3D Transient Simulation Of A Planar SOFC: Bridging Microstructure And Multiphysics Models.

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Abstract

Modelling solid oxide fuel cells(SOFCS), involves these complex physicochemical interactions: electrochemical reactions, fluid flow, heat transfer, and charge carrier transport inside porous microstructures. The existing models often do simplify the electrodes structures and decouple the physics, which limit their accuracy for transient simulations needed for predicting performance assessment and microstructure optimisation [1]. Here we present a model built in COMSOL Multiphysics V6.2, that address this gap by integrating realistic 3D microscale electrode model with macroscale multiphysics in a time-domain framework, and capable of capturing the coupled behaviour in cold start and thermal load variations.
Figure-1 shows the simulation setup and domain assignment to physics modules and multiphysics couplers. This model is an upgrade built on the SOFC-unit-cell example in application libraries. The geometry of unit-cell is planar with gas channels, electrolyte (8YSZ), anode (42% 8YSZ, 33% Ni, 25% porosity), and cathode (LSCF, 37%-46% porosity), considering anisotropic and tortuous properties [2].
Figure-2 showcases the electrode's microstructure impact on unit-cell performance predictions, in this case the LSCF(46%) exhibits relatively higher power density. Simulation of Cold-start condition was performed by solving the transient problem of heat diffusion. The initial condition is set by letting the air inlet temperature at 500°C and hydrogen inlet temperature at 800°C. Figure-3 (left) showcases temperature contours after 60 minutes, the thermal gradient is high near gas inlets but uniform temperature inside the electrodes where electrochemical reactions occur. Figure-3 (right) showcases the time evolution of average temperature over the unit-cell, chemical heat loss, and Joule heating. It indicates a high initial loss occurring at 10min of start before stabilising after 40 minutes.
This study establishes a comprehensive framework for microstructure-resolved, 3D transient simulation of SOFC, linking microscale electrode morphology to macroscale system performance by bridging scales and physics. This approach will accelerate SOFC development for resilient energy applications[3].

Reference

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[2] E. Langner, et al.,"Determination of the effective conductivities of solid oxide fuel cell electrodes using the first-order homogenization method", PAMM, 2023, 10, DOI: 10.1002/pamm.202300105
[3] A. Semenov, et al., "Modelling and simulation of the electro-chemo-thermo-mechanical behaviour of solid oxide fuel cells considering creep", 2025, 05, DOI: 10.1007/s00707-025-04334-5

Figures used in the abstract

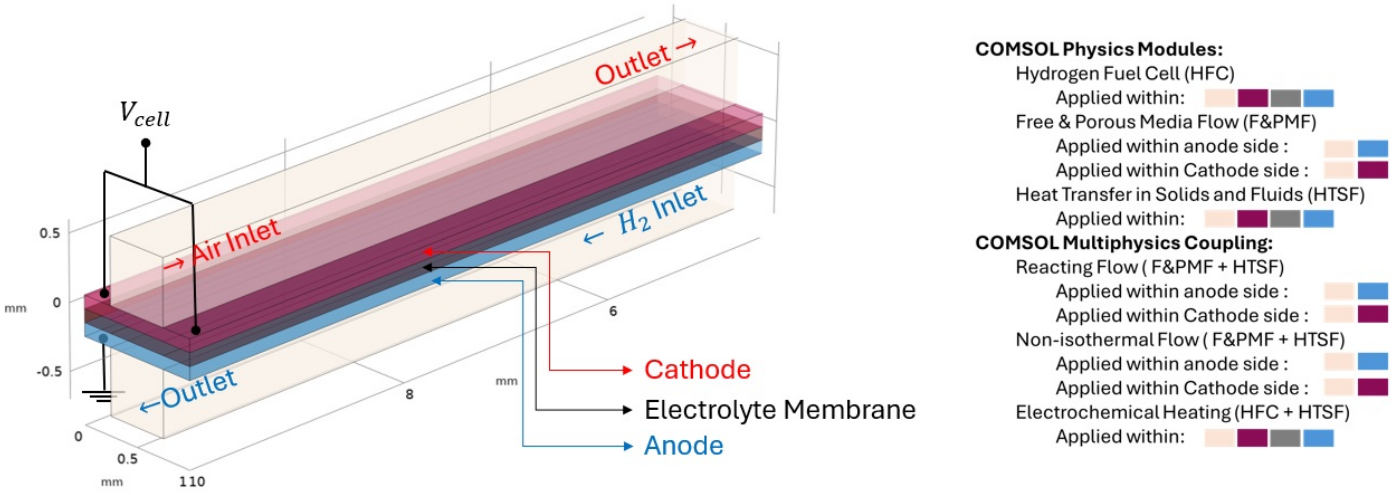

Figure 1 : Simulation setup and Geometry and physics domain assignments in COMSOL Multiphysics for planar SOFC

