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FAST CHARGING OF A LITHIUM-ION BATTERY :

CHARGING CURRENT CONTROL STRATEGY BASED ON ONLINE EVALUATION OF THE CHARGEABILITY STATUS OF ITS CELLS.

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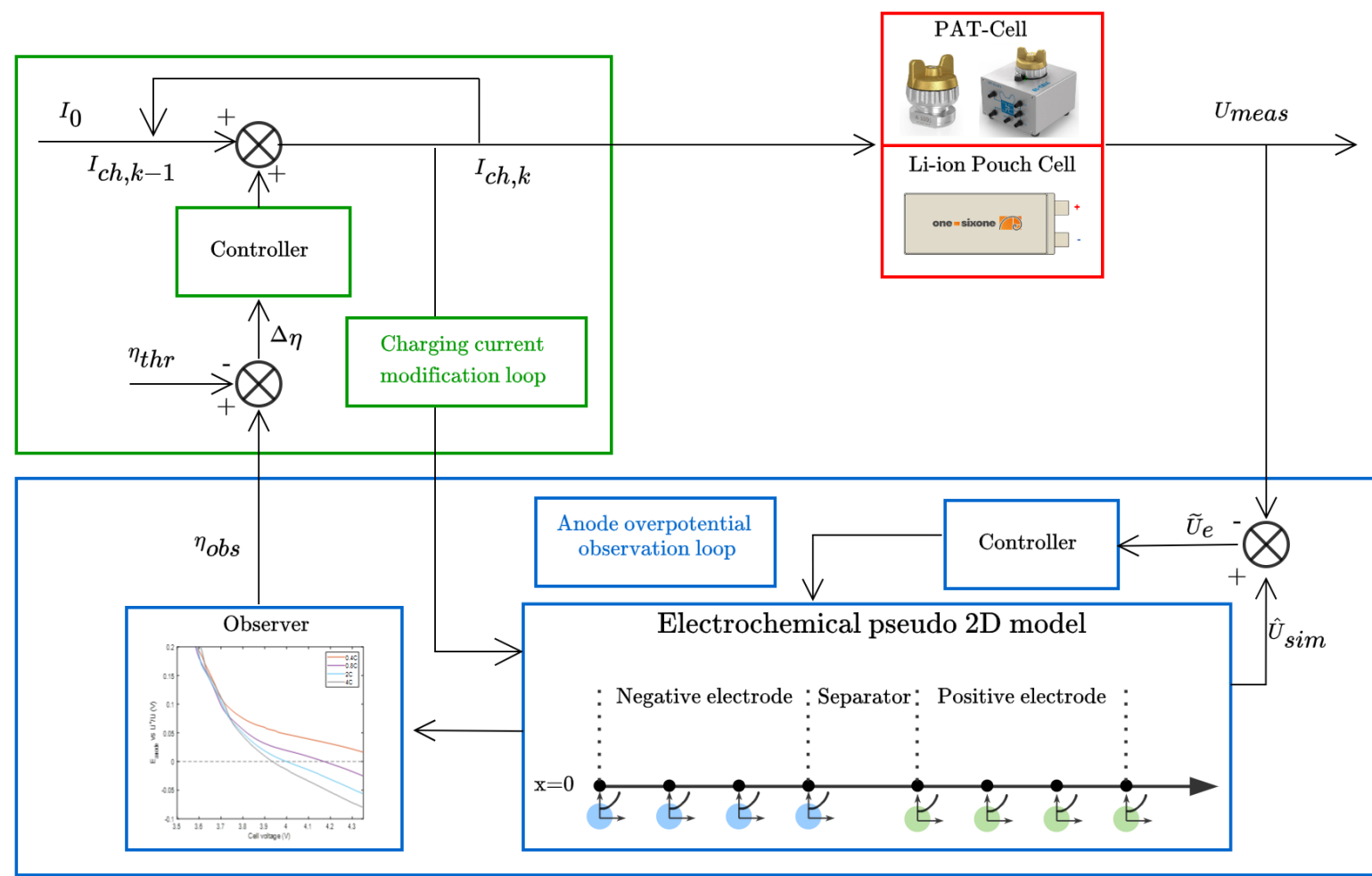
CONTEXT

