Mitigating Performance Degradation and Preventing Delamination of LSM/YSZ Cell under Solid Oxide Electrolysis Operation by Infiltrating Sr-Fe-O Nanoparticles in the Air Electrode

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Introduction

- Solid oxide electrolysis cell (SOEC) as a highly effective fuel generation system had gotten much more interest since SOEC technology could produce pure H_2 without releasing any greenhouse gases into environment and no need to separated H_2 from other gaseous byproduct.
- One of the most important challenge for commercially application of SOEC technology is the cell's long-term performance degradation caused by grain structure change in electrolyte[1], Ni depletion, delamination[2-5] and second phase formation[5] in the H_2 electrode, the delamination and nonconductive second phase formation in air electrode[6-7].
- Irreversible Ni mobility and depletion away from[2, 8] or toward[3] the electrolyte in H_2 electrode caused performance degradation for SOEC under high operational temperature, high current density.
- Delamination of air electrode from the electrolyte caused performance degradation too for SOEC operation due to microstructural changes, the penetration of evolved oxygen into the closed pores/defects or high oxygen pressure buildup in the electrolyte/air electrode interface[6, 9-10].
- LSM is the most commonly used air electrode for SOEC operation due to its good electronic conductivity, high catalytic activity, and chemical and thermal compatibility with YSZ electrolyte. One of the major problems with LSM-based SOEC cells is long term stability due to poor oxygen ion conductivity of LSM, which generated high oxygen partial pressure between the air electrode/electrolyte interface and caused delamination of LSM from electrolyte.
- Infiltration of nanoparticles in the LSM electrode not only improve the electro-catalytic activity for the oxygen oxidation reaction due to the enhancement of high surface area, the extension of the TPB and the enhancement in surface exchange rate, but also mitigate delamination of the LSM electrode from electrolyte[11].

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Purpose of the Study

- Mitigate performance degradation and delamination of air electrode from electrolyte for LSM/YSZ cell operated under SOEC by Infiltration of Sr-Fe-O in air electrode of LSM/YSZ cell.
- Evaluate nanostructure of Sr-Fe-O infiltrated LSM/YSZ cell before and after long term test through TEM/HRTEM studies and analysis.
- Gauge what improved performance and performance stability of Sr-Fe-O infiltrated cells.

Experimental Methods

Cells:

- Commercially available Nexceris cells
- Cathode: LSM[$(La_{0.8}Sr_{0.2})_{0.98}MnO_3$] / LSM-YSZ active layer
- Electrolyte: YSZ
- Anode: Ni-YSZ

Infiltration of nano-materials in LSM/YSZ cells

- Infiltrated nanomaterials: Sr-Fe-O
- Particle size is expected to be 50-100nm
- Solvent: Aqueous citric acid solution
- Chemical Precursors: Metal Nitrate (0.125M-0.25M)
- Temperature: 450-850°C
- Time: Repeat infiltration until 0.3 mg-0.7 mg infiltration nanomaterial obtained

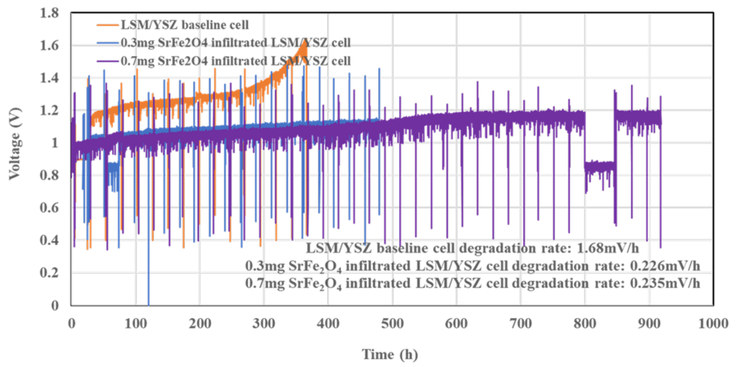
Operating Conditions:

- 800°C, 0.5 A/cm² current load, 60% steam in H_2 electrode

TEM/HRTEM and EDS studies and analysis:

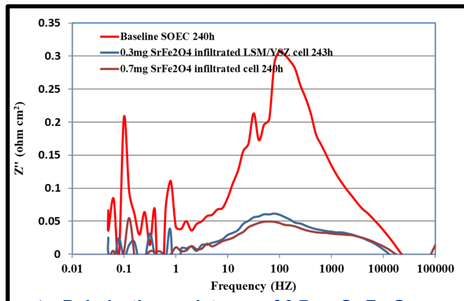
- Nanostructure changes of Sr-Fe-O infiltrated cell before and after long term test by TEM/HRTEM observation

Stability Test of Uninfiltrated and Sr-Fe-O Infiltrated LSM/YSZ Cells Under SOEC Mode @ 60% Steam, 0.5A/cm² and 800°C

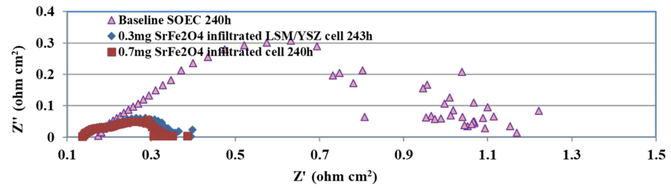


- Uninfiltrated LSM/YSZ baseline cell was delaminated in the air electrode after 350h test under SOEC mode.
- Infiltration of Sr-Fe-O(Sr:Fe=1:2) in the air electrode improved the performance and mitigated performance degradation.
- Infiltration of Sr-Fe-O(Sr:Fe=1:2) in the air electrode extended the operational duration of the cell with no visible delamination in the air electrode.
- More Sr-Fe-O infiltration in the air electrode didn't show significant performance improvement and performance degradation mitigation.

