Multiphysics Modeling Of A Multi-Layer Thin Heater For Electric Vehicle Battery Packs

M. Lazzarin[1], M. Zerbetto[1]

[1]Inova Lab s.r.l. Padova, Italy

Abstract

The push to electrify vehicles has highlighted a critical need for advanced thermal management systems in electric vehicle (EV) battery packs. Maintaining a stable temperature for these batteries is crucial for their efficiency, lifespan, and safety, as they are highly sensitive to temperature changes. Cold weather specifically impairs battery performance, making auxiliary heating solutions essential. Etched foil heaters are a promising technology in this area.
This work, carried out for Silga Connect Technology, presents the development and numerical modeling of a multi-layer etched foil heater using COMSOL Multiphysics®. The goal is to simulate and optimize the thermal and electrical performance of the heater integrated into an EV battery pack environment. The heater consists of a metallic foil etched to form a specific resistive pattern, embedded within dielectric and structural layers, forming a laminated stack. The model accounts for the coupled physics of Joule heating, heat transfer in solids, and electrical conduction, including layer-specific material properties and boundary conditions representative of the operational constraints in automotive applications.
Silga Connect Technology contributed their expertise in thin heater production, supporting the design phase with critical manufacturing knowledge and subsequently fabricating the finalized heater prototypes used for model validation and testing.
A key aspect of the study involves the characterization of temperature distribution and thermal gradients within the heater and adjacent battery components under different operating scenarios. These include varying input voltages, ambient temperatures, and contact conditions with neighboring battery surfaces. Special attention is given to the transient thermal behavior during initial startup and steady-state operation, as well as the influence of design parameters such as foil geometry, layer thicknesses, and material selections on heater performance.
The model is implemented using a multiphysics approach that integrates the Electric Currents and Heat Transfer in Solids interfaces within COMSOL. The layered structure is built using the Thin Layer and Multilayer Stack features to accurately represent the laminated architecture of the heater. Parametric sweeps and sensitivity analyses are performed to evaluate the influence of design modifications, and the model is validated against analytical approximations and empirical constraints typical of automotive thermal systems.
The results offer insight into the design trade-offs involved in achieving uniform heating, fast response time, and minimal energy consumption. This modeling approach provides a valuable tool for the design optimization of battery heating systems, supporting the broader goal of enhancing the reliability and energy efficiency of EV thermal management solutions.
By leveraging COMSOL Multiphysics for the virtual prototyping of complex, multi-layered thermal systems, this work contributes to the development of next-generation components that meet the stringent performance, safety, and efficiency standards of the electric mobility sector.

