Modeling Lithium Plating to Achieve Fast Charging of Lithium ion Batteries

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Transportation

https://youtu.be/fWFixYSos7c

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Introduction

Transportation makes up for 25% of the U.S. total petroleum use

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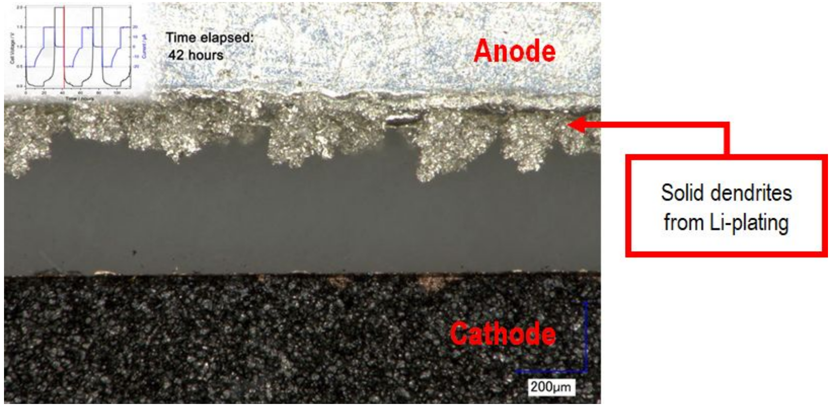
There is a regulatory interest in reducing our carbon footprint and reliance on fossil fuels

↓

Aggressive targets for vehicle electrification and CO2 emissions [1]

To make electric vehicles more desirable to consumers, fast and accessible charging needs to be made widely available.

At the battery level, **lithium plating** (Li-plating) is the main limiting factor for fast charging.



[2]

Irreversibly plated lithium is unfavorable to both <u>cell life</u> as well as <u>safety</u> due to the risk of piercing the separator and shorting the electrodes

Better understanding of the Li-plating (and reversible Li-stripping) reactions needs to be developed to enable fast charging of electric vehicles.

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Objective

Use nondestructive experimental techniques coupled with electrochemical modeling to predict and understand the mechanisms associated with Li-plating

Measure individual cell electrode potential during fast charging using a reference electrode to quantify and predict the onset of lithium plating

→

Build a physics-based **model** to capture the effects of Li-plating and Li-stripping on overall cell behavior and match results seen in experimental data

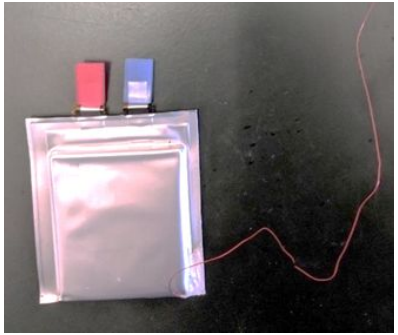
→

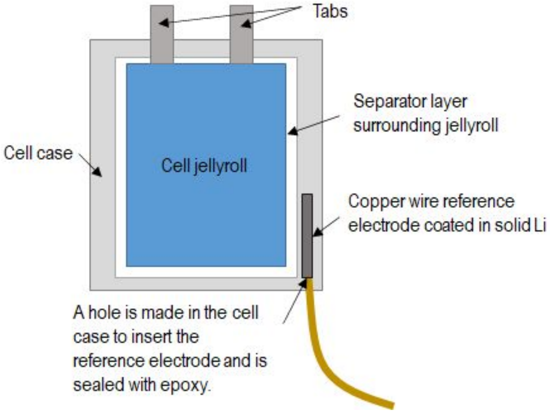
Use the model to **analyze** the physical phenomena occurring in the cell during fast charging and predict the onset and location of Li-plating

