



Vrije
Universiteit
Brussel



Mobility, Logistics and
Automotive Technology
Research Centre



Electric Vehicle Symposium & Exhibition

June 19-22, 2016 | du 19 au 22 juin 2016

Montréal, Québec, Canada

Lithium-ion capacitor – optimization of thermal management from cell to module level

Gert Berckmans*,¹, Ahmadou Samba¹, Noshin Omar¹, Jan Ronsmans², Mehdi Soltani¹,
Yousef Firouz¹, Peter Van den Bossche¹, Joeri Van Mierlo¹, Joris Jaquemont¹

¹Vrije Universiteit Brussel, MOBI research group, Pleinlaan 2, 1050 Brussels, Belgium

²JSR Micro NV, Technologielaan 8, 3011 Leuven, Belgium



Summary

1. Introduction
2. LiCap model
3. Parameters extraction
4. Results 1D and 3D modelling
5. Conclusion

Introduction

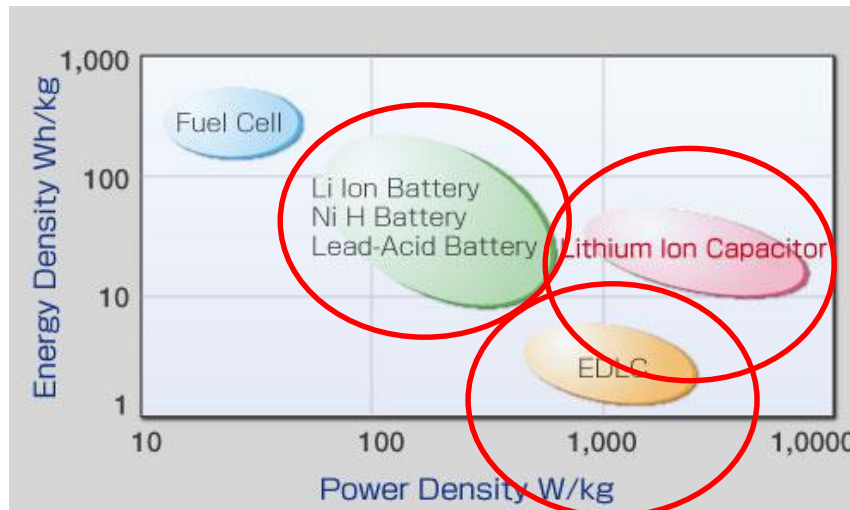
Context:

Due to the increasing demand of using high energy and high power storages in electrified vehicles, advanced energy storage systems (ESSs) have emerged:

- Hybrid systems with electric double-layer capacitor (EDLC) and Lithium-ion battery (LiB) but main barriers:
 - Cost;
 - Weight;
 - Volume;

In the last decade, other type of ESS has been developed (Lithium-ion capacitor or hybrid capacitor):

- Higher operating conditions (3.8Vmax);
- Energy density of 15 Wh/kg ;
- 10 kW/kg could be achieved.



Ragone plot

Introduction

LiCap:

- Hybrid energy storage system;
- Combines the mechanism of Li-ion battery with the cathode and EDLC.

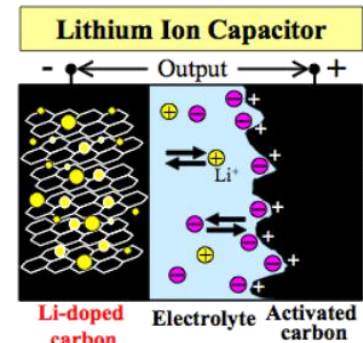
Meets the requirements of automotive battery pack:

- Coping with the high power output during acceleration and braking
- High storage capacity to ensure sufficient driving range
- Competitive energy efficiency
- High cycle life

Principal barrier:

- High internal heat generation:
 - Problem for module;
 - Accelerates aging;
 - Provokes thermal runaway.

