Lithium-Ion Battery Simulation for Greener Ford Vehicles

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Outline

- **Vehicle Electrification at Ford** from Nickel/Metal-Hydride to Lithium-Ion Batteries
  - The Hybrid Electric Vehicle (HEV)
  - The Plug-in Hybrid Electric Vehicle (PHEV)
  - The Battery Electric Vehicle (BEV)
- **Li-Ion Battery Chemistry**
- **Li-Ion Battery Modeling (HEV)**
  - Comparison of model calculations to experimental pulse/rest behavior
  - Contributions to overvoltage during pulse and rest periods
  - Model calculations of lithium distribution
  - Sensitivity of voltage relaxation to particle characteristics
  - Sensitivity of initial overvoltage to anisotropy in solid-state Li diffusivity

Ford's current HEV lineup utilizes Nickel/Metal Hydride Battery Technology

Ford's Next-Generation HEVs will use Lithium-Ion Battery Technology

- Fusion
- C-max
- Escape

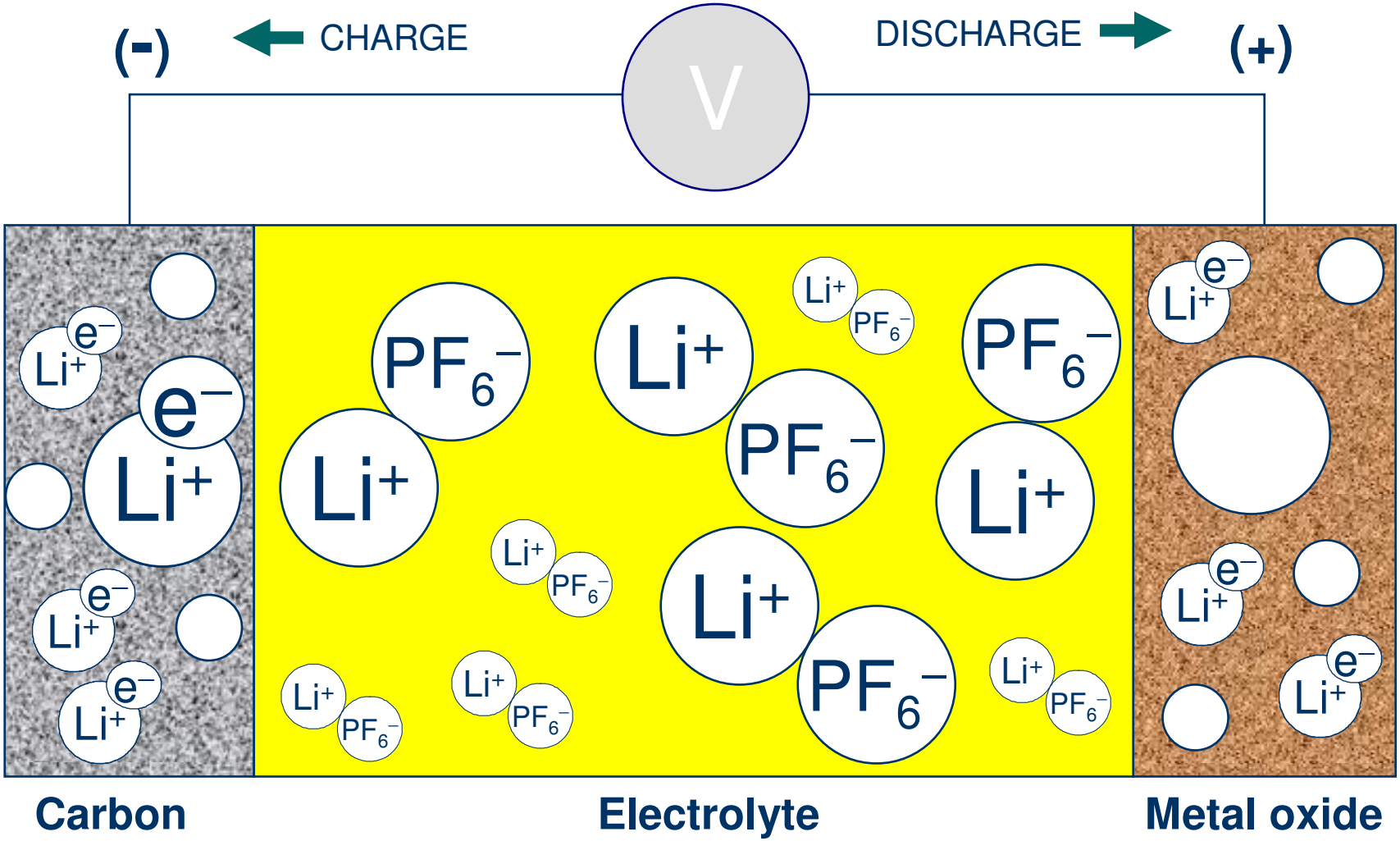
Ford's Plug-In Hybrid Electric Vehicles
will use Lithium-Ion Battery Technology