Charging time reduction allows :

- Minimizing the battery size and therefore reducing the vehicle acquisition cost and GHG emissions primarily owing to the production of the battery.
- Using the vehicle for both short and long trips (travels, etc).
- Reducing the time spent at charging stations.

METHODOLOGY

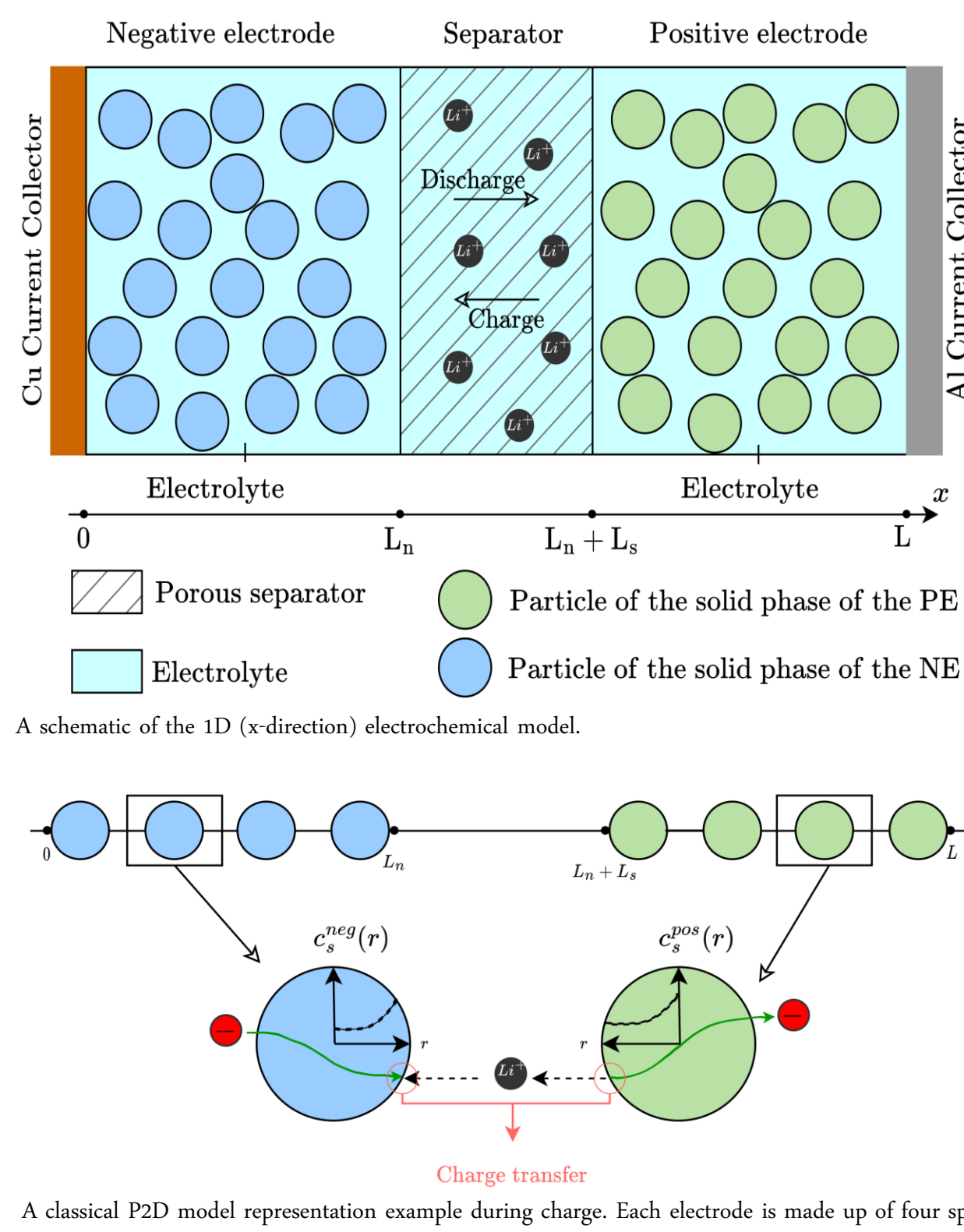
This algorithm enhances the charging current in order to maintain the observed overpotential near the threshold potential while reducing the charging time and protecting the cell's state-of-health SOH.