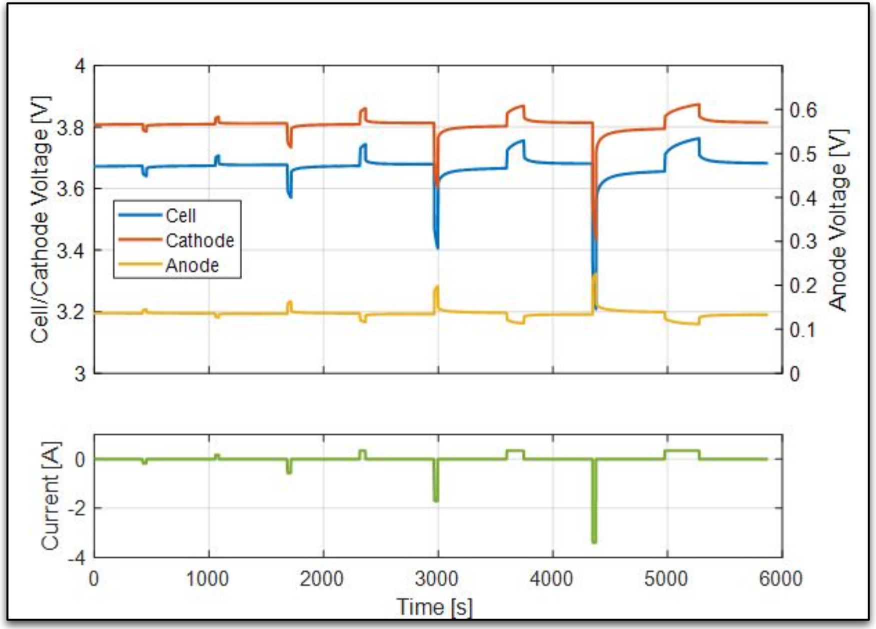
Measure → Model → Analysis

Methods: Experimental

- A **reference electrode** was inserted into an existing pouch cell by piercing a small hole in one of the corners of the pouch cell and inserting a 22 AWG copper wire covered in electroplated solid Li into the cell.
- The reference electrode in the cell gives the benefit of **measuring the anode and cathode potentials independently**, allowing for in-situ tracing of the behavior of the individual working electrodes and **tracking of the potential of the anode to measure the onset of Li-plating**







Example results from the reference electrode data collection, in which the anode and cathode potentials can be read in-situ as the cell is cycled.

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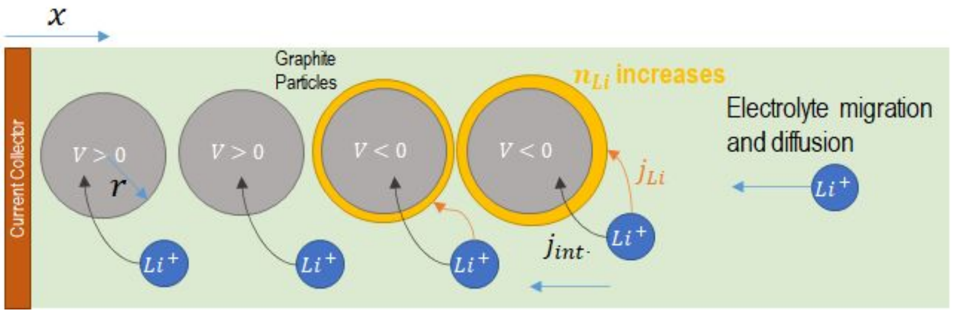
Methods: Modeling

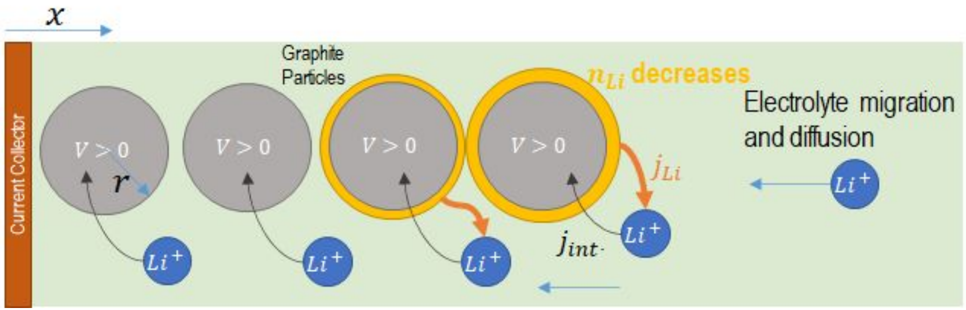
Measure → **Model** → Analysis

A **mechanism** for lithium plating and Lithium stripping was postulated and applied to a single cycle of fast charging with reversible plating



Plating Process:

The amount of plated lithium grows due to a side reaction current density, leading to the formation of solid lithium in presence of a favored plating potential.