- Need for a proper thermal management system (TMS)



LIC's capacitance is twice compared to EDLC

LiCap working mechanisms

Introduction

To develop a TMS:

Accurate thermal model



Presentation of a 3D electrothermal LiCap model based on a COMSOL interface validated with thermal images.

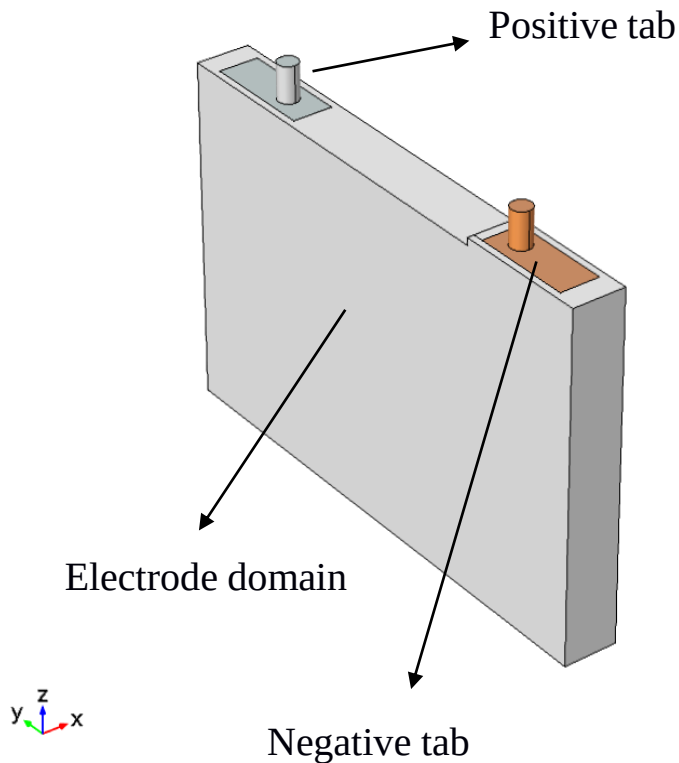
Main originalities:

- LiCap technology
- Thermal study

Model cell development (1)

Geometry:

Composed of three domains



Model:

Uses basic thermal equations

Heat equation:

generated heat stored inside the cell.

$$\rho C_p \frac{dT}{dt} = \left[\lambda_x \frac{\partial^2 T}{\partial^2 x} + \lambda_y \frac{\partial^2 T}{\partial^2 y} + \lambda_z \frac{\partial^2 T}{\partial^2 z} \right] + \dot{q}$$

Heat exchange at surroundings:

$$-\left[\lambda_x \frac{\partial T}{\partial x} + \lambda_y \frac{\partial T}{\partial y} + \lambda_z \frac{\partial T}{\partial z} \right]_{boundaries} = h(T - T_a)_{boundaries}$$

Heat source:

$$\dot{q} = I(U - V) - IT \frac{\partial U}{\partial T}$$

$$\dot{q} = \frac{R' I^2}{V_{tab}}; \quad R' = \rho' \frac{l}{S}$$

- Capacitance: 2300F,
- Nominal cell voltage: 3.3V,
- Cell weight: 300 g.

Model cell development (2)

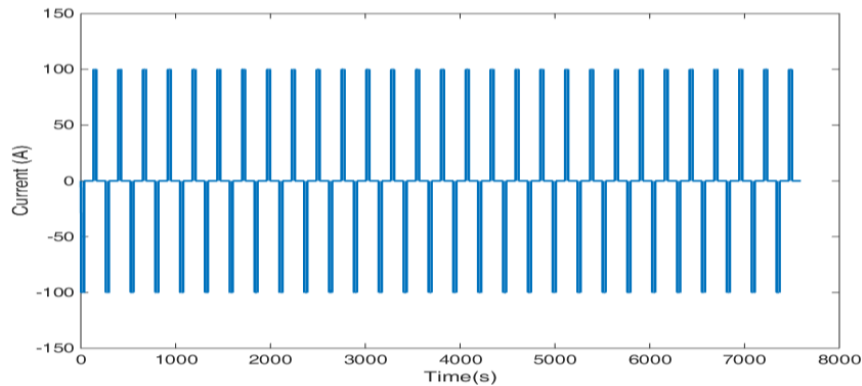
Required inputs:

- Density (ρ)
- Convective heat coefficient (h)
- Heat sources ($\dot{q}$)
- Thermal conductivity ($\lambda_x \lambda_y, \lambda_z$)
- Heat capacity (C_p)

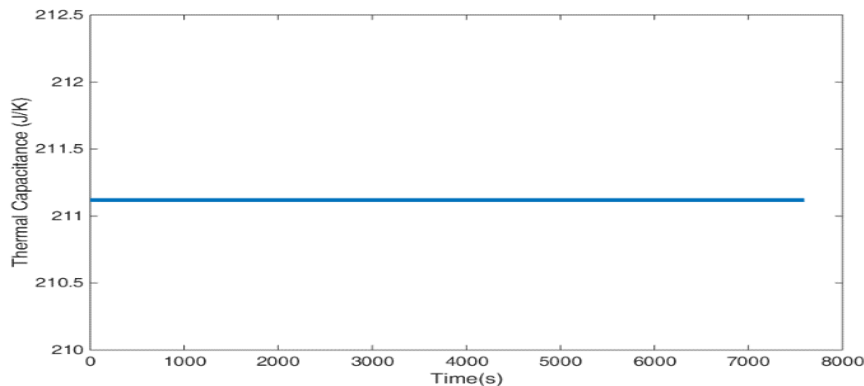
Parameters extracted from validated 1D electro-thermal matlab model

Results (1)

Parameter extraction

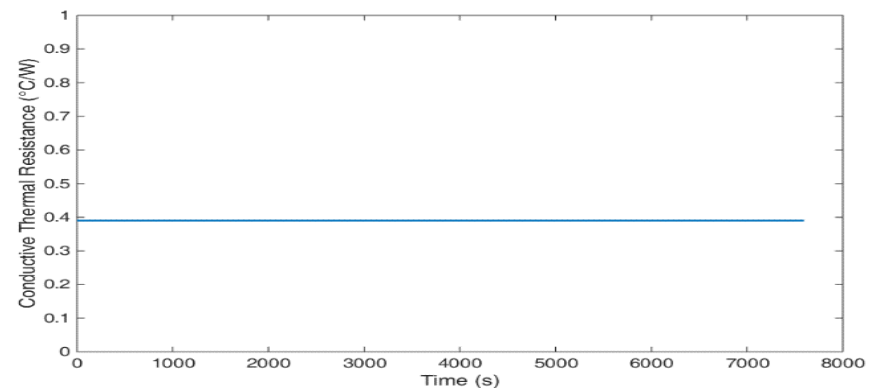


Applied load profile



Thermal capacitance
based on load profile

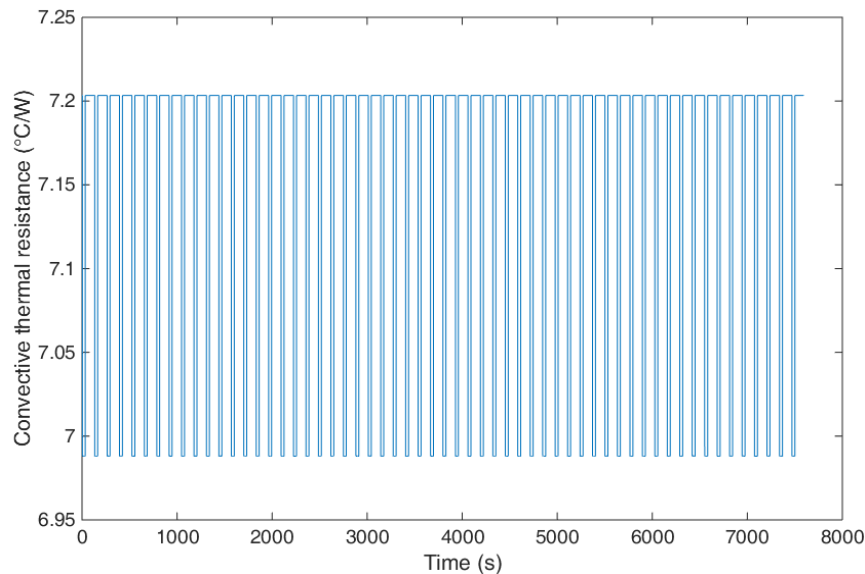
Parameter estimation algorithm;
Measured temperature compared
with the simulation.