- Development of an electrochemical P2D model suitable for fast charge.
- Online estimation of the model's states and parameters (Kalman Filter EKF).
- Control of the charging current in real-time based on the observation of the negative electrode potential → robust fast charging algorithm.
- Validation of the protocol by cycle ageing followed by post-mortem analysis.

ELECTROCHEMICAL PSEUDO 2-D MODEL

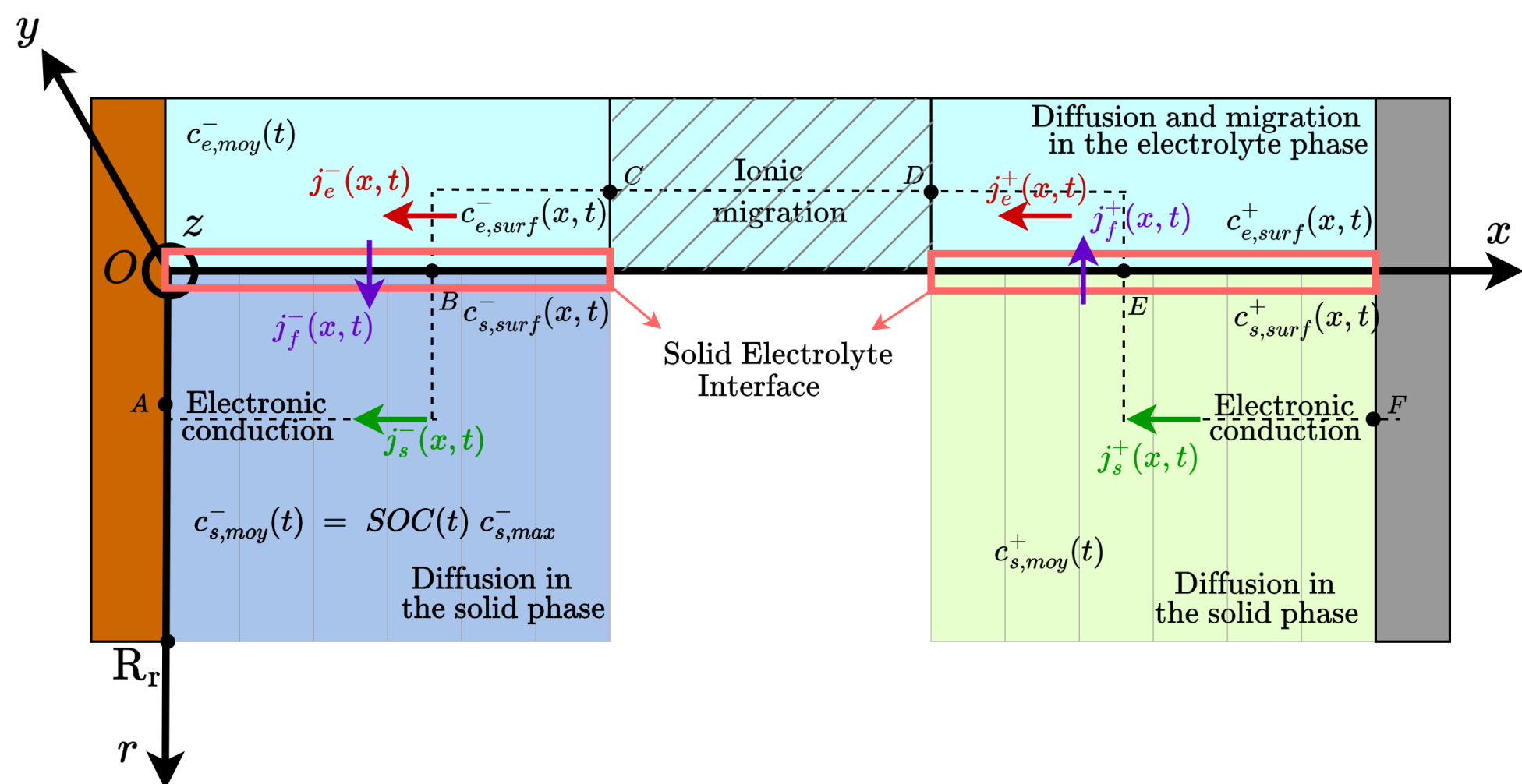
Classical approach : Newman's Full order P2D model



