Numerical Simulation of Electrolyte-Supported Planar Button Solid Oxide Fuel Cell

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Abstract

Introduction: Solid oxide fuel cells (SOFCs) use solid ceramics as their electrolyte material and operate at high temperature ranges of 400°C to 1000°C. SOFCs have great fuel flexibility, are compatible with both steam and gas turbines, have relatively higher power density and are ideal for stationary power generation. In order to produce fuel cells with higher power density, efficiency, durability and cost-effectiveness; researchers have been experimenting with different materials, operating conditions and manufacturing methods.

One way to improve cell performance is by using better electrolyte materials. This paper will show by numerical simulation the results of using two electrolyte materials: 8 mol% Y_2O_3 stabilized ZrO_2 [YSZ] and Scandia-doped Ceria Zirconia $Sc_{0.17}Ce_{0.08}ZrO_2$ [SCSZ]. SCSZ has a significantly higher ionic conductivity than YSZ and will produce less ohmic loss (Figure 1). Unfortunately, SCSZ undergoes phase transitions at the operating temperatures of SOFCs while YSZ maintains its phase stability. To use advantages from both materials, SCSZ layers are placed within two outer layers of YSZ. Each layer has a thickness of 30µm. This design should provide higher ionic conductivity and greater stability with the outer YSZ layers protecting the inner SCSZ layers. A total of nine electrolyte designs were developed and tested: 3-, 4-, and 6-layered designs of pure YSZ, pure SCSZ, and the layered combination (Figure 2). In this paper, an electrolyte-supported planar button solid oxide fuel cell is modeled in COMSOL, which is then used to analyze the performance of the SOFC with different electrolyte materials and configurations. Validation of the model was done against experimental results of another planar SOFC [1, 2].

Use of COMSOL Multiphysics: The SOFCs with the nine electrolyte designs will be simulated using the Batteries and Fuel Cells module in COMSOL Multiphysics 4.2a. The physics used in the modeling includes electrochemistry and fluid mechanics. The main governing equations include charge conservation equation, Maxwell-Stefan diffusion model, Butler-Volmer equation and Brinkman equations. Figure 3 shows the geometry, dimensions, and materials used for the SOFC. The meshing was done in COMSOL using free tetrahedral elements. To solve for the current-voltage relationship in a SOFC, the voltage can be solved from current or vice versa. In this model, a parametric sweep of the polarization overpotential was done; hence calculating current from voltage.

Results: The simulations results are summarized in Figure 4. The table shows that 3-layered pure

SCSZ electrolyte produced the highest power density while the 6-layered pure YSZ electrolyte produced the least power density. These results make sense, since the increase in the electrolyte thickness increases the ohmic losses and is in agreement with results presented by Arpornwichanop et al. [3]. The graph in Figure 4 shows that the SOFC with YSZ-2SCSZ-YSZ electrolyte performs better than the SOFC with pure YSZ, and has a better stability compared to the SOFC with pure SCSZ.

Conclusion: The choice of the electrolyte depends on the application, in some cases performance maybe the priority but in other cases performance may need to be sacrificed for other considerations.

Reference

1. Joongmyeon Bae, Singkwang Lim, Hyunjin Jee, Jung Hyun Kim, Young-Sung Yoo, Taehee Lee, Small stack performance of intermediate temperature-operating solid oxide fuel cells using stainless steel interconnects and anode-supported single cell, Journal of Power Sources, 172 (2007) 100-107.
2. William J. Sembler, Sunil Kumar, Optimization of a Single-Cell Solid-Oxide Fuel Cell Using Computational Fluid Dynamics, Journal of Fuel Cell Science and Technology, April 2011, Vol. 8.
3. Yaneeporn Patcharavorachot, Amornchai Arpornwichanop, Anon Chuachuensuk, Electrochemical study of a planar solid oxide fuel cell: Role of support structures, Journal of Power Sources, 177 (2008) 254-261.

