Red-Ox Robust Ceramic Anode Supported Solid Oxide Fuel Cells

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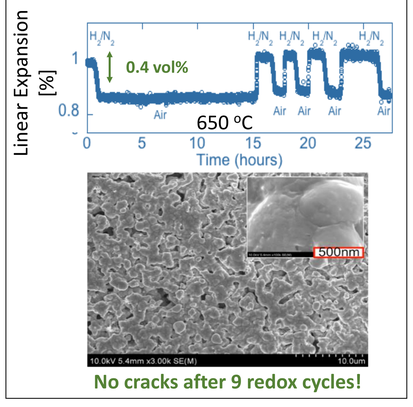
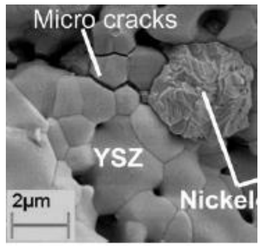
Introduction

All-ceramic anode based solid oxide fuel cells (SOFCs) offer the opportunity to address reduction-oxidation (red-ox) induced mechanical instability and coking issues associated with conventional Ni-based cermet anodes. Unlike state-of-the-art ceramic anodes, Redox's new ceramic material operates at lower temperatures (450-600 °C versus > 800 °C) and does not require very low PO2 reducing pre-treatments at high temperature (e.g., > 900 °C) to obtain sufficient conductivity for SOFC operation.

Redox ceramic anode → small Δoxygen = small dimensional change (0.4 vol%)



Ni-cermet anodes prone to mechanical failure during redox cycling



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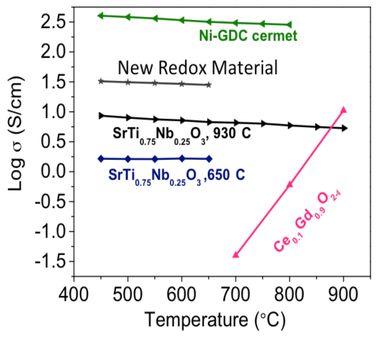
~69 vol% expansion of Ni → NiO

Anode electrical conductivity



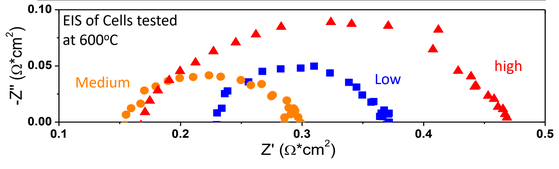
Project Goals and Approach

- *Optimize ceramic anode supported cell fabrication conditions and electrochemical performance (sintering temperature vs. infiltration uptake);*
- *Scale up ceramic anode supported SOFC to 10 cm by 10 cm scale and test stacks in reformate;*
- *Cost modeling (grid and non-grid failures via discrete simulations);*
- *Humidity and temperature study for cell storage*

Results

1. Ceramic Anode Electrochemical Performance Optimization

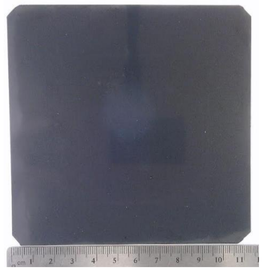
Sintering Temperature	Low	Medium	High
shrinkage	16%	20%	21.5%
Anode infiltrate uptake (no vacuum)	8 wt% (3 times)	6 wt% (4 times)	6 wt% (6 times)

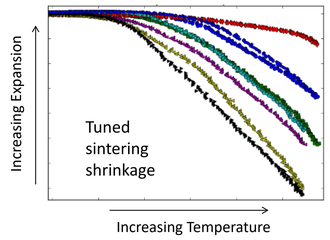


- Cell shrinks more with increasing firing temperature
- Higher firing temperature may improve mechanical strength but the trade-off is lower catalyst infiltrate uptake
- The medium firing temperature is the most optimized. The cell has the least Ohmic resistance and polarization resistance

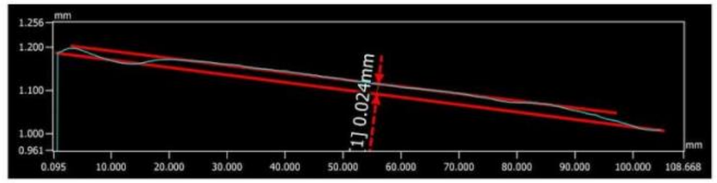
2. Ceramic anode supported SOFC Scaling Up

Single 10 cm by 10 cm ceramic anode supported cell

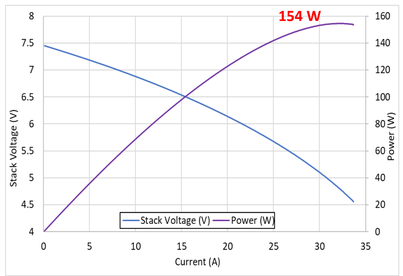




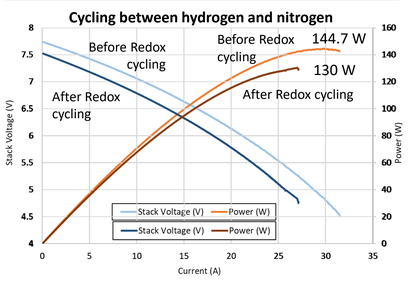
- *Achieved very flat all-ceramic anode cells fabricated at R&D, and "production" scale*
- *Demonstrated firing in large "production" kiln with commercial partner*