- Initially developed by Newman and Tiedmann in 1975 [2].
- One of the first to use partial differential equations (PDE) to describe local electrochemical phenomena.
- Based on porous electrode theory : an electrode is a superposition of solid matrix and electrolytic phase.
- Particles of active material = spheres.
- Given the electrode's thickness, the particles are thought to have a very small radius.
- The solid is connected to the electrolyte through mass balances and reaction rate, which is obtained by the potential difference between the phases.

[2] Johan Newman and William Tiedmann, "Porous-electrode theory with battery applications", in: *AIChE Journal* 21.1 (1975), pp. 25-41.

Our approach : Homogenization of porous electrodes



- Butler-Volmer equation : $j_f(x, t) = a_s i_0 \left[\exp\left(\frac{\alpha_a F}{RT} \eta_s(x, t)\right) - \exp\left(\frac{\alpha_c F}{RT} \eta_s(x, t)\right) \right]$
- Local electrode overpotential : $\eta_s(x, t) = \phi_s(x, t) - \phi_e(x, t) - OCP\left(\frac{c_{s,surf}}{c_{s,max}}\right)$
- Mass conservation in the electrolyte : $\epsilon_e \frac{\partial c_e}{\partial t}(x, t) = \frac{\partial}{\partial x} \left(D_e^{eff} \frac{\partial c_e}{\partial x^2}(x, t) \right) + \frac{(1-t_+)}{F} j_f(x, t)$
- Charge conservation in the electrolyte : $j_e(x, t) = -\kappa_e^{eff} \frac{\partial \phi_e}{\partial x}(x, t) - \kappa_D^{eff} \frac{\partial \ln(c_e(x, t))}{\partial x}$
- Mass conservation in the solid phase : $\frac{\partial c_s}{\partial t}(x, r, t) = D_s \frac{\partial^2 c_s}{\partial x^2}(x, r, t)$
- Charge conservation in the solid phase : $j_s(x, t) = -\sigma_s^{eff} \frac{\partial \phi_s}{\partial x}(x, t)$