Figures used in the abstract

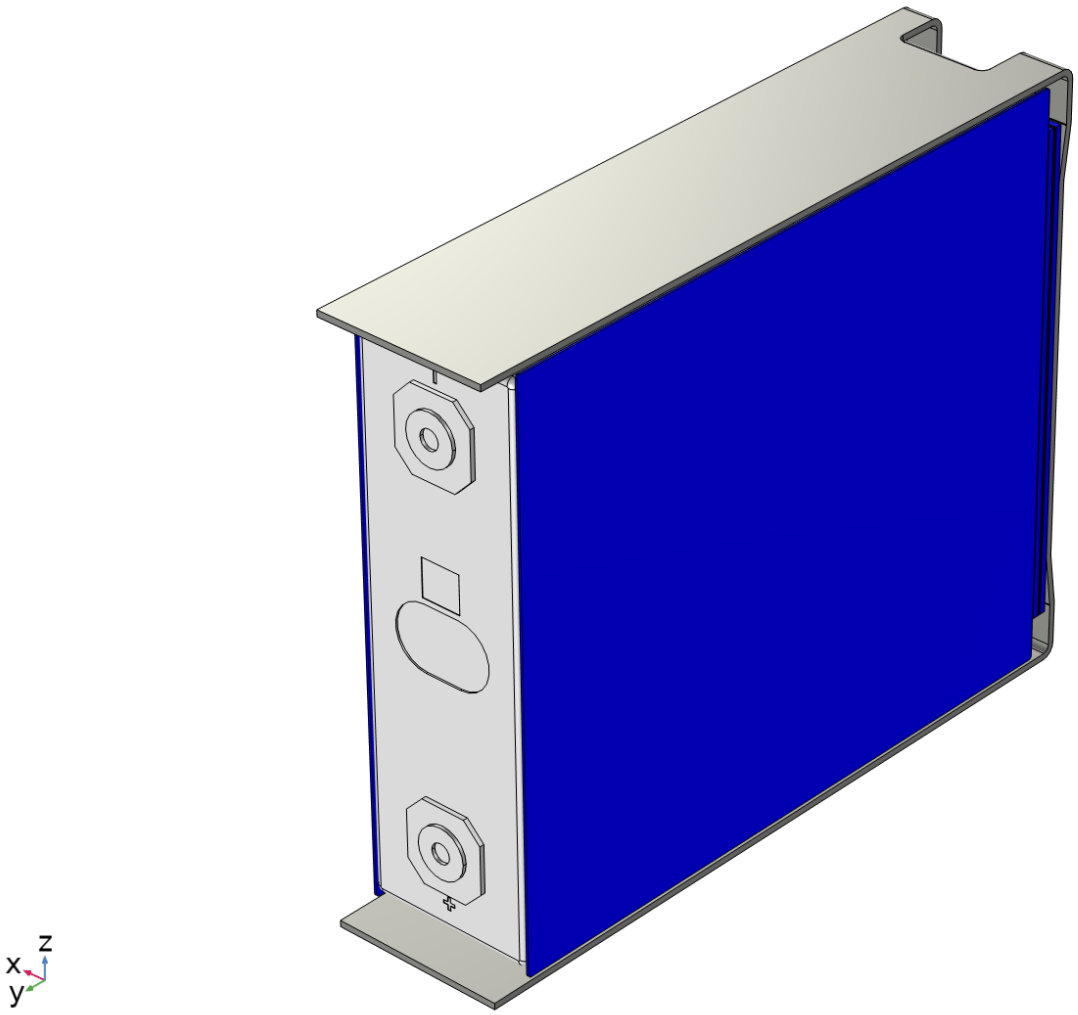

Figure 1 : Geometry of single cell

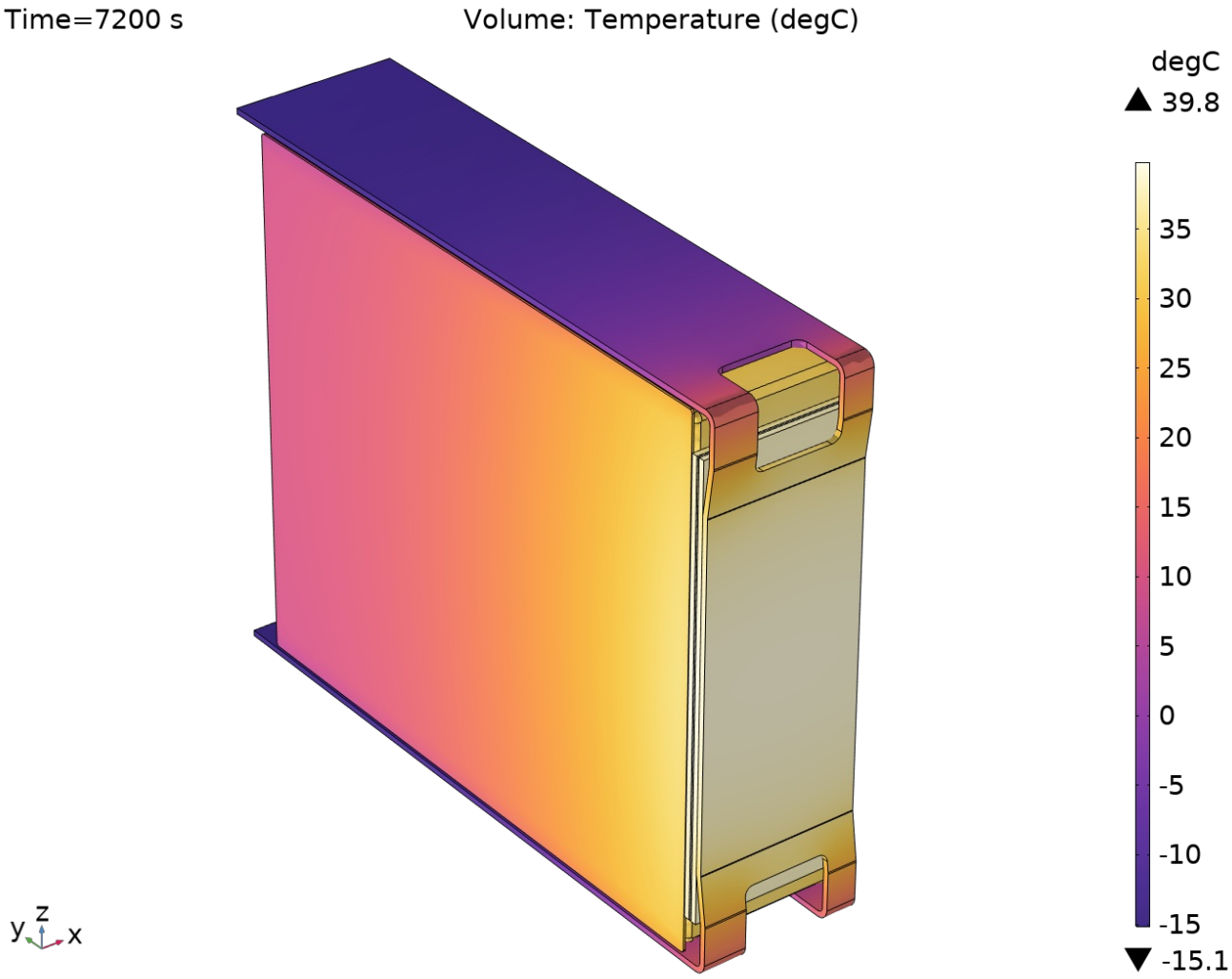