- C-max Energi

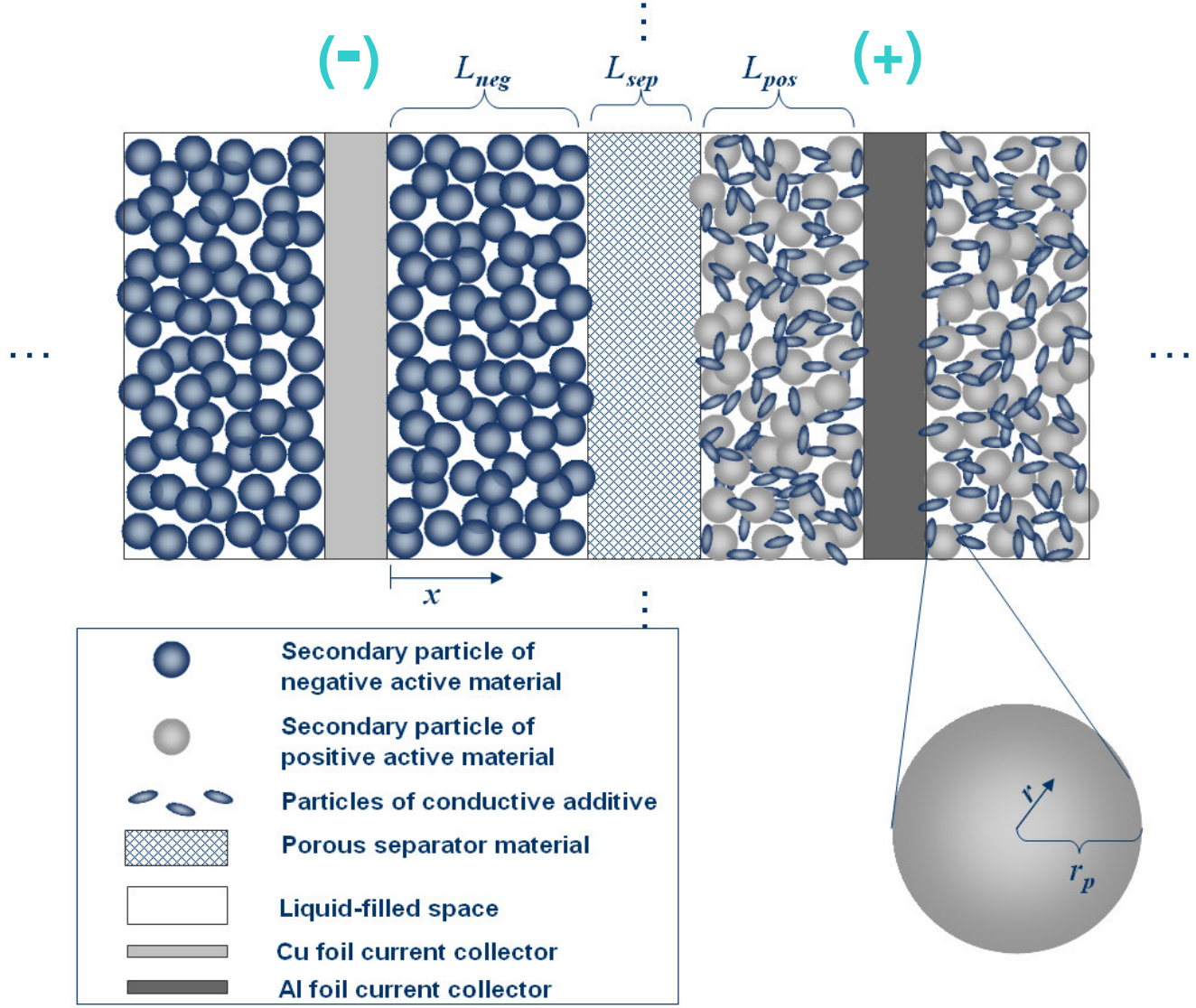
Ford's All-Electric Vehicles

- Focus
- Transit Connect

Lithium-Ion Battery Chemistry