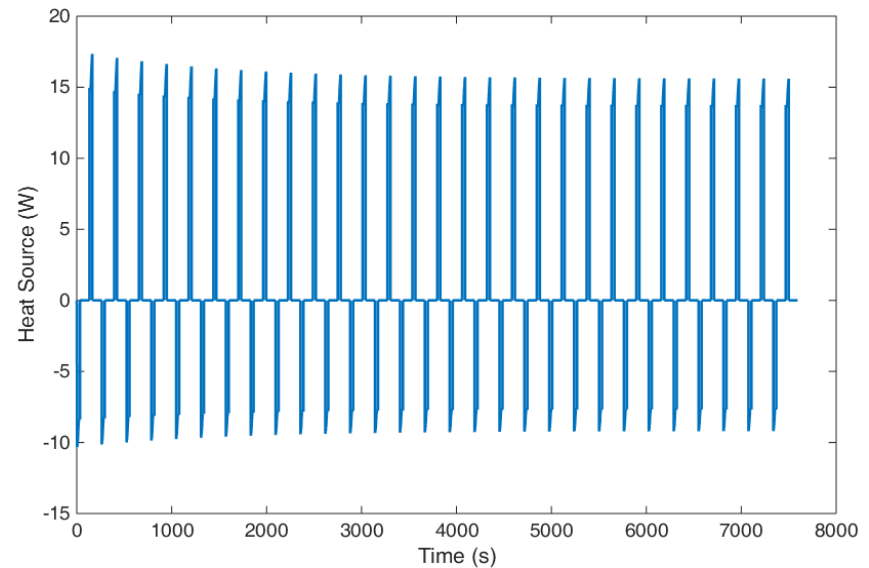
Conductive thermal resistance
based on load profile

Results (2)

