Solid Oxide Fuel Cell Composite Cathode Performance and Morphology: Effects of Particle Size Distribution

A.T. Duong and D.R. Mumm

Department of Chemical Engineering and Material Science, University of California-Irvine, 916 Engineering Tower, Irvine, CA 92697

Solid oxide fuel cells are promising energy conversion devices that are central to the move towards renewable energy technology. SOFCs compose of an electrolyte (8mole% Yttria Stabilized Zirconia, pure ionic conductor) sandwiched between a cathode and an anode layers with electronic and ionic conducting capabilities (Figure 1), respectively. Composites of lanthanum strontium manganese oxide (LSM) and YSZ have been shown to be effective and robust as cathode systems for solid oxide fuel cells. Relative to SOFC systems with single-phase LSM electrodes, compositing LSM and YSZ produces a lower resistance cathode and lower over-potential cathode. Prior studies reported in the literature have shown that electrode resistance decreases with increasing composite cathode thickness [1,2]. Additionally, compositional studies of LSM-YSZ cathodes have shown that compositions near 50/50 wt% were optimal with regards to minimizing electrode polarization resistance [3,4]. Despite the demonstrated performance of LSM-YSZ cathode systems, improvements in lowering over-potential loss and polarization resistance are still necessary to meet established metrics for SOFC system commercial viability. Nevertheless, these studies have shown that there is significant potential for tailoring the microstructure to improve cathode performance.

Previous studies have identified a few key factors in microstructure that may be linked to performance of porous composite cathodes. 1) The triple phase boundary (the boundary that adjoins the LSM phase and the YSZ phase) are sites where oxygen reduction reaction (ORR) occur. It follows that the more sites available for ORR, the higher performance. 2) Not all TPBs are active. Connectivity analysis of TPB distribution in composite cathodes have shown that TPBs of percolated LSM and YSZ phases are electrochemically active (EA-TPB) [5-6]. In this work, four topological configurations of LSM-YSZ electrodes – all comprising a 50/50 wt% ratio of the two phases – are compared. The results illustrate that compositing of LSM-YSZ materials of varying starting particle sizes (fixed overall weight ratio) yields significant electrochemical performance differences that correlate directly with changes in EA-TPB length and surface area participating in ORR. AC impedance was used for performance evaluation, as measured by the polarization resistance values ($R_p$). In general, the higher the polarization resistance, FIB/SEM was employed to serial section porous composite cathodes, generating stacks of images that could be 3D reconstructed. Using the reconstructed volumes (Figure 2) quantitative assessment of microstructural parameters could be extracted and correlated with performance values.

Based on this study a few conclusions were made. 1) TPB can be directly correlated with cathode performance. A near one–to-one correlation between the specific parameters of the microstructure (triple phase boundary and surface area) and performance ($1/R_p$) could be established (Figure 3). 2) The coarser the particle size, and larger the particle size disparity, the lower the TPB length and surface area density – resulting in lower performance. The results are discussed in terms of implications for design of optimal SOFC composite electrode microstructure.
References
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FIG 1: Solid Oxide Fuel Cell stack. Oxygen is sent to the composite cathode to be reduced to ionic oxygen. Oxygen ions ionically conduct through the electrolyte to be oxidized to form H₂O.

FIG 2: Reconstructed volume of a SOFC cathode

FIG 3: Plot of TPB density and Conductivity with particle size of the electrode. A strong correlation between the performance and TPB density, showing that the larger the particle sized disparity, the lower the TPB density leading to lower performance.

<table>
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<tr>
<th>Sample #</th>
<th>LSM Particle Size (µm)</th>
<th>YSZ Particle Size (µm)</th>
<th>Ratio of LSM/YSZ Particle Size</th>
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