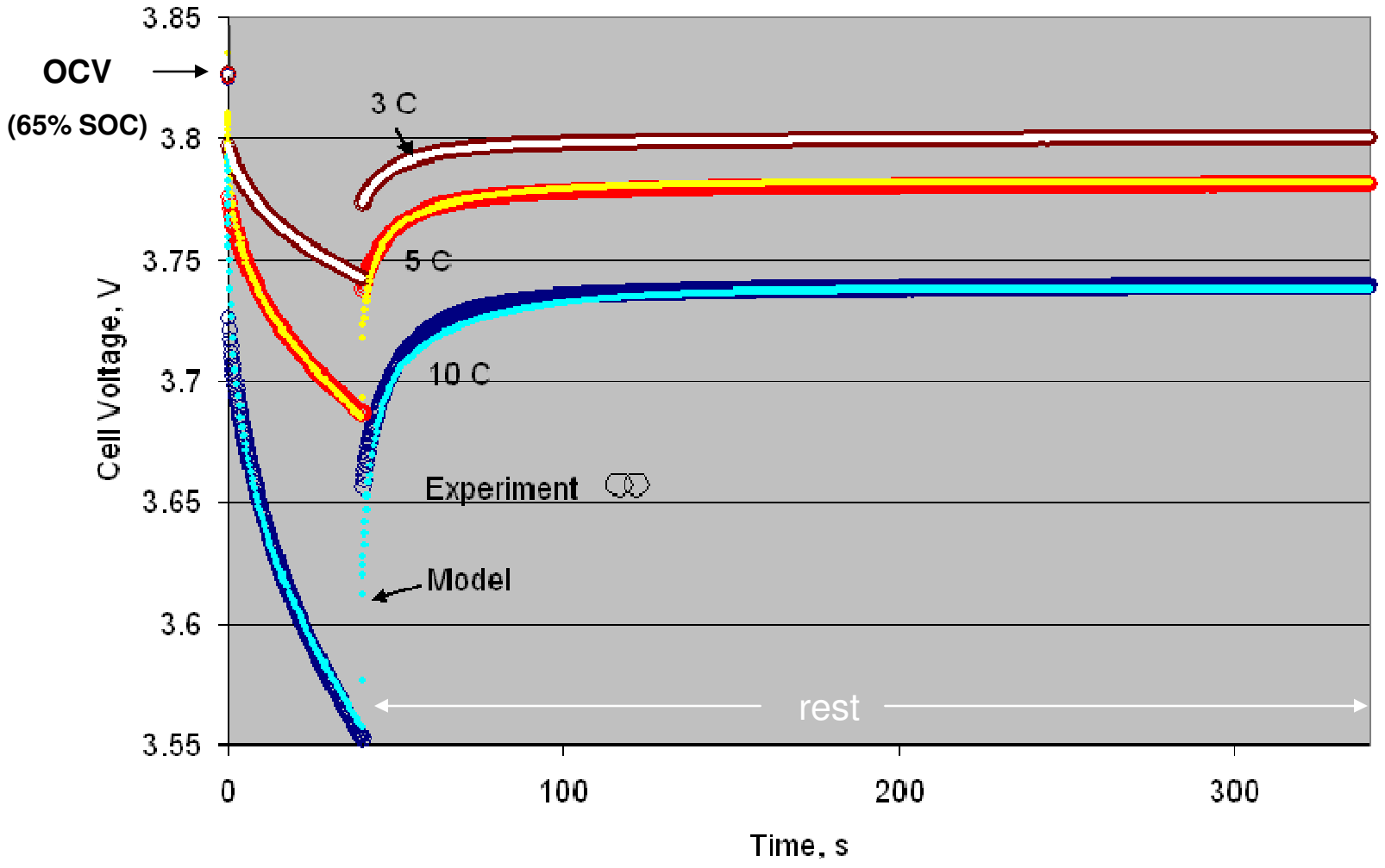


Lithium-Ion Cell Model

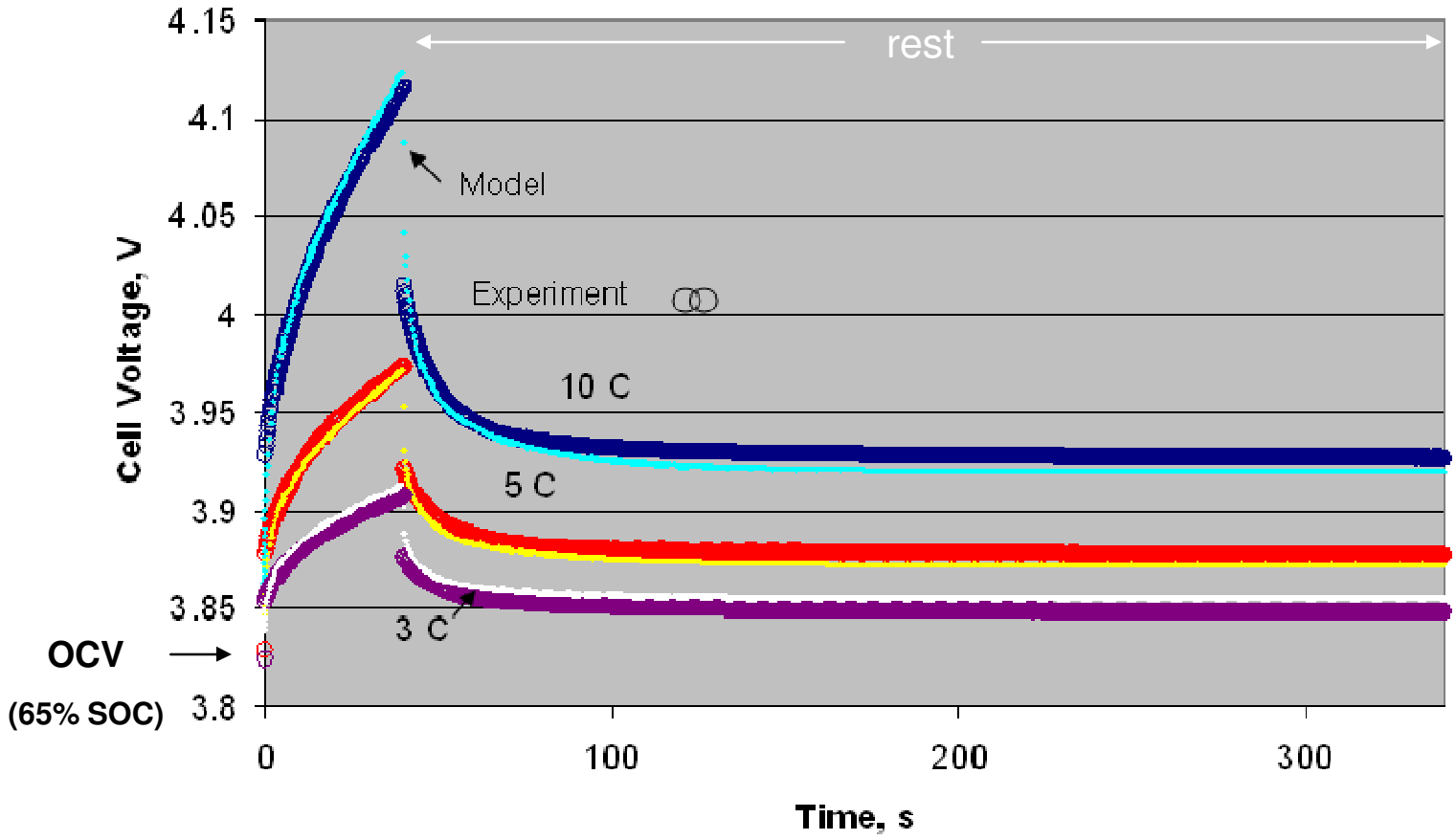


Journal of Power Sources, **196**, 412-427 (2011)