Parameter extraction



Convective thermal resistance
based on load profile

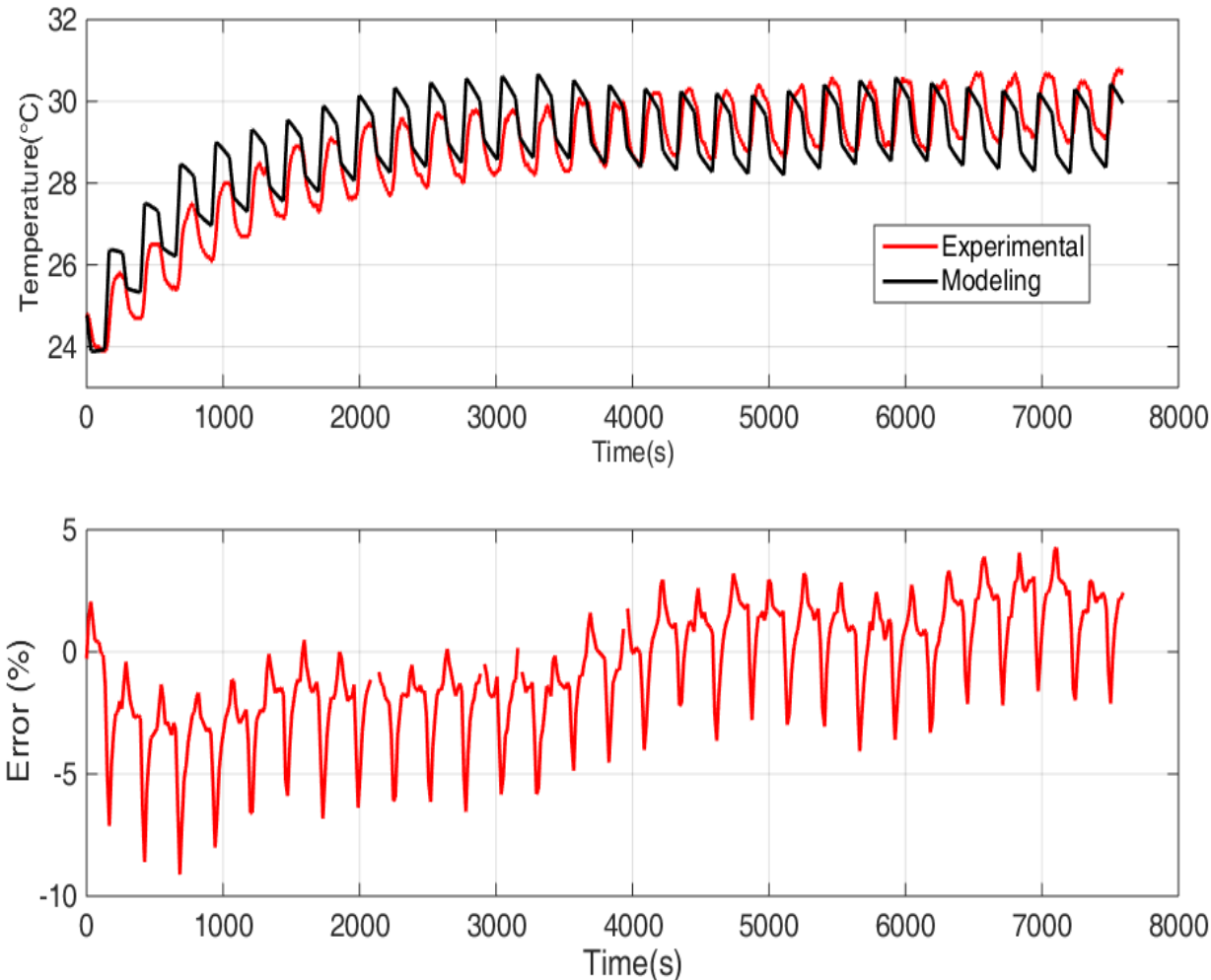


Heat source based on load profile

With the different inputs the thermal behaviour of the LIC cell can be simulated

Results (3)