Stripping Process:

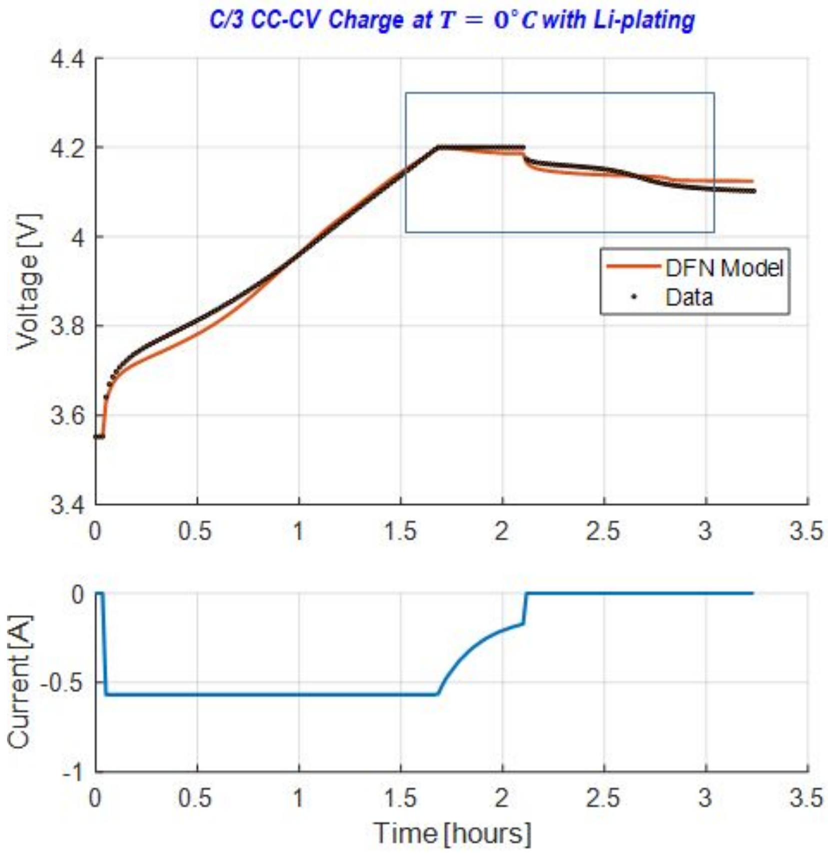
The amount of plated lithium can decrease as a result of a side reaction current density that dissolves the solid lithium in presence of a favored stripping potential, resulting in increased concentration of ionic lithium in the electrolyte solution and successive intercalation into the graphite.

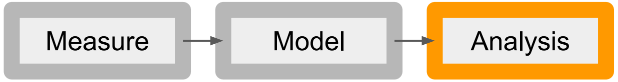
Measure → Model → **Analysis**

Results: Cell Potential

The proposed mechanism was inserted as a **side reaction in a physics-based electrochemical DFN (Doyle-Fuller-Newman) model** of the processes occuring in the cell to match the voltage plateau behavior in the cell indicating the presence of the Li-stripping side reaction [3]