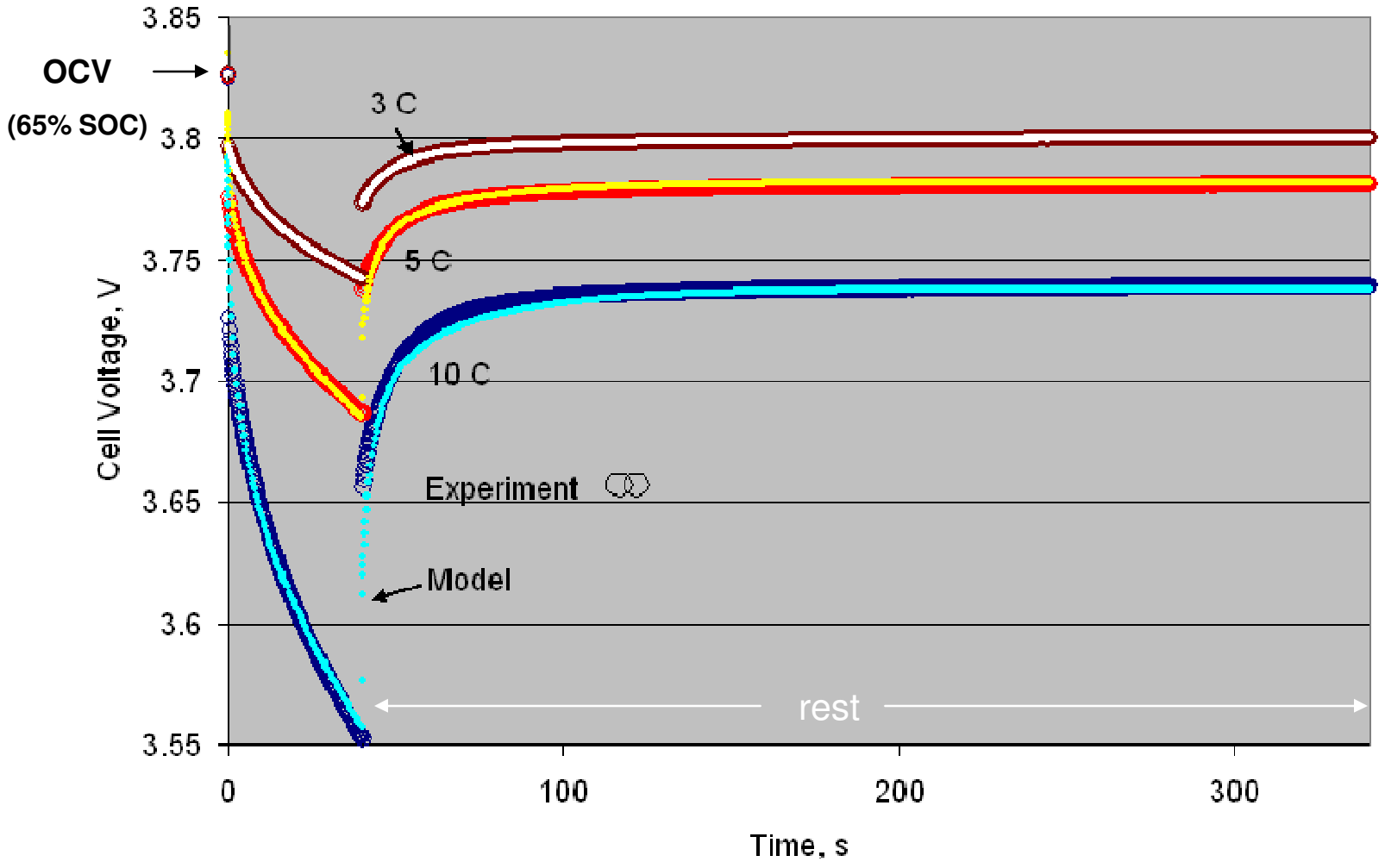
Discharge Current Pulse: Model vs. Experiment



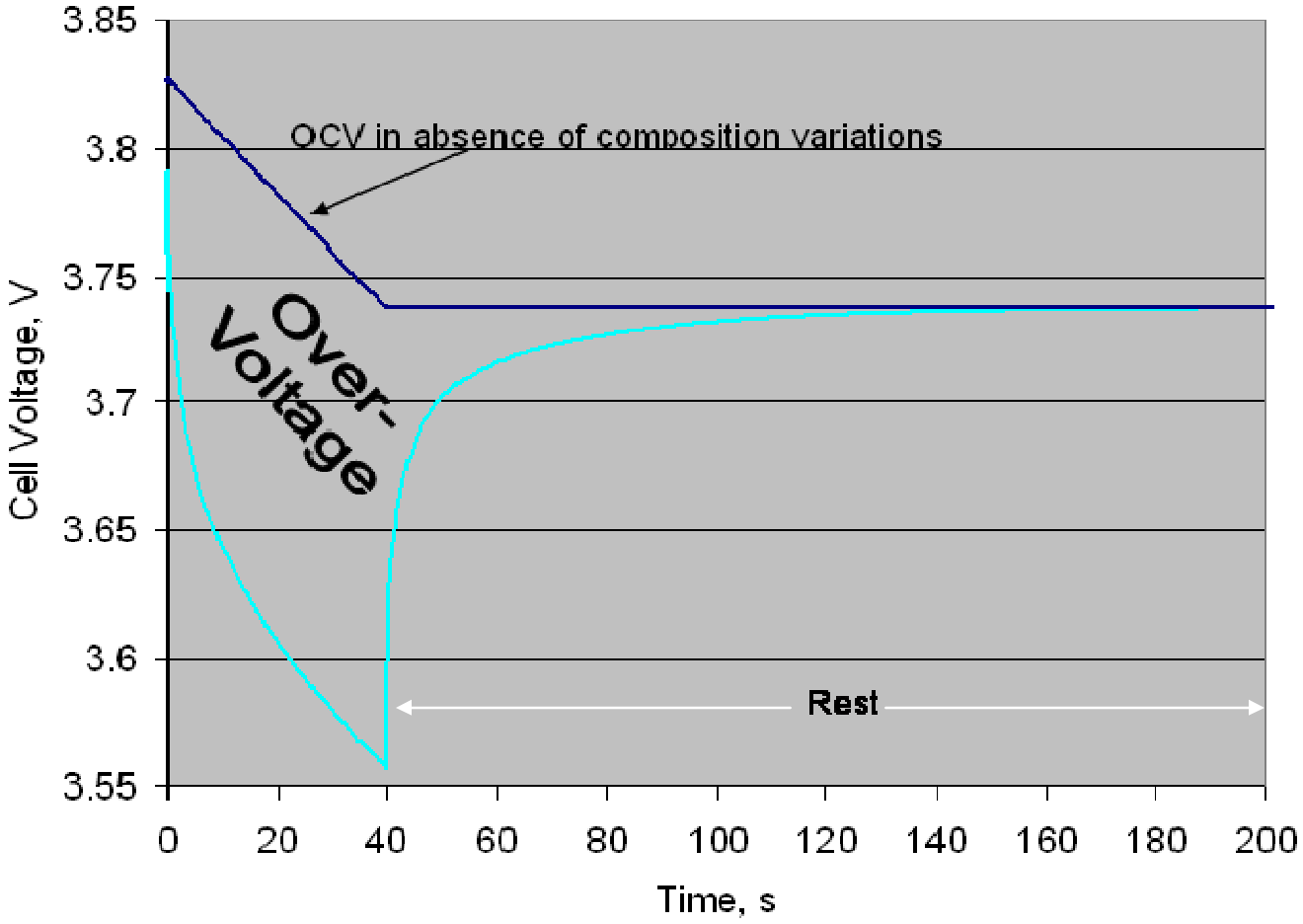
Charge Current Pulse: Model vs. Experiment