CHALLENGES

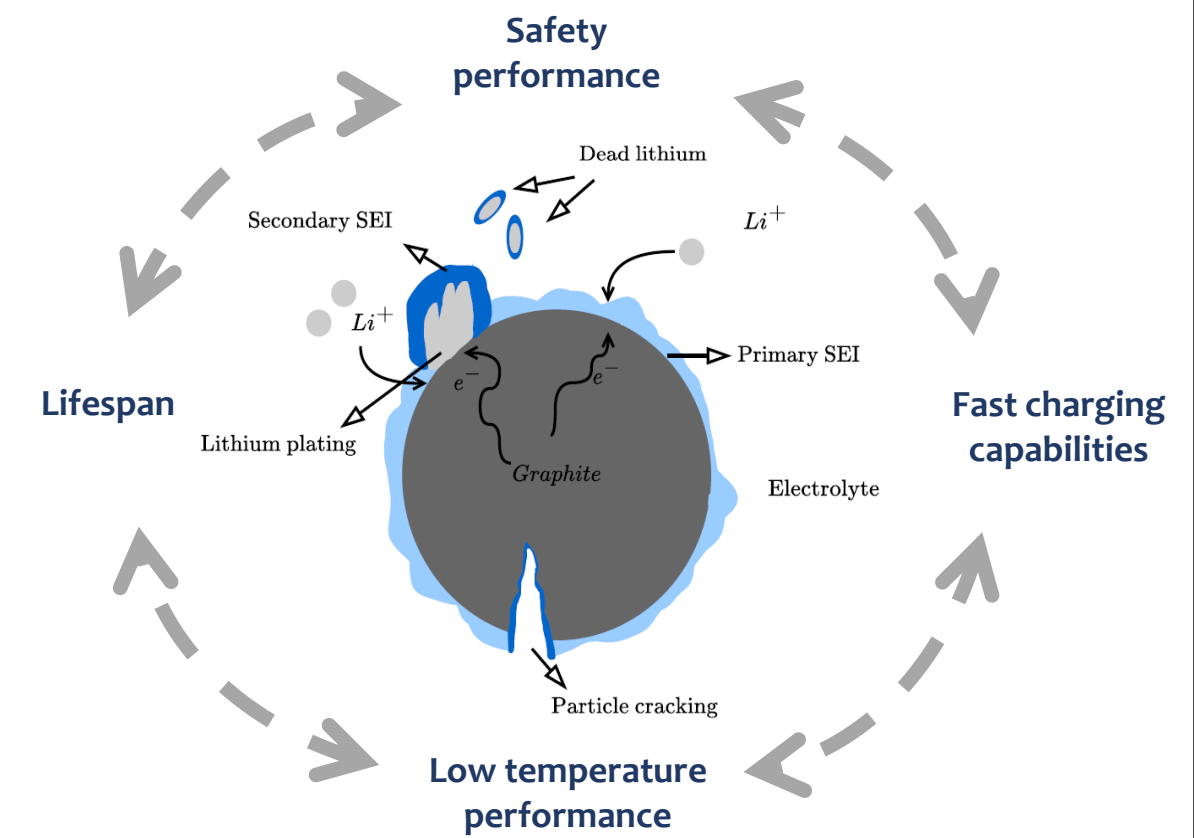
Standard fast charging methods of Li-ion batteries :

- Shorten the overall lifespan by degradation of the negative electrode.
- Can cause potential risks such as :
 - Internal short circuits produced by Li-plating at the negative electrode.
 - Thermal runaway owing to heat generation (high temperature).