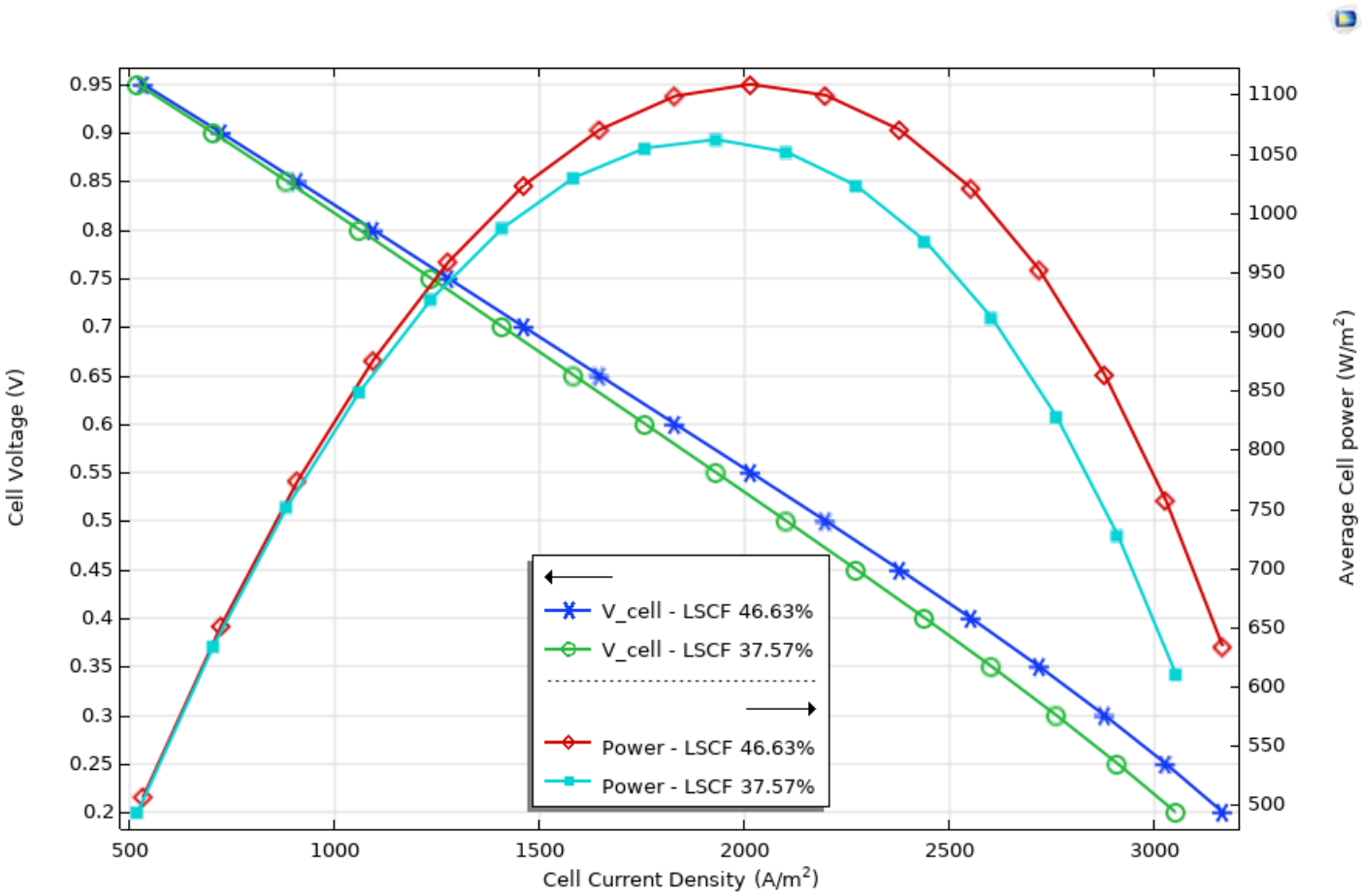

Figure 2 : Polarization curve (I/V) and power-density comparison between LSCF-37% and LSCF-46% cathode microstructures.

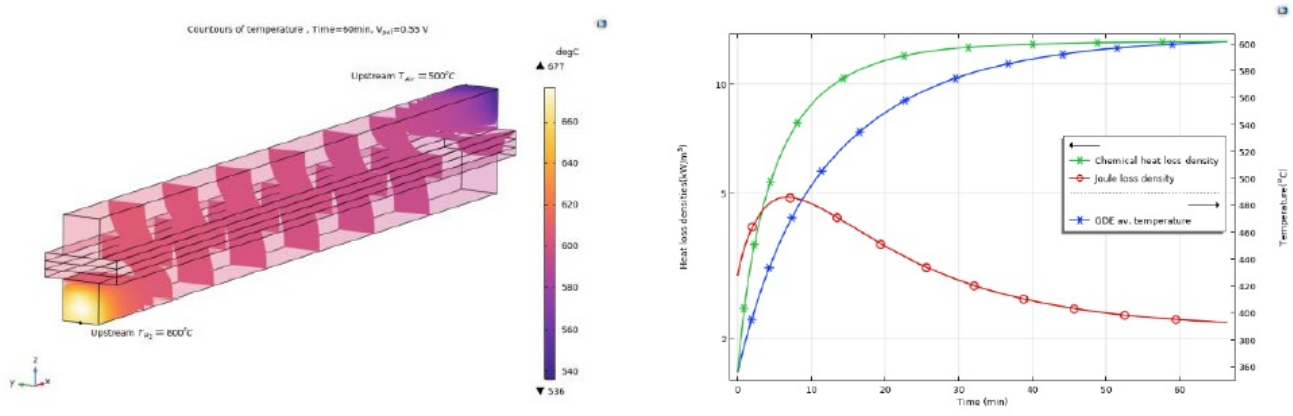

Figure 3 : Left: Temperature contours across SOFC after 60 min operation. Right Transient profiles of temperature, chemical heat loss, and Joule loss during cold start.