Discharge Current Pulse: Model vs. Experiment



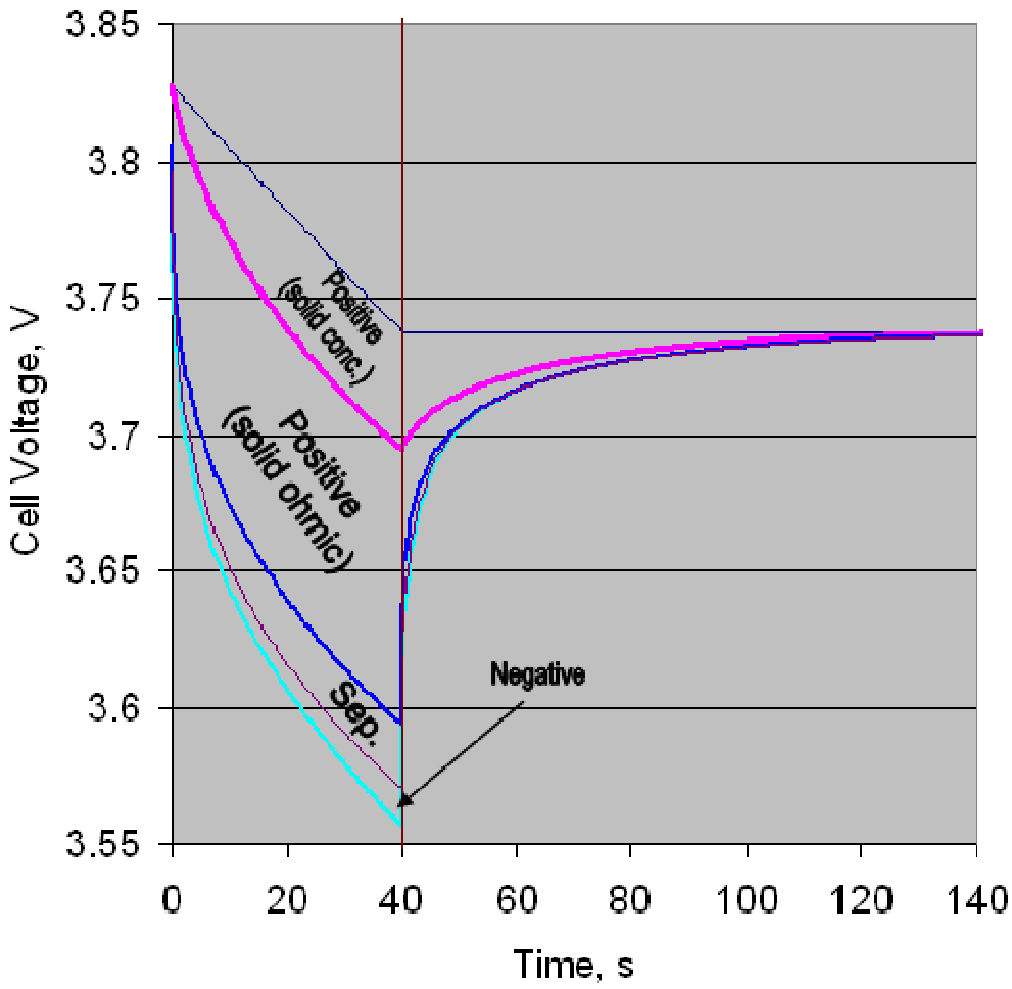
Current Pulse: Calculated Overvoltage Behavior



The voltage relaxation period is about 200 s.

What are the significant contributors to the overvoltage, especially during the rest period?

