSCF cathode** (0.08 Ω•cm²) is much smaller than that of the bare LSCF cathode ((0.27 Ω•cm²) at 700°C.

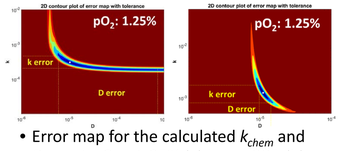
3. Advanced Electrochemical Properties Characterization

PI: Beomtak Na (NETL)

- **Modified ECR (Electrical Conductivity Relaxation)**



- Porous LSCF layer on dense LSCF ECR sample

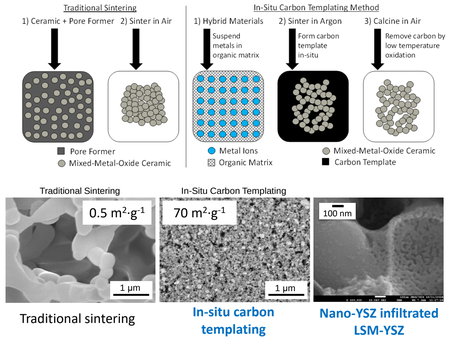


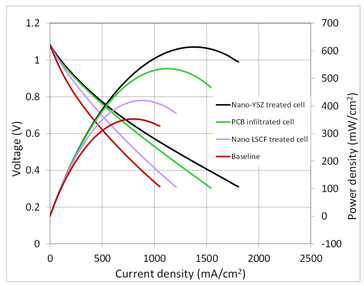
- Error map for the calculated k_{chem} and D_{chem} at pO_2 = 1.25% (a) bare LSCF, (b) LSCF coated with porous layer.

- A novel approach of determining highly accurate bulk diffusion coefficient (D_{chem}) using the electrical conductivity relaxation (ECR) was developed.
- Coating the surfaces of bar samples with porous, in-kind particles (e.g. porous LSCF on dense LSCF bar sample) enabled reduction in the characteristic thickness (L_c) and determination of D_{chem} values with minimal error, which couldn't be achieved by a conventional method.

Development

4. Nanostructured Cathode by Hybrid Materials-assisted Templating (PI: Michael Gross(Wake Forest Univ.))

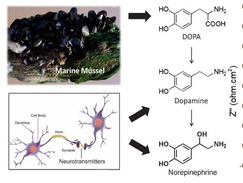




- Hybrid Materials: metal and organic components mixed at atomic level
- Sintering in inert atmosphere: carbon template forms in-situ and remains during sintering; carbon is subsequently burned out at 700°C.
- Nano-YSZ infiltrated LSM-YSZ cathode showed very stable performance (0.67%/200h vs. 1.86%/200h for (PrBa)CoO_x infiltrated cathode)

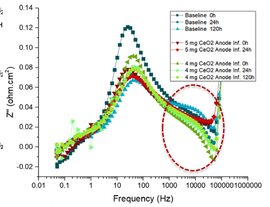
5. Bio Surfactant-assisted Anode Infiltration

PI: Edward Sabolsky/Ozcan Ozmen (West Virginia Univ.)



- pNE offers smoother and more uniform coating

H. Lee, et al., *Angew. Chem. Int.*, (2013) 9187



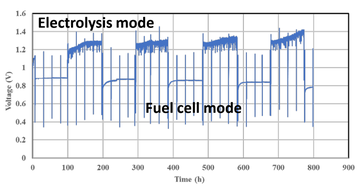
- Anode resistance decreased by the bio surfactant - assisted infiltration

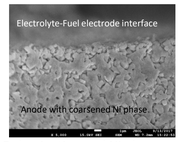
- The surfactant-assisted infiltration protocol was verified for industrial planar fuel cells.
- The efficacy of CeO_2 nano-catalyst infiltration at the anode showed higher impact at lower operating temperature and high fuel utilization condition.

Deployment

6. Reversible Solid Oxide Cell and Degradation Mitigation

PI: Yueying Fan(NETL)





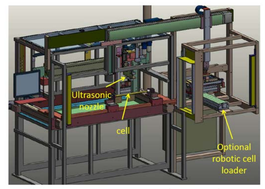
Delamination and Ni phase coarsening are evident from the fuel cell tested under electrolysis mode.

- Cell: Nexceris w/ LSM-YSZ cathode
- Temperature: 800°C
- Electrolysis (cathode): **60% H_2O** – 10% H_2 - 30% N_2
- Fuel Cell (anode): 25% H_2 - 75% N_2

- Reversible solid oxide cells (r-SOC) were successfully operated at 800°C for 800 h.
- Electrode degradation was severe under electrolysis mode, and partial performance recovery under fuel cell mode was identified by impedance spectra analysis.
- Critical issues specific to r-SOFC, such as electrode performance and reliability, a set of active materials, and operating parameters suitable for reversible operation, are addressed.
- The technology will be integrated into a grid by generating electricity and hydrogen.

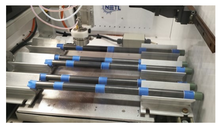
7. Application of Cathode Infiltration for Atrex Energy

PI: Praveen Cheekatamarla(Atrex), Gregory Hackett/Shiwoo Lee (NETL)



Factory-scale automatic spraying infiltration system installed at Atrex

Ref) Chengxiang (Shawn) Ji (Atrex Energy, Inc.), 2017 18th annual SOFC Project Review Meeting (Pittsburgh, PA)



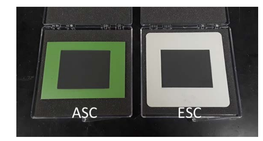
Spray infiltration process at NETL

- DOE's TCF (Technology Commercialization Fund) was completed successfully.
  - NETL modified the spraying infiltration process to effectively apply for Atrex tubular cells and could reduce the processing time required for cathode infiltration within one day.
  - Atrex Energy has constructed a factory-scale automatic spraying infiltration system based on the NETL's technology.
  - An 1.5 kW stack was constructed by Atrex after infiltrating Atrex commercial cells using the automatic spray system. The infiltration process improved the Atrex fuel cell performance without noticeable degradation for 2,000 hours.

8. Application of NETL/WVU Infiltration for Nexceris

PI: Neil Kidner(Nexceris), Ed Sabolsky(WVU), Greg Hackett/Shiwoo Lee (NETL)

- NETL's cathode infiltration and WVU/NETL's anode infiltration were applied for Nexceris planar fuel cells.
- 13-30% reduction in ASR and 3-13% increase in power density were obtained by cathode infiltration.
- Bio surfactant-assisted anode infiltration developed by WVU/NETL was successfully verified.



Electrocatalyst-infiltrated Nexceris ASC/ESC

U.S. DEPARTMENT OF ENERGY

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