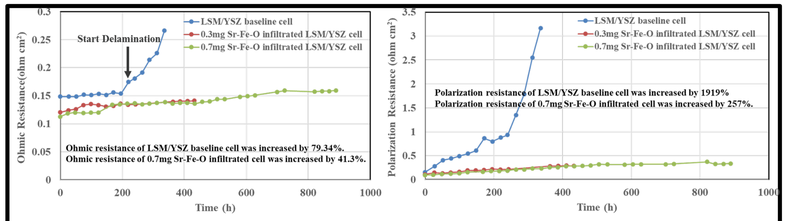
EIS Comparison of Sr-Fe-O Infiltrated and Uninfiltrated LSM/YSZ Cell under SOEC Operational Mode



- Polarization resistance of 0.7mg Sr-Fe-O infiltrated cell was increased by 0.272 mΩ cm² per hour.
- The polarization resistance of infiltrated cell was increased almost 20 times less than that of uninfiltrated cell, which mitigated the performance degradation by Sr-Fe-O infiltration in air electrode.
- Sr-Fe-O infiltration in the air electrode decreased impedance for both H_2 electrode and air electrode, which improved the cell performance.
- Sr-Fe-O infiltration in the air electrode also significantly decreased polarization resistance, which increased the cell's performance due to increased ORR activity through Sr-Fe-O infiltration in air electrode.
- Polarization resistance of uninfiltrated cell was increased by 4.979 mΩ cm² per hour.
- Polarization resistance of 0.3mg Sr-Fe-O infiltrated cell was increased by 0.375 mΩ cm² per hour.

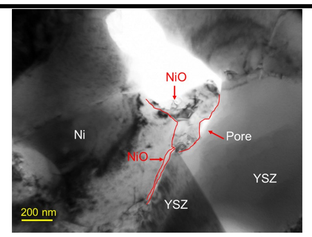


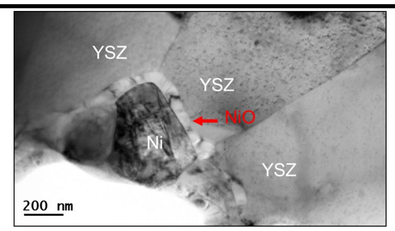
Ohmic/Polarization Resistance of Sr-Fe-O infiltrated and Uninfiltrated LSM/YSZ Cell Under SOEC Operational Mode

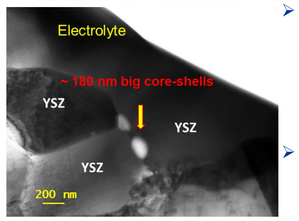


- Ohmic resistance was decreased a little after infiltration of Sr-Fe-O in the air electrode.
- Infiltration of Sr-Fe-O in the air electrode decreased the polarization resistance of the cell significantly during long term test of SOEC mode.
- Polarization resistance was increased a lot more than the ohmic resistance during the SOEC operation long term test.
- Polarization resistance increase contributed more performance degradation than the ohmic resistance increase during long term SOEC test of LSM/YSZ cell.

TEM Studies on H_2 Electrode for Uninfiltrated and Sr-Fe-O Infiltrated LSM/YSZ Cell Operated Under SOEC







- Less dense, but much larger core-shells with dimension of ~ 100-180 nm, largely accumulated at the triple YSZ/YSZ GBs junctions were formed in H_2 electrode for both uninfiltrated and Sr-Fe-O infiltrated LSM/YSZ cell, which could cause the cell's performance degradation.
- NiO ribbon and granular NiO phase were formed at the Ni/YSZ interface for both uninfiltrated and Sr-Fe-O infiltrated LSM/YSZ cell, which may also cause performance degradation.

Summary & Conclusion

- Nano sized Sr-Fe-O infiltration in the air electrode of LSM/YSZ cell had proved to be feasible technique to mitigate the cell's performance degradation by several times and extend SOEC operational duration without visible delamination in the air electrode when the infiltrated cell was taken out.
- The infiltration of Sr-Fe-O nanoparticles in air electrode of LSM/YSZ cell not only mitigated the cell's ohmic resistance increase by several times, but also mitigated the cell's polarization resistance increase by about 20 times, which significantly increased the cell's performance and mitigated the cell's performance degradation and extended the SOEC operation duration without delamination in the air electrode.
- TEM studies on H_2 electrode of both uninfiltrated and infiltrated cells observed less dense, but much larger core-shells with dimension of ~ 100-180 nm, largely accumulated at the triple YSZ/YSZ GBs junctions, which could cause the performance degradation. Granular NiO phase is present at the original TPBs, which could cause performance degradation too.

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