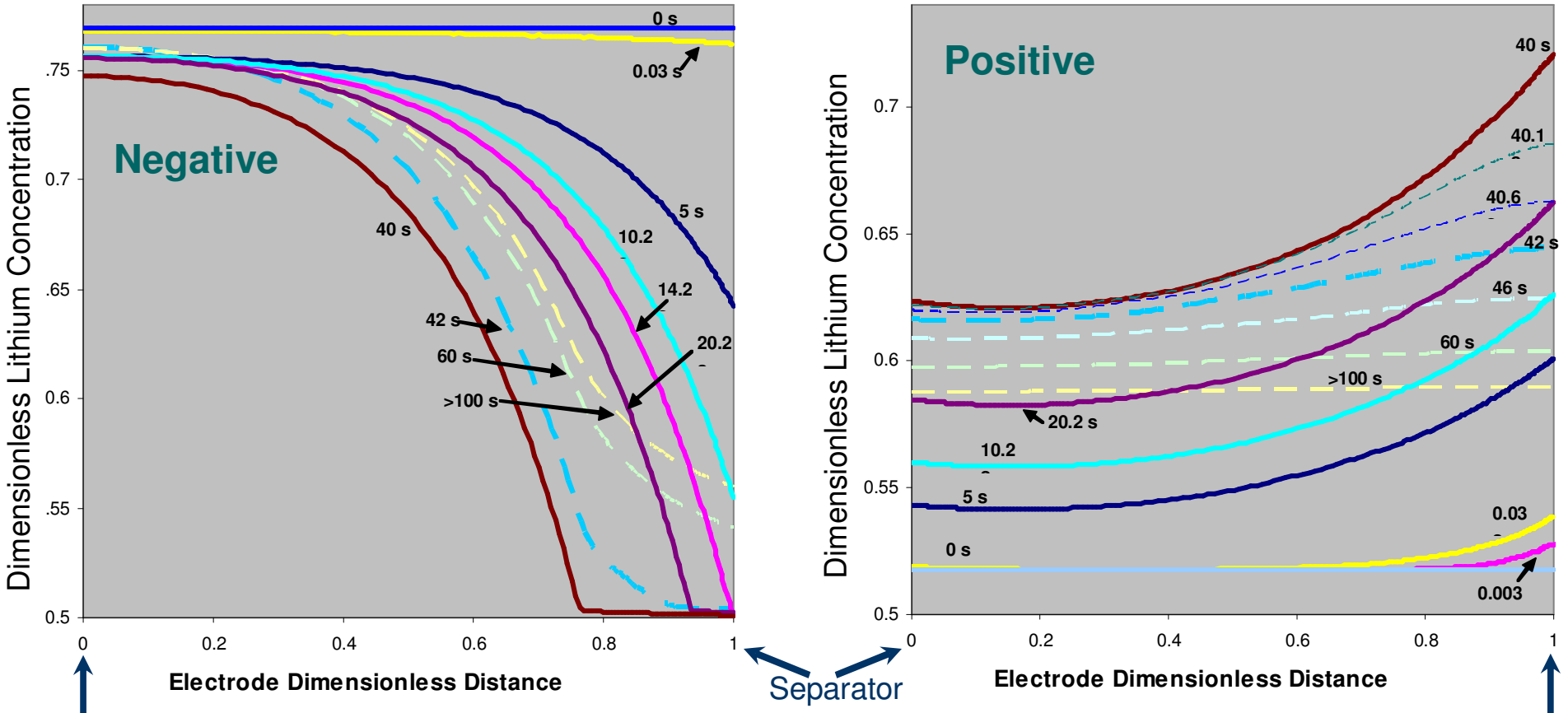
Calculated Overvoltage



Primary contributors

1. electronic resistance of solid active material at the positive terminal
2. resistance to solid-state lithium transport in positive active material
3. separator resistance

Calculations: Solid-Phase Li Composition (at Particle Surfaces) Throughout the Electrodes



