Operation of an LSGMC Electrolyte-Supported SOFC with Composite Ceramic Anode and Cathode

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An all-perovskite-based intermediate-temperature fuel cell was fabricated from materials synthesized using glycine-nitrate process (GNP) and modified Pechini synthesis routes. Yttrium-doped strontium titanate (SYT) was chosen as the conductive ceramic anode component to avoid problems associated with Ni-based anodes. La$_0.8$Sr$_0.2$Ga$_0.8$Mg$_0.1$Co$_0.1$O$_3$-$\delta$ (LSGMC) electrolyte-supported solid oxide fuel cells (SOFCs) with composite ceramic anode and cathode exhibit a relatively high power density of 0.246 W/cm$^2$ at 800°C at 0.5 V.

Operation of a fuel cell in the “intermediate” temperature range of 650–800°C has the potential to reduce fuel cell system costs significantly by allowing use of less exotic materials for balance-of-plant components, by reducing thermal degradation, and by allowing the use of gaskets. Fuel cell stack materials must be chosen to be mechanically compatible with matching coefficient of thermal expansion, chemically compatible such that no deleterious or nonconductive phases are formed at interfaces of dissimilar materials and chemically stable in both the anode’s strong reducing environment and the cathode’s oxidizing environment. Doped LaGaO$_3$ perovskites have been reported to be good electrolyte material candidates. Ishihara et al. reported high pure ionic conductivity; yet, few reports have focused on the b site with cobalt (LSGMC) further enhances ionic conductivity. The total conductivity of LSGMC was found to be optimal at the composition La$_0.8$Sr$_0.2$Ga$_0.8$Mg$_0.1$Co$_0.1$O$_3$-$\delta$. In the present work, all cells were tested using this composite for the electrolyte.

The use of composite electrodes in fuel cells has been reported as a method of improving the cell performance and decreasing polarization losses. In the present work, composites of electronically conductive ceramic, catalytic material, and ionically conducting ceramic are used in both the anode and the cathode.

Anodes used in intermediate-temperature fuel cells must exhibit mechanical compatibility (coefficient of thermal expansion) with the electrolyte as well as chemical compatibility. Chemical incompatibility with conventional nickel-based anodes due to the formation of LaNiO$_3$ have led to the investigation of other potential anode materials. Hui et al. reported high electronic conductivities for yttrium-doped strontium titanate (SYT) in strongly reducing atmospheres and tested it as a potential anode material with yttrium-stabilized zirconium (YSZ) electrolytes. SYT of the composition Sr$_{0.8}$Y$_{0.2}$TiO$_3$-$\delta$ was used as the electronically conducting component of the anode in the present work. LSGMC of the same formula as the electrolyte was added as an ionically conducting component to extend the electrochemically active area further into the electrode. Lanthanum-doped ceria (LDC) was added as a component to catalyze the anode reactions and decrease the activation overpotential.

The SYT used in this work was synthesized using a modified Pechini process due to the high cost of titanium nitrate that would otherwise be required for the glycine-nitrate process (GNP). The SYT synthesis was followed by calcining in air at 900°C for 8 h, which was found to be optimal by testing a range of calcining temperatures (800–1400°C) and durations (4–8 h). All other materials used in cell fabrication were synthesized using GNP. The resulting powders were calcined at temperatures and durations determined to be optimal by characterizing the powders with X-ray diffraction (XRD, Bruker 5000) to analyze phase purity. Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) were used to verify the microstructure and composition of the powders.

A representative cell cross section in Fig. 1 shows the cell configuration was used to separate out the impedance contributions of the cathode and anode materials.

The anode was made from a mixture of 60% SYT, 20% LDC, and 20% LSGMC by weight. An ink of the composite anode was made using a mortar and pestle to mix the anode powder with a polytetrafluoroethylene (PTFE)-modified Pechini organic binder (Heraeus V006). Scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS) were used to verify the microstructure and composition of the powders. The SYT synthesis was followed by calcining in air at 900°C for 8 h, which was found to be optimal by testing a range of calcining temperatures (800–1400°C) and durations (4–8 h). All other materials used in cell fabrication were synthesized using GNP. The resulting powders were calcined at temperatures and durations determined to be optimal by characterizing the powders with X-ray diffraction (XRD, Bruker 5000) to analyze phase purity. Scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) were used to verify the microstructure and composition of the powders.
before the cell was tested. A decrease in total cell area specific resistance (ASR) of 0.1 \text{ \Omega cm}^2 was observed after the reduction treatment.

The ac impedance spectra of the full cell, shown in Fig. 3, reveals that little of the measured ASR of the entire cell is due to the cathode or cathode-electrolyte interfacial impedances. The anode ac impedance spectrum shows that much of the full cell measured ASR is due to the anode’s contribution, in bulk resistance and in interfacial resistance. Values measured for full-cell ASR are within expected values for this temperature range using this materials set, though there is room for improvement of anode ASR.

Open-circuit voltages of 0.91–0.95 V were observed as shown in Fig. 4. This number is lower than the expected Nernst voltage for these temperatures. This could be due to reactant cross leakage or minor carrier conductivity introduced by the presence of Co in the electrolyte. Further work is planned to isolate the ionic and electronic contributions to electrolyte conductivity.

The peak power density of 0.246 W/cm² at 800°C is respectable for this material and temperature. These figures compare favorably to the power densities achieved by Hui and Petric using doped SYT anodes on a YSZ-based solid oxide fuel cell at a higher temperature (1000°C). Although Hui and Petric did not report detailed anode performance, their cell performance was likely limited by the SYT anode as illustrated by the anode and cathode interfacial impedance results of Fig. 3. The reason for improved cell performance in this work is likely due to use of a different electrolyte (LSGMC vs YSZ), a composite anode vs a noncomposite anode as well as a different synthesis route for SYT (modified Pechini process vs solid-state reaction).

Future work on dual-mode (fuel cell and electrolyzer) operation of this cell is also planned. Investigation of the durability of this materials set is also planned, as well as operation of anode-supported cells with much thinner LSGMC electrolyte membrane layers. Concerns about the suitability of this material as a conductive anode component remain due to the oxygen partial-pressure dependence of its conductivity. Necessity of reduction pretreatments must be addressed to successfully use this materials set as an intermediate-temperature fuel cell.

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