Load profile at 25°C



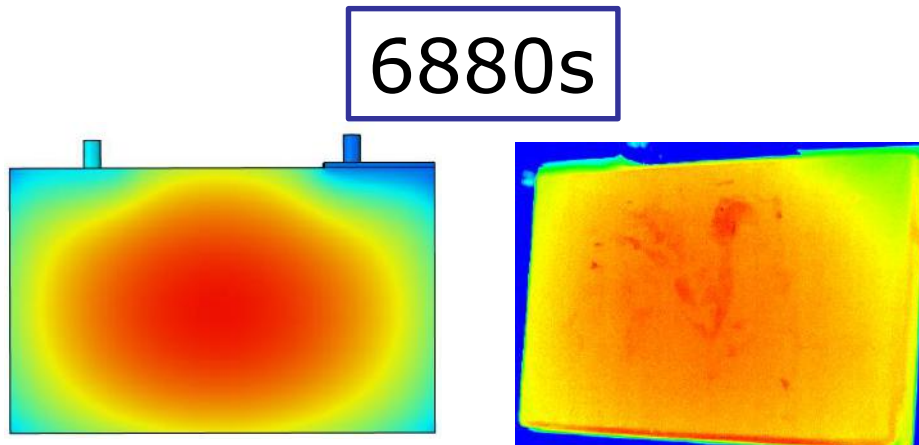
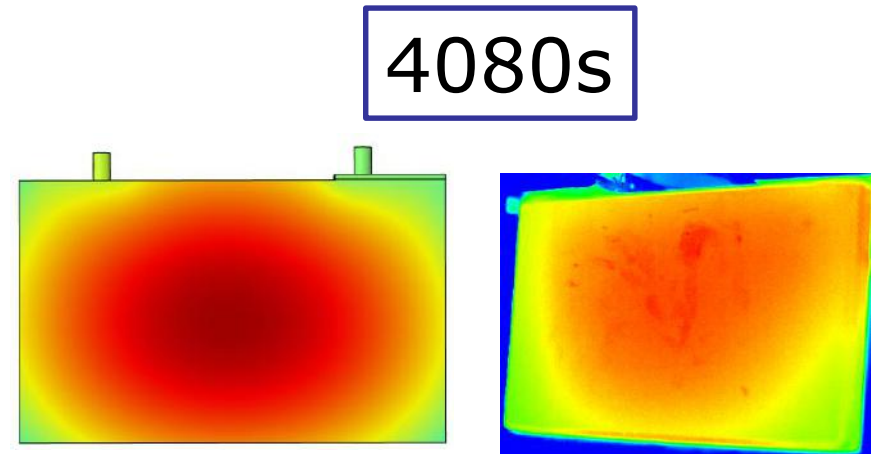
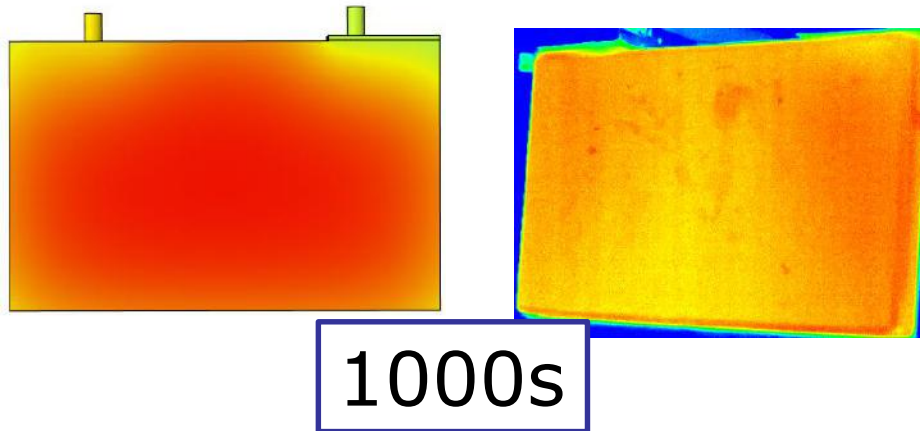
Remarks:

- A good match is found between the experimental and simulation
- Difference between the simulation and experimental values are less than 1°C
- Temperature increases during the discharge, but decreases during the charge due to the high endothermic heat source

Results (4)