Negative: Reaction starts at the separator interface

Positive: Reaction starts at the Al current-collector interface

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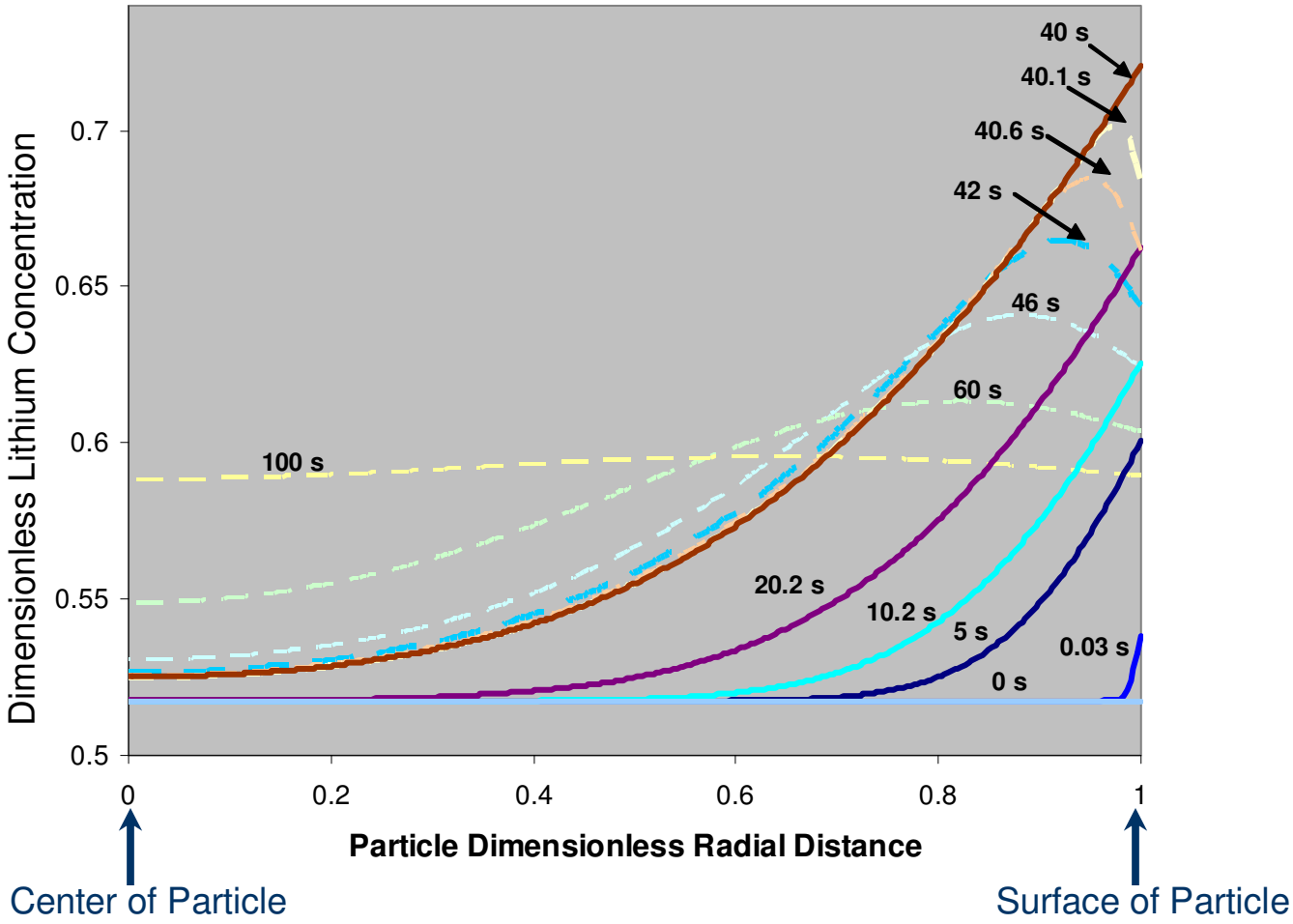
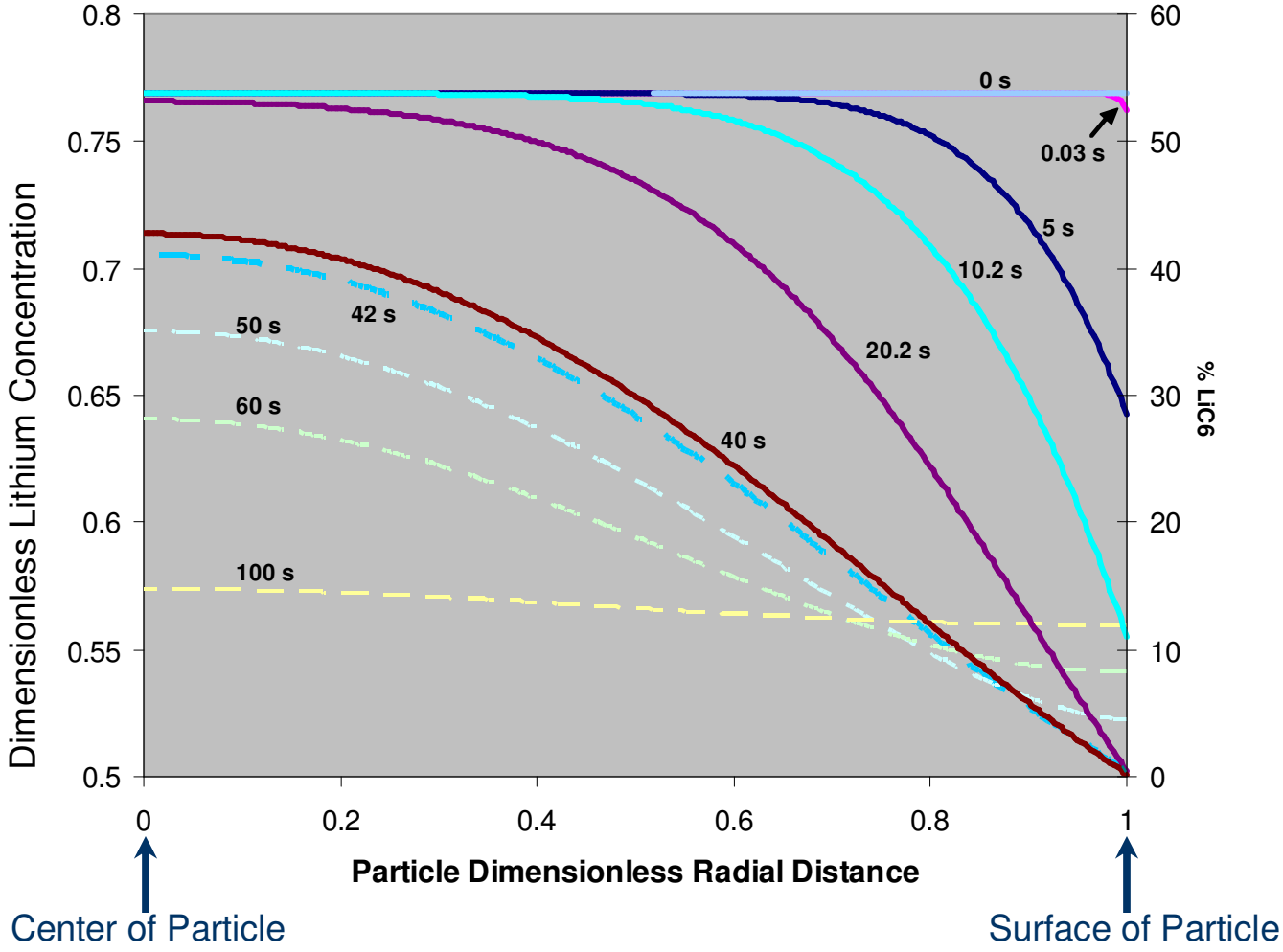
Calculations: Solid-Phase Li Composition Throughout a Particle at the Al Current-Collector Interface in the Positive Electrode