Figures used in the abstract

3-layered		4-layered		6-layered		6-layered		6-layered	
YSZ-1SCSZ-YSZ		YSZ-2SCSZ-YSZ		YSZ		YSZ-4SCSZ-YSZ		SCSZ	
Temperature °C	Ionic Conductivity (S/m)	Temperature °C	Ionic Conductivity (S/m)	Temperature °C	Ionic Conductivity (S/m)	Temperature °C	Ionic Conductivity (S/m)	Temperature °C	Ionic Conductivity (S/m)
500.22	0.11	500.06	0.12	501.03	0.08	500.16	0.16	496.52	0.21
550.10	0.27	550.38	0.32	550.12	0.21	550.42	0.43	547.30	0.52
600.99	0.63	601.36	0.74	602.19	0.43	601.57	0.98	598.71	1.40
651.54	1.29	652.08	1.51	653.03	0.83	651.94	2.01	649.66	2.92
701.92	2.38	702.40	2.76	702.05	1.57	701.98	3.61	700.40	5.07
752.24	3.86	752.56	4.49	752.40	2.68	752.57	5.88	751.21	7.94
802.55	6.01	802.91	6.89	802.73	4.24	803.36	8.86	802.00	11.62

Figure 1: Ionic conductivity of the electrolyte materials.

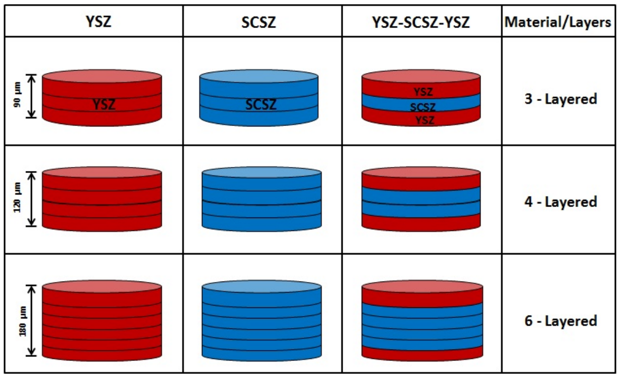


Figure 2: Electrolyte designs developed and tested

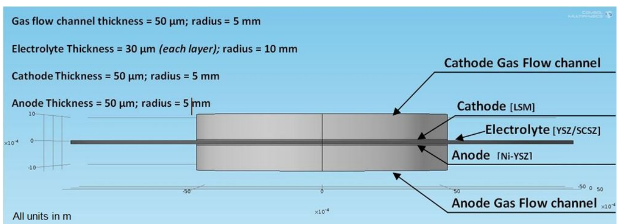
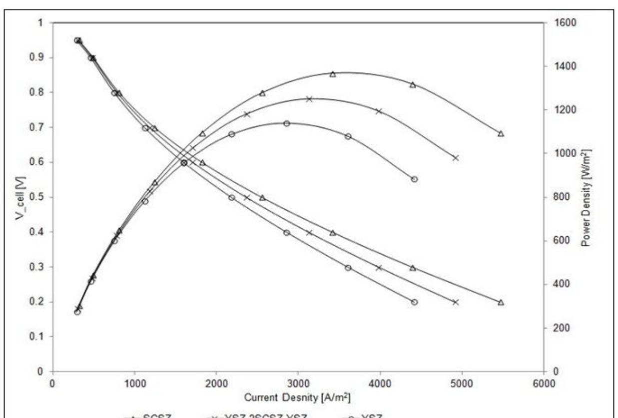


Figure 3: SOFC geometry with the dimensions and materials used.



Maximum Power Density [W/m²]			
	SCSZ	YSZ	YSZ-SCSZ-YSZ
3-layered	*1403.07*	1222.24	1292.60
4-layered	1378.76	1150.14	1260.67
6-layered	1273.77	*980.96*	1206.36

Figure 4: Below: Table summarizes the SOFC power density results for all the electrolytes; Top: Voltage plotted against current density and power density for 4-layered YSZ-SCSZ-YSZ electrolyte SOFC.