Thermal image validation

At different time steps with the load profile



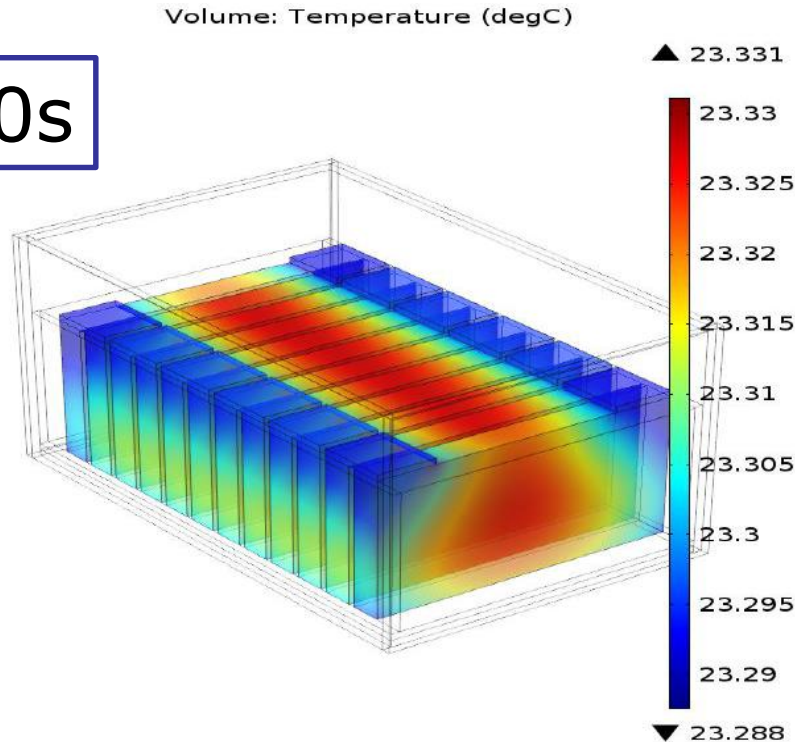
Remarks:

- Temperature nearly uniform;
- The maximum is located near the positive tab due to the higher resistance of the aluminium;
- A good agreement between the experimental and simulation.

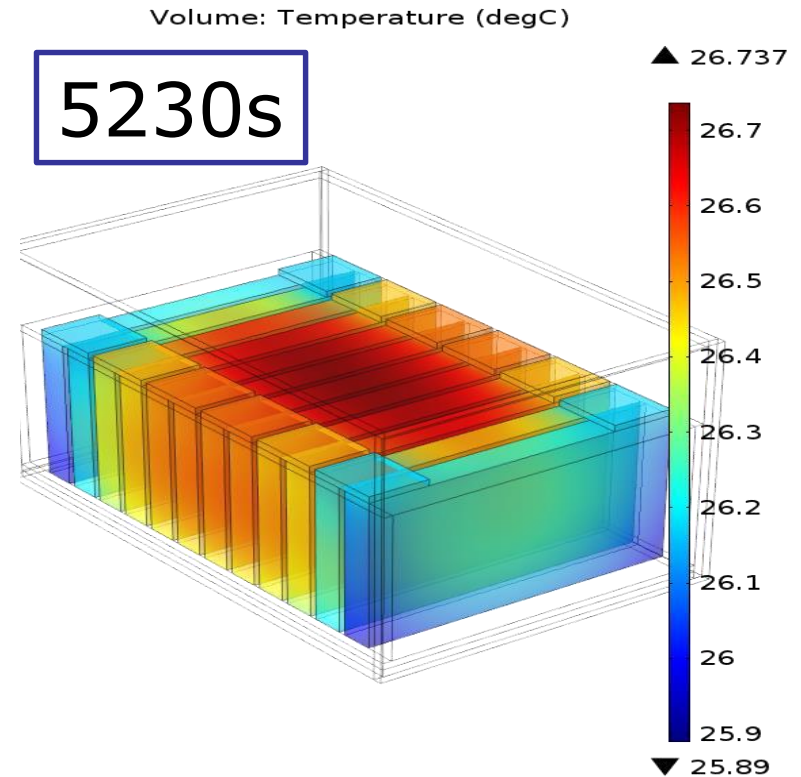
Results (5)

Following the 3D cell model, model has been extended to module level 48V (12 cells in series).

200s



5230s



Remarks:

- Temperature increase is more located at the middle of the module;
- Passive air-cooling will not be enough to have a uniform temperature distribution.

Conclusion

3D thermal model of lithium ion capacitor
created and validated

- Error max 2°C
- Module level

Perspectives:

- Simulation and development cooling system
- Different initial temperatures
- Module arrangement

Thank you, Merci