LITHIUM PLATING AGING MECHANISM

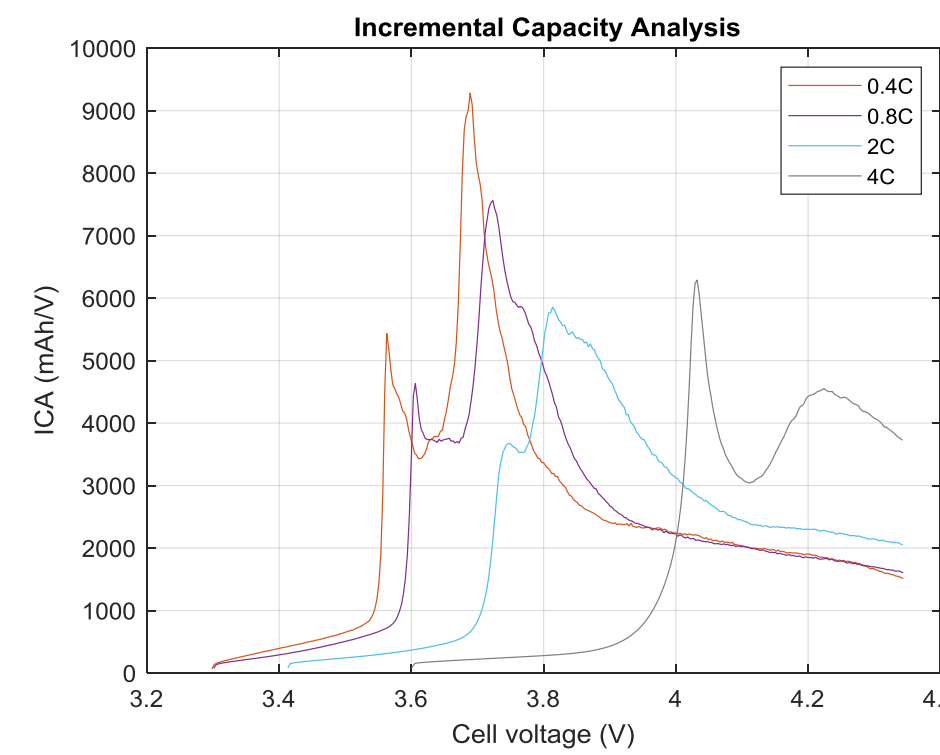
Li-plating is one of the major factors influencing the ageing and safety performance of Li-ion batteries throughout the charging process [1] : during the extraction of Li⁺ ions from the positive electrode and their insertion into negative electrode with reduction to lithium metal.

The onset of Li-plating happens when the open circuit potential of the graphite electrode goes below 0 V.



Li-plating Detection Method

On ICA curves, intercalation peaks shift towards higher voltages for high charging rates (4C) as the cell polarization increases (charge transfer and mass transport effects as well as ohmic drop across the electrolyte).

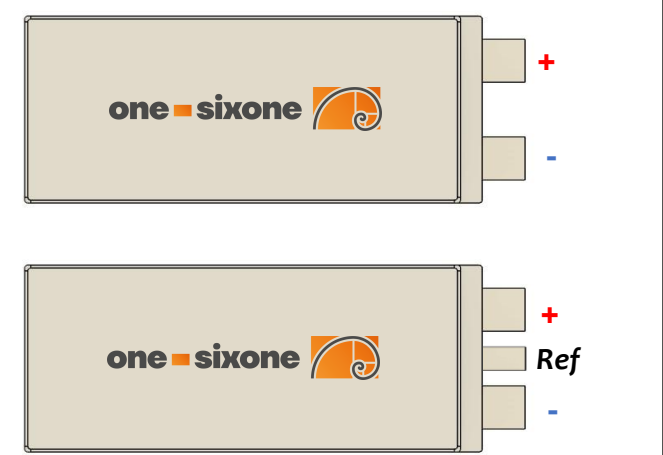


[1] M. Fleischhammer, T. Waldmann, G. Biele, B.J. Hogg, and M. Wohlfahrt, "Interaction of cyclic ageing at high rate and low temperatures and safety in lithium-ion batteries," *Journal of Power Sources*, vol. 274, pp. 432-439, 2015

EXPERIMENTAL MEANS

Li-ion pouch cells designed by One-sixone to charge from 20% to 80% SOC in 20 mins (280 Wh/kg) and 10 mins (250 Wh/kg) :

- L x W x H = 142 x 65 x 8 mm.
- Full cell capacity = 12.7 Ah.
- 3-electrode cell capacity = 2.6 Ah.



