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

Amjad Aman[1], Russell Gentile[1], Yan Chen[1], Yunjun Xu[1], Xinyu Huang[2], Nina Orlovskaya[1]

1. University of Central Florida, Department of Mechanical and Aerospace Engineering, Orlando, FL 32816, USA
2. University of South Carolina, Department of Mechanical Engineering, Columbia, SC 29208, USA

Introduction: Solid oxide fuel cells (SOFCs) are electrochemical conversion devices that utilize ceramics as their electrolyte, they operate at relatively high temperatures, typically 400ºC to 1000ºC, and have a relatively high efficiency of about 50-60% with the theoretical efficiency predicted up to 83% [1]. While single cells can be anode, cathode or electrolyte supported, with much work done in the past on anode-supported cells, the research presented in this paper focuses on the electrolyte-supported cell design.

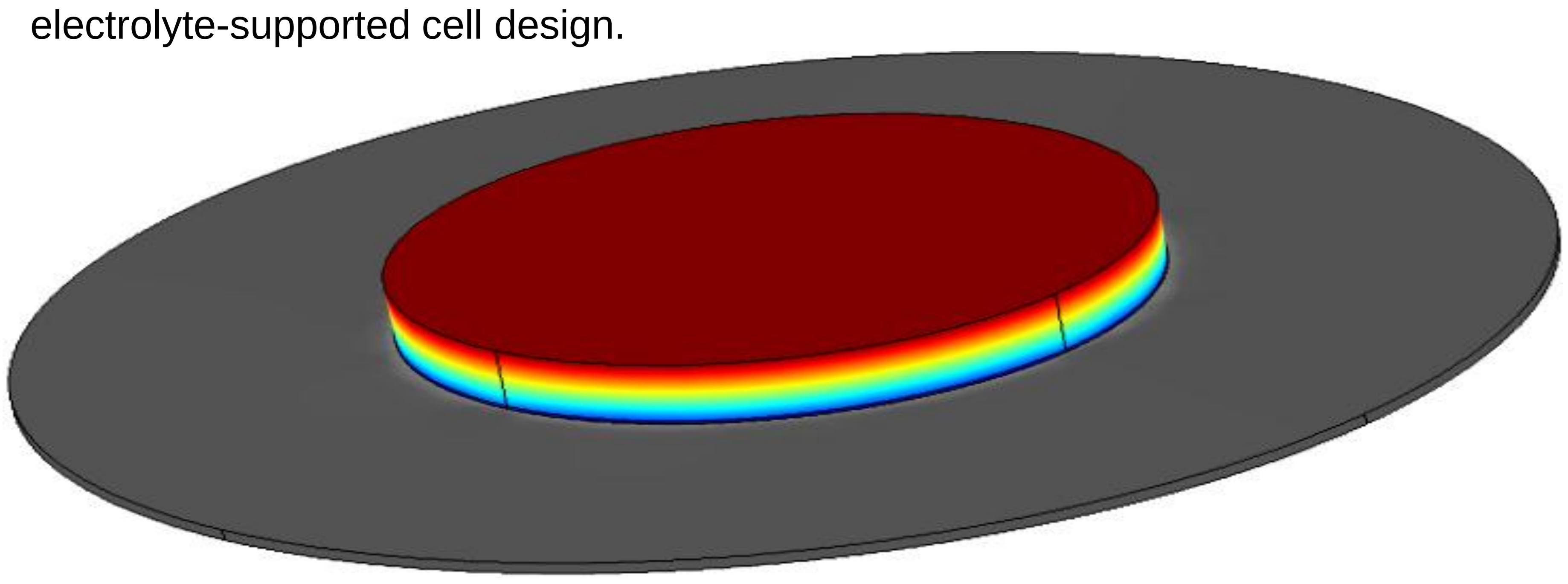

Figure 1. Overview of SOFC

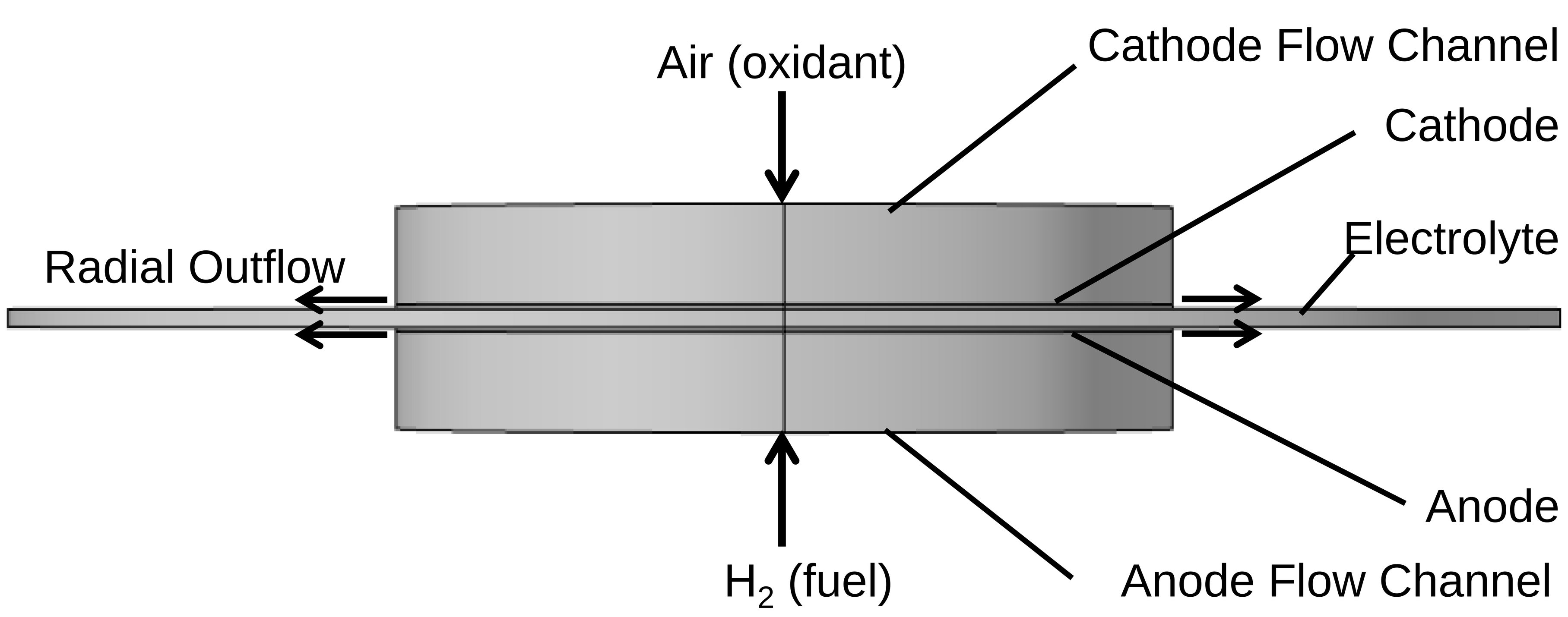

Figure 2. Electrolyte-Supported Planar Button single cell model

Electrolyte Design:

- YSZ is the most explored and widely used electrolyte material for high temperature SOFCs.
- YSZ has good ionic conductivity at 1000ºC, but at lower operational temperatures the ionic conductivity decreases.
- SCSZ exhibits much higher ionic conductivity at lower operational temperatures, but it exhibits cubic to rhombohedral phase transition which affects both the electrolyte and overall cell performance [4, 5].
- A layered electrolyte design is adopted. Thin YSZ electrolyte layers are placed on the outer surfaces of thin SCSZ electrolyte layers.
- A total of nine electrolytes produced: 3-, 4- and 6-layered designs using only YSZ or only SCSZ layers stacked one upon the other as well as laminate designs consisting of YSZ/xSCSZ/YSZ, where x = 1, 2 and 3.
- The cathode and anode material used were $(La_{0.6}Sr_{0.4})_{0.99}Co_{0.2}Fe_{0.8}O_3$ and Ni-YSZ respectively.