Figure 2 : thermal distribution in the single cell

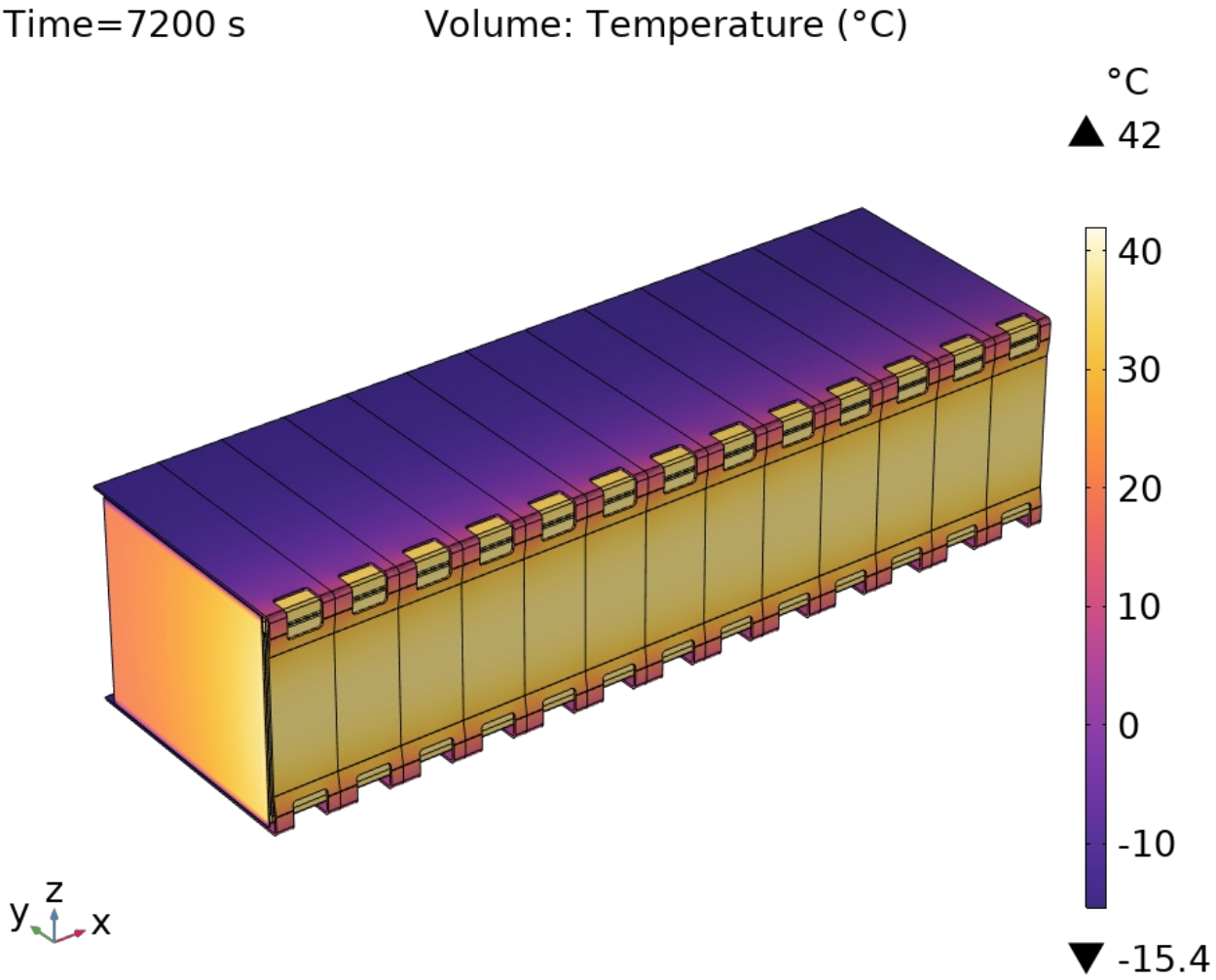