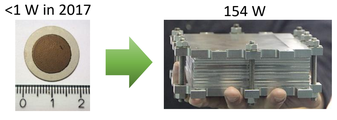


10-cell 10 cm by 10 cm Ceramic Anode Stack



- First 10-cell 10 cm by 10 cm ceramic anode stack tested at 600ºC in hydrogen
- The cell components of the ceramic anode supported SOFCs are made with "Production" materials
- Redox Power Systems has successfully scaled up the ceramic anode supported cell from button cell to 150W stack

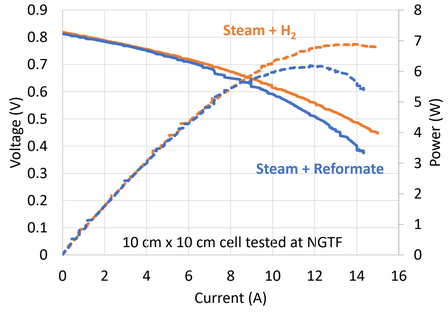




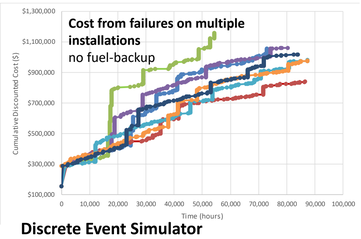
- Degradation in performance after red-ox cycling
- Previous 5 cm by 5 cm tests showed 3 red-ox cycles with minimal ASR, OCV, and seal degradation, but more cycles led to degradation
- Future work includes continued anode structure modification to improve stack red-ox stability

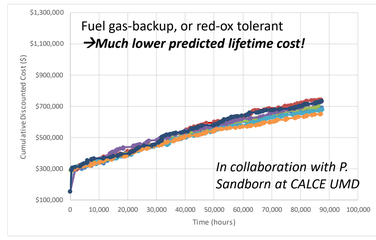
Single 10 cm by 10 cm Ceramic Anode Cell in Reformate

- First operation of an all-ceramic anode cell on reformed natural gas at NGTF (Natural Gas Testing Facility)
- Steam : fuel ratio (10:1) was used as the testing condition to simulate high fuel utilization. Concentration polarization was observed in both tests.
- Within a wide range of current (0-8A), the stack behaves similarly in steamed hydrogen and in reformate, which demonstrates the steam reforming system integrated in the Redox cube demo is effective



3. Cost Modeling

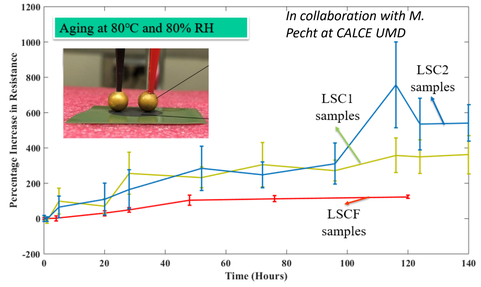




Discrete Event Simulator

- Simulates cost of system over lifetime of warranty
- Includes estimates of mean-time-to-failure (MTTF) of system components
- Developed model predicting natural gas interruptions (est. 0.22 mean gas interruptions per year)
- Ceramic anode cells don't require backup fuels, making it cheaper than the Ni-cermet SOFC systems.
- Simulations with red-ox tolerant SOFC has much lower lifetime cost (largely related to "stack failures" with fuel loss)

4. Temperature and Humidity Study for SOFC Storage



SOFC degradation from fabrication and storage processes important and largely unexplored

Investigated role of high humidity on electrode materials

- Increase in sheet resistance of common cathodes (LSC and LSCF) at 80% RH at 80 ºC (no change in dry conditions)
- Degradation likely related to Sr accumulation at electrode surface
- Storage at lower humidity conditions (~<50% RH) advised

Future Work

- Perform long term test on ceramic anode supported SOFC stacks in both hydrogen and reformate (*Note: initial reformate tests are encouraging*).
- Degradation mechanism study on ceramic anode supported SOFCs
- Continue anode structure modification for better performance and stability
- 1 kW stack demonstration
- Perform sensitivity analysis of discrete event simulator and refine input parameters

Summary and Conclusions

- Redox Power Systems has developed a new type of ceramic anode-supported SOFC and successfully scale it up to 10 cm by 10 cm scale.
- The 10-cell 10 cm by 10 cm stack outputs over 150 W in hydrogen, and shows good stability in reformate and under re-dox stability
- Developed discrete event simulator and natural gas grid failure rate models → demonstrated dramatic reduced lifetime cost with red-ox tolerant SOFCs
- Demonstrated high humidity related to potential SOFC storage and fabrication (~80% RH at 80 ºC) degrades common SOFC electrode conductivity and should be avoided

Acknowledgement

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