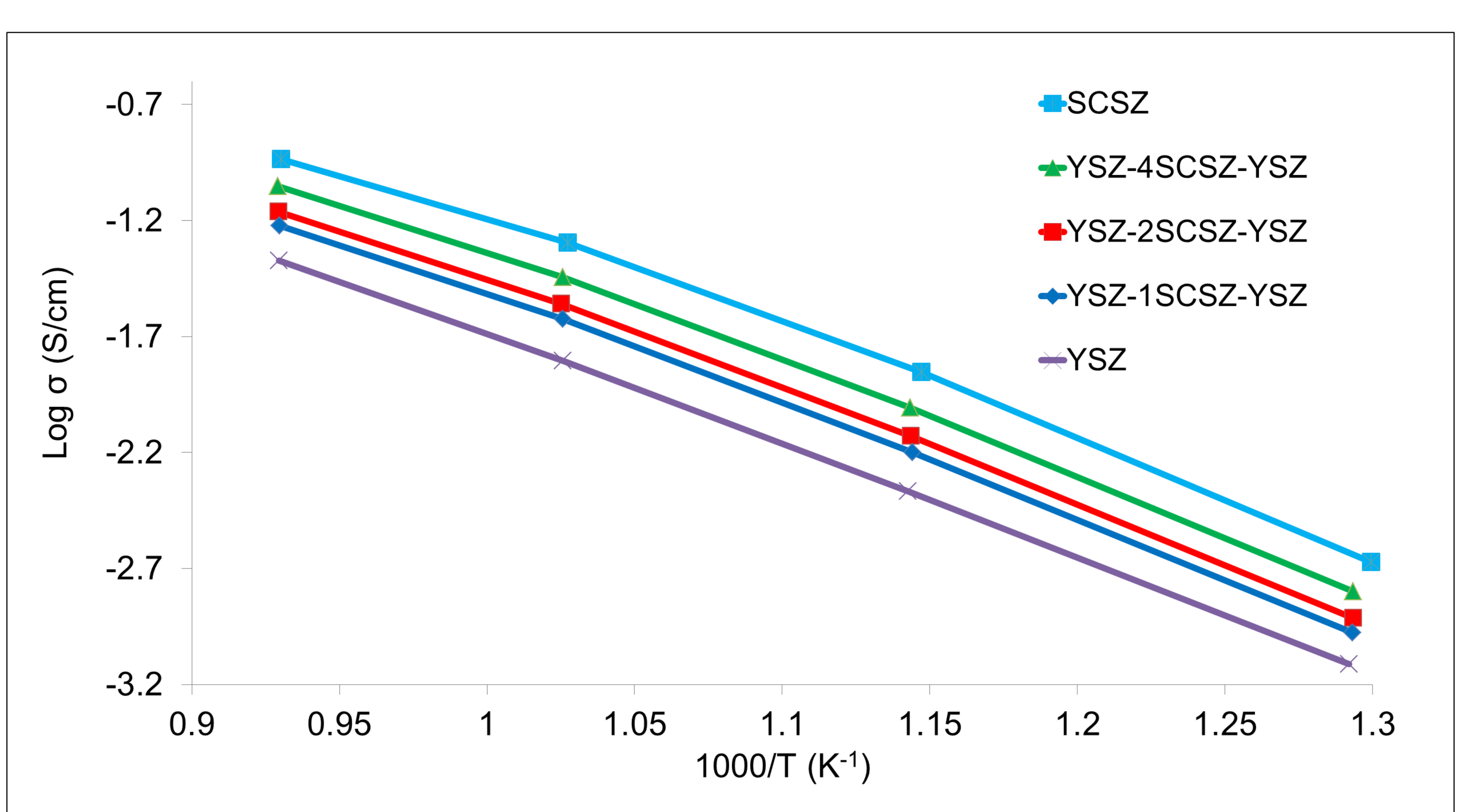

Figure 3. Electrolyte ionic conductivities

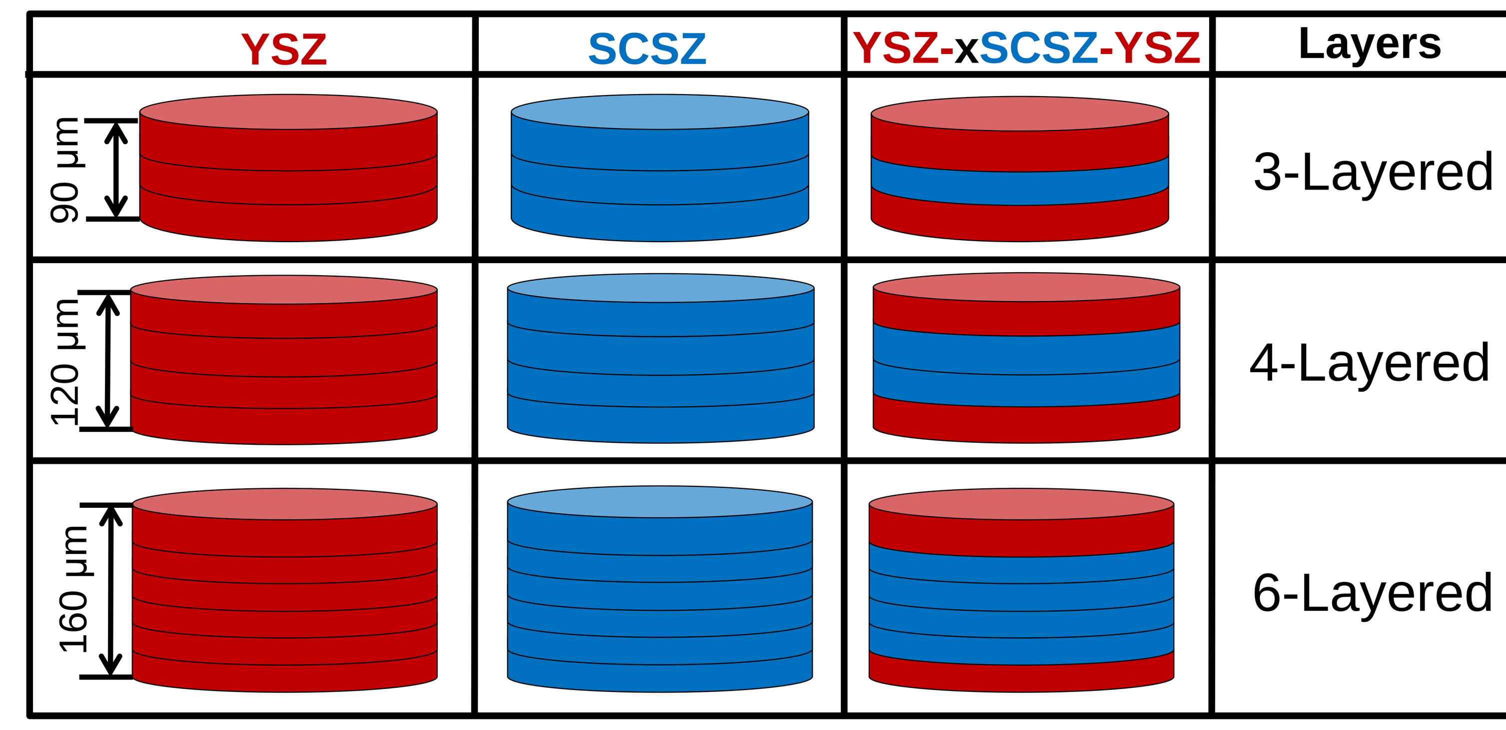

Figure 4. Electrolyte design

Modeling Methodology: The complete modeling from building the geometry to post-processing was carried out using COMSOL Multiphysics 4.3 with Batteries and Fuel Cells module. The three nodes that were used: Secondary Current Distribution, Transport of Concentrated Species, Free and Porous Media Flow. The main governing equations include charge conservation equation, Maxwell-Stefan diffusion model, non-linear Butler-Volmer equation and Brinkman equations.

Assumptions made in the model:

- Steady state condition, neglecting any transient conditions at the start-up or end of cycle.
- Material properties remain constant.
- The model focuses on the individual fuel cell; interconnects and other aspects of the fuel cell system are not considered.
- Fluids are assumed to follow the ideal gas law and are incompressible.
- Heat transfer effects like joule heating are not considered.
- The electrolyte is considered to be very dense and the porosity is considered zero.

Results & Conclusion: The simulation results showed that the hybrid layered electrolytes YSZ-xSCSZ-YSZ electrolytes demonstrated optimal performance and stability compared to the pure YSZ or pure SCSZ electrolytes. The thicker the electrolyte, higher the ohmic losses and hence the performance will lower.