Figure 3 : thermal distribution in the battery pack

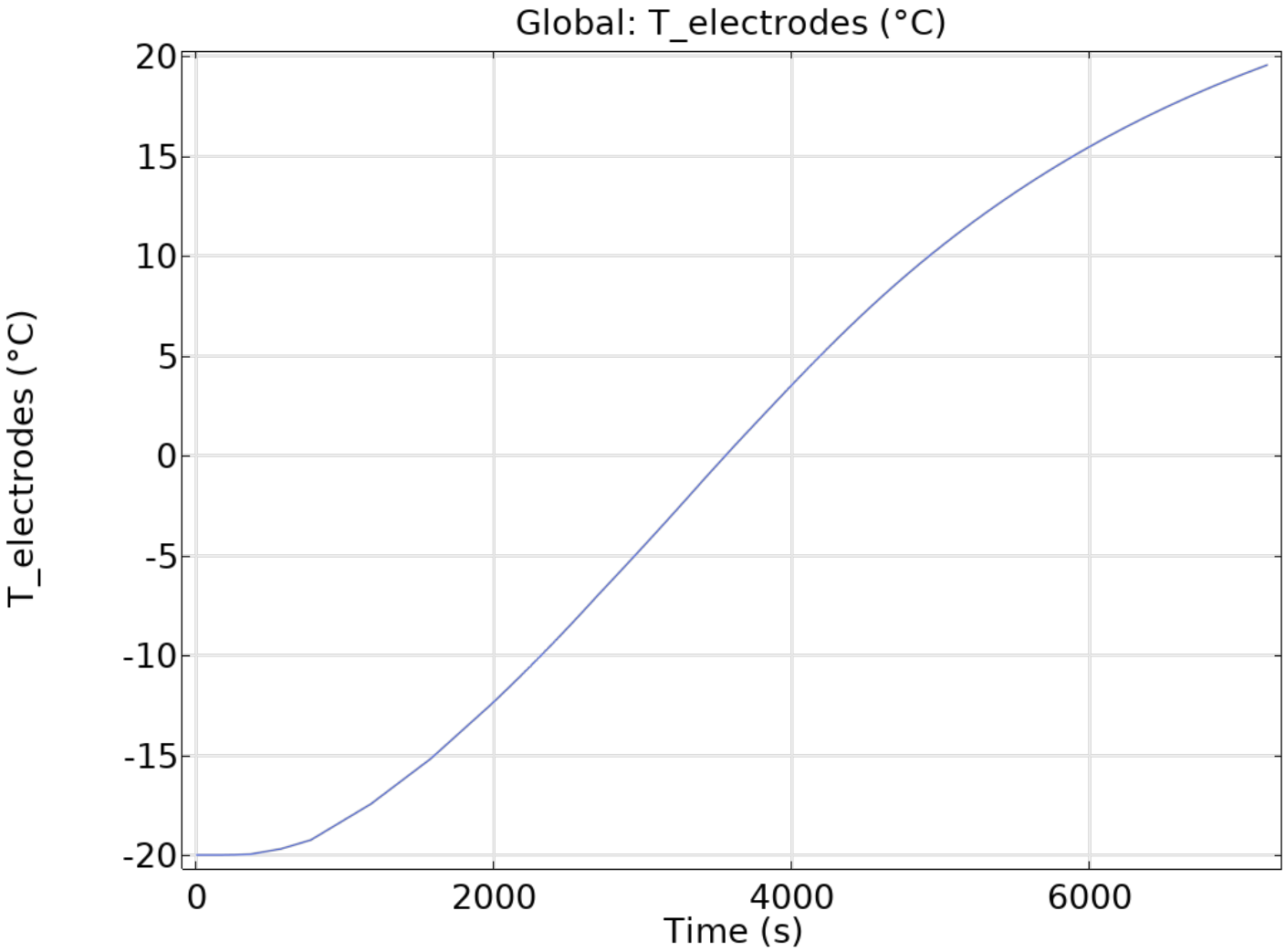

Figure 4 : thermal transient in the battery pack