Cell teardown and electrochemical property analysis

PAT-Cell, test cell for 2- and 3-electrode testing of battery materials designed by EL-CELL GmbH (Germany)

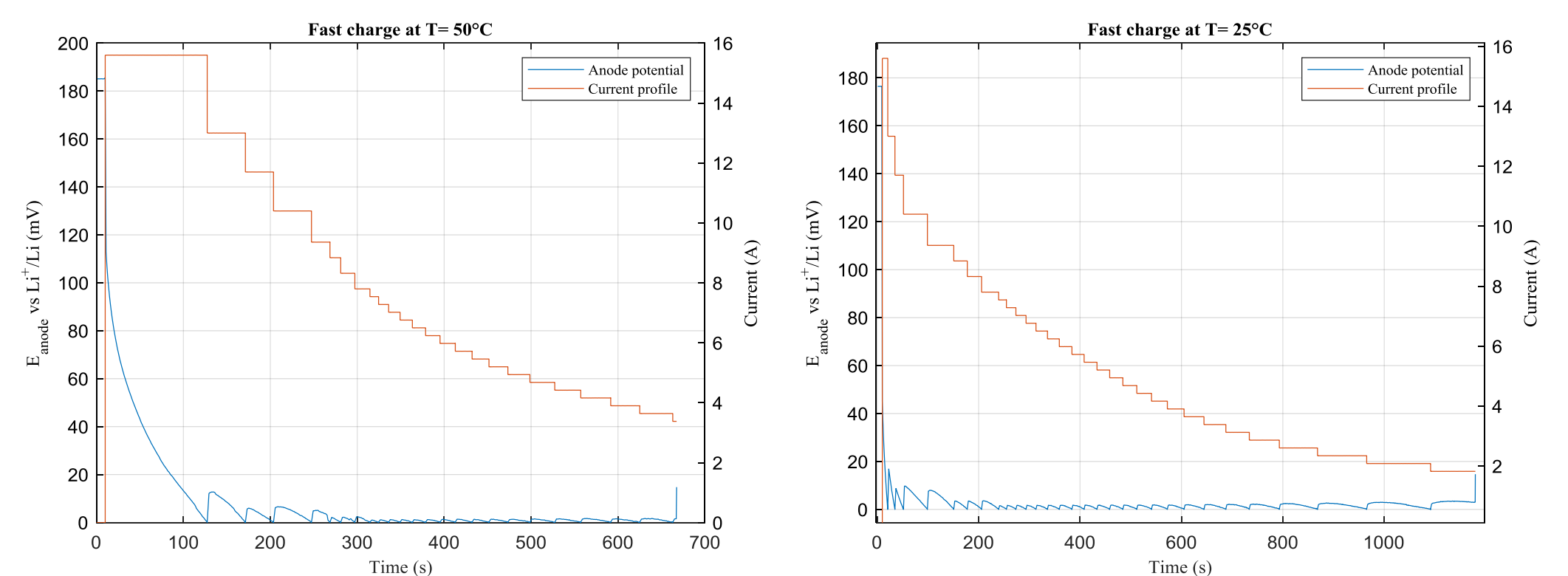
- Parametrization of the 12.7 Ah pouch cells P2D model.
- Galvanostatic Intermittent Titration Technique (GITT) tests to obtain the OCP, the diffusion coefficients and lithium stoichiometry of the electrodes.
- Fast charging tests while monitoring the negative electrode potential.



<https://www.el-cell.com/products/test-cells/standard-test-cells/pat-cell/>

OPTIMAL FAST CHARGING PROTOCOL

Multistage Constant Current MCC



- This protocol is controlled by the E_{NE} < 0V condition.
- It requires access to the negative electrode potential, which must be measured or simulated by means of an electrochemical P2D model.
- It guarantees no Li-plating as E_{NE} is constantly above 0V vs. Li/Li⁺.

PERSPECTIVES

- Estimate the model's parameters online using Extended Kalman Filter EKF.
- Determine through experimental techniques the electrodes' electrochemical, chemical and physical properties using PAT-cells.
- Develop the fast charging algorithm using a PID controller .

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