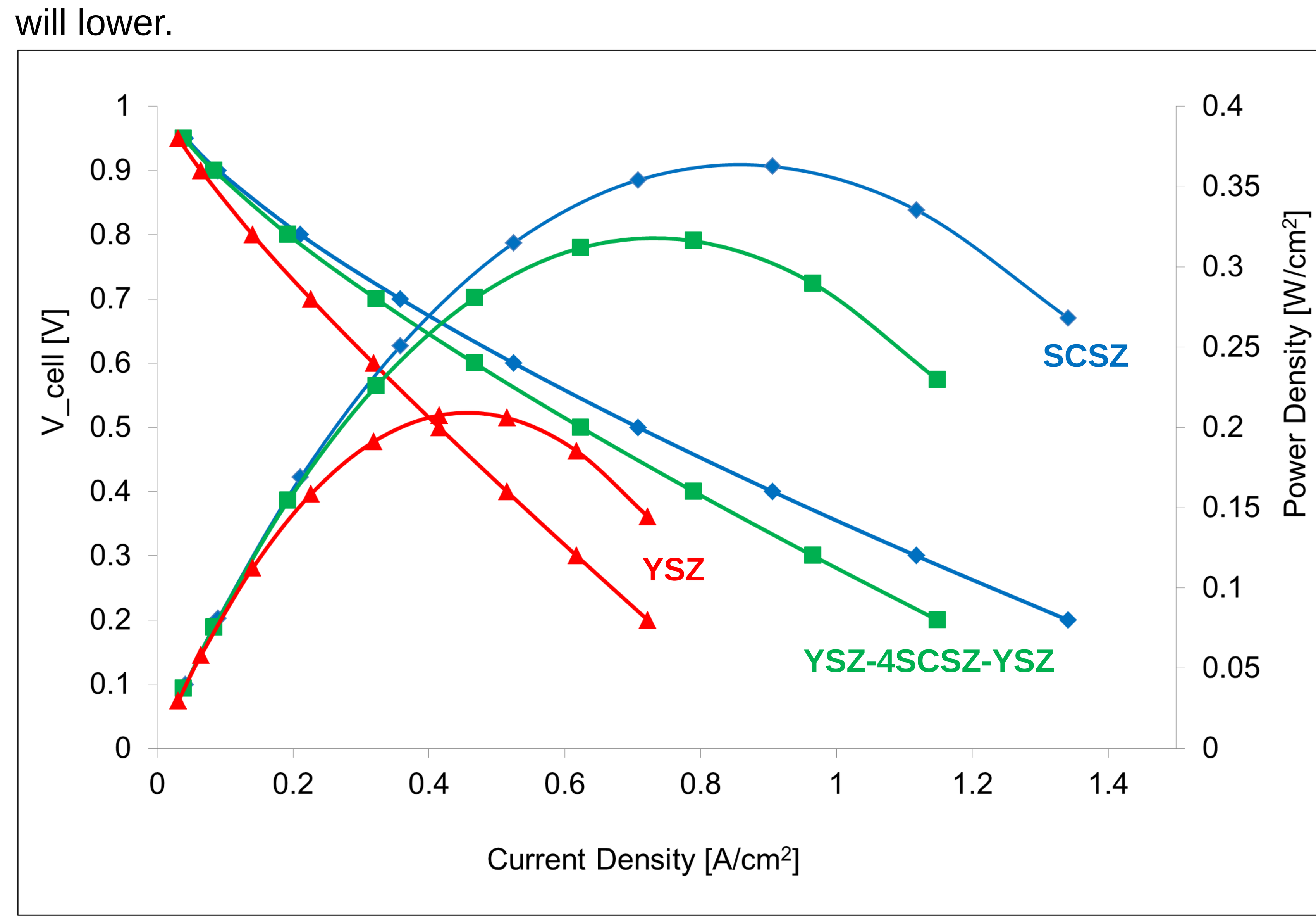

Figure 5. Current-Voltage-Power Density Plot for 6-layered Electrolyte SOFCs

	Max Power Density [W/m²]			% increase (YSZ to Y-xS-Y)	% increase (Y-xS-Y to SCSZ)
	YSZ	Y-xS-Y	SCSZ		
3-Layered	3243.41	3739.38	4798.72	15.29	28.33
4-Layered	2807.7	3479.07	4488.77	23.91	29.02
6-Layered	2093.38	3188.95	3658.03	52.33	14.71

Figure 6. Summary of results

Acknowledgements: This work was supported by the NSF project CMMI-1030833.