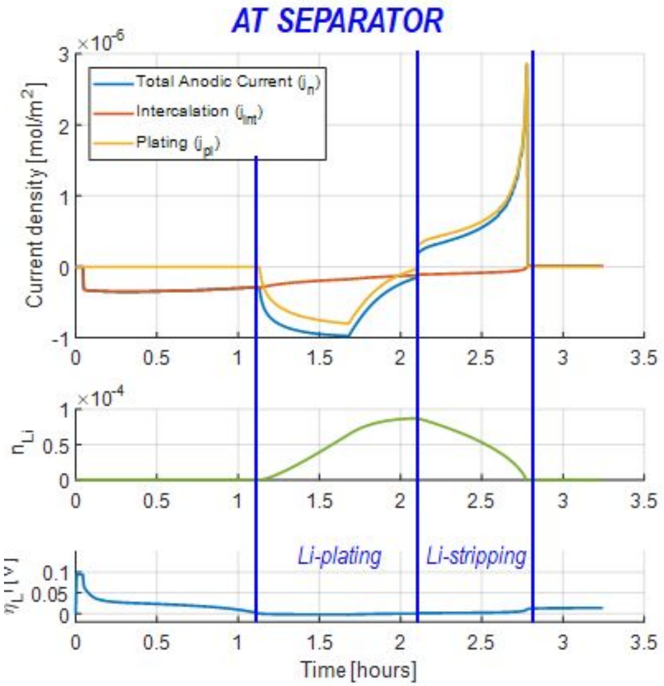
Once calibrated, these model outputs can be studied to **understand the mechanisms driving the Li-plating and Li-stripping reaction**

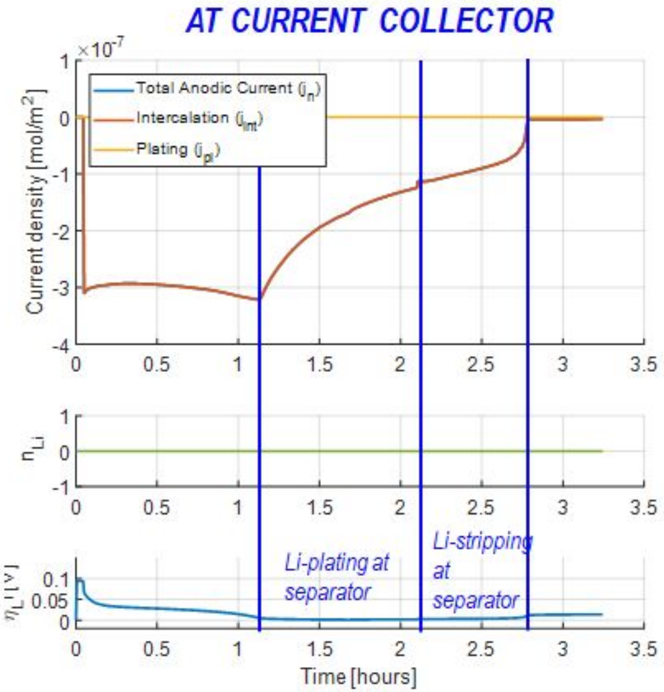




Results: Plating Prediction

The model can capture the **non-uniform plating behavior** through the depth of the anode and the consequent changes in plating and intercalation current density and gives insight into the location, quantity, and potential of Li-plating in the cell





Conclusions

Modeling fundamental physical processes in cell based on results of experimental phenomena

Investigation of the root causes and dynamics of the Li-plating and Li-stripping reactions

Design studies for cell construction and applied current profiles to avoid Li-plating and enable fast charging of electric vehicles

Outcomes of this work

Enable the increased desirability and competitiveness of electric vehicles

Future work

Expand these models to predict **long-term effects** of Li-plating on the cell, not just for single cycles of fast charging

Opportunities to **develop and apply** new charging protocols or cell designs using model-based predictions of Li-plating and Li-stripping reactions

References

[1] US Department of Energy, “Enabling Fast Charging: A Technology Gap Assessment,” US Department of Energy, Oct. 2017. Accessed: Mar. 03, 2019. [Online]. Available: https://www.energy.gov/sites/prod/files/2017/10/f38/XFC%20Technology%20Gap%20Assessment%20Report_FINAL_10202017.pdf.

[2] “Lithium metal dendrites: Pictures speak louder than words | EL-CELL.” https://el-cell.com/lithium-metal-dendrites-pictures-speak-louder-than-words/

[3] M. Doyle, “Modeling of Galvanostatic Charge and Discharge of the Lithium/Polymer/Insertion Cell,” *J. Electrochem. Soc.*, vol. 140, no. 6, p. 1526, 1993, doi: 10.1149/1.2221597.

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