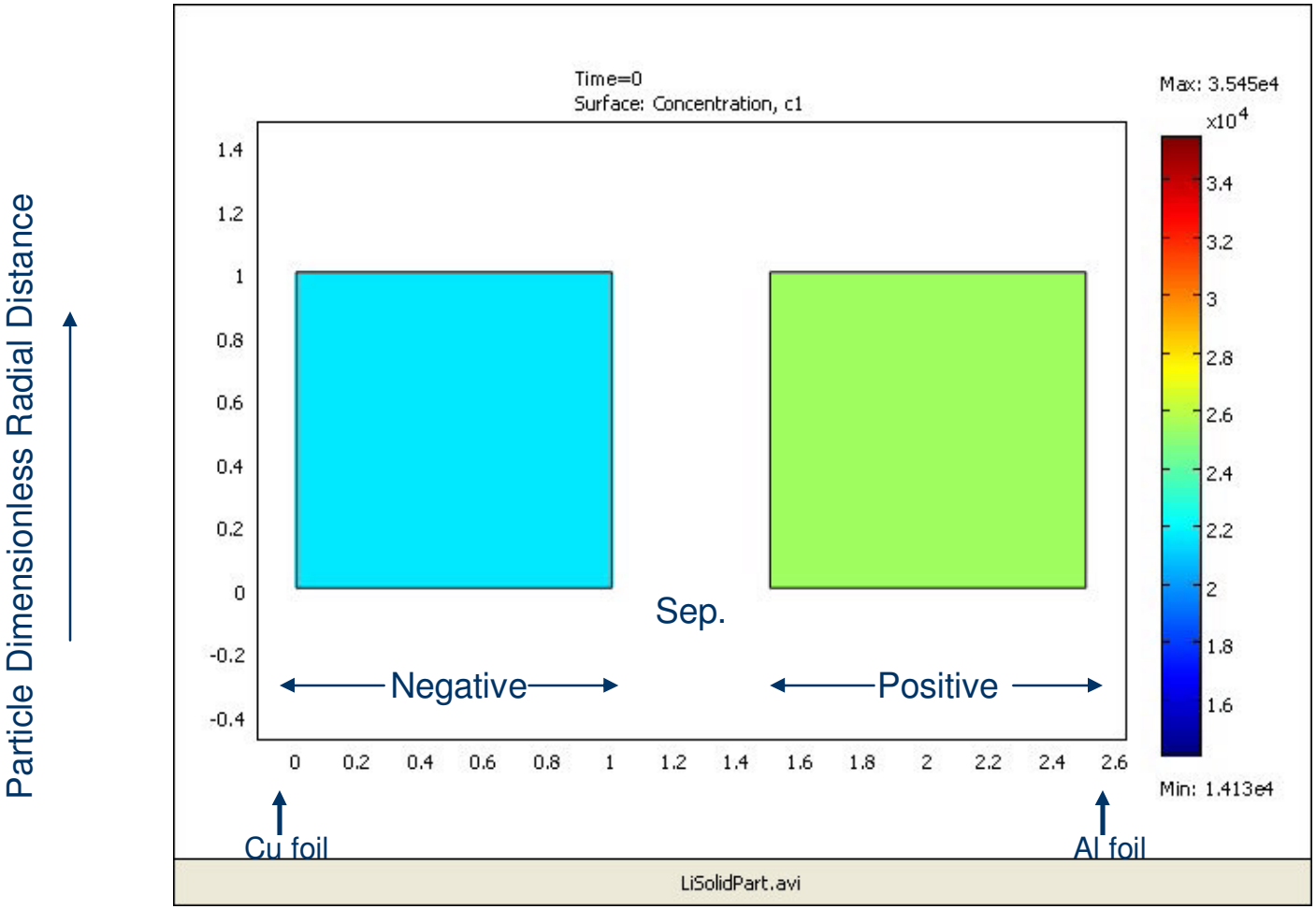
These concentration variations are responsible for the overvoltage that persists during the rest period.

Calculations: Solid-Phase Li Composition Throughout a Particle at the Separator Interface in the Negative Electrode

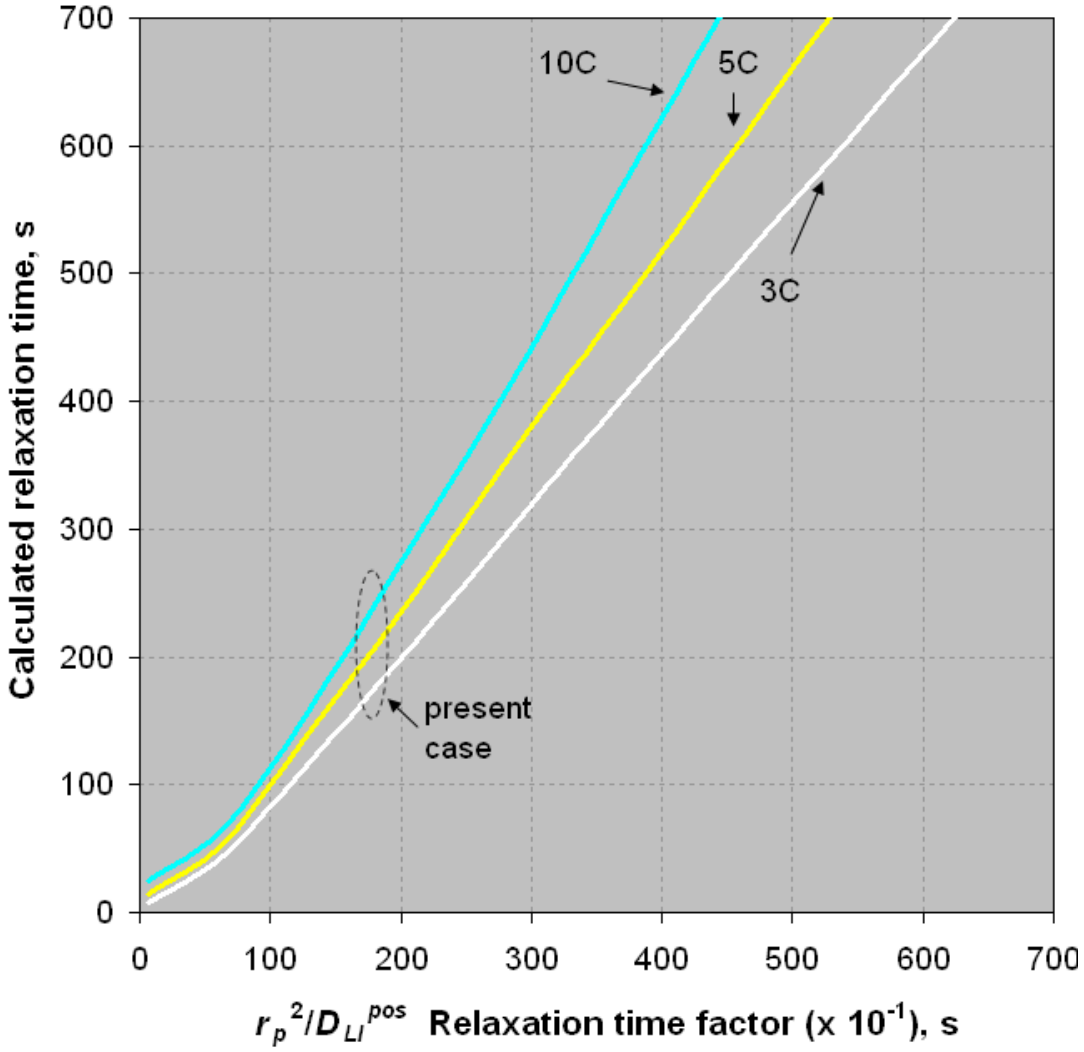


These composition variations are not responsible for overvoltage (because of the two-phase nature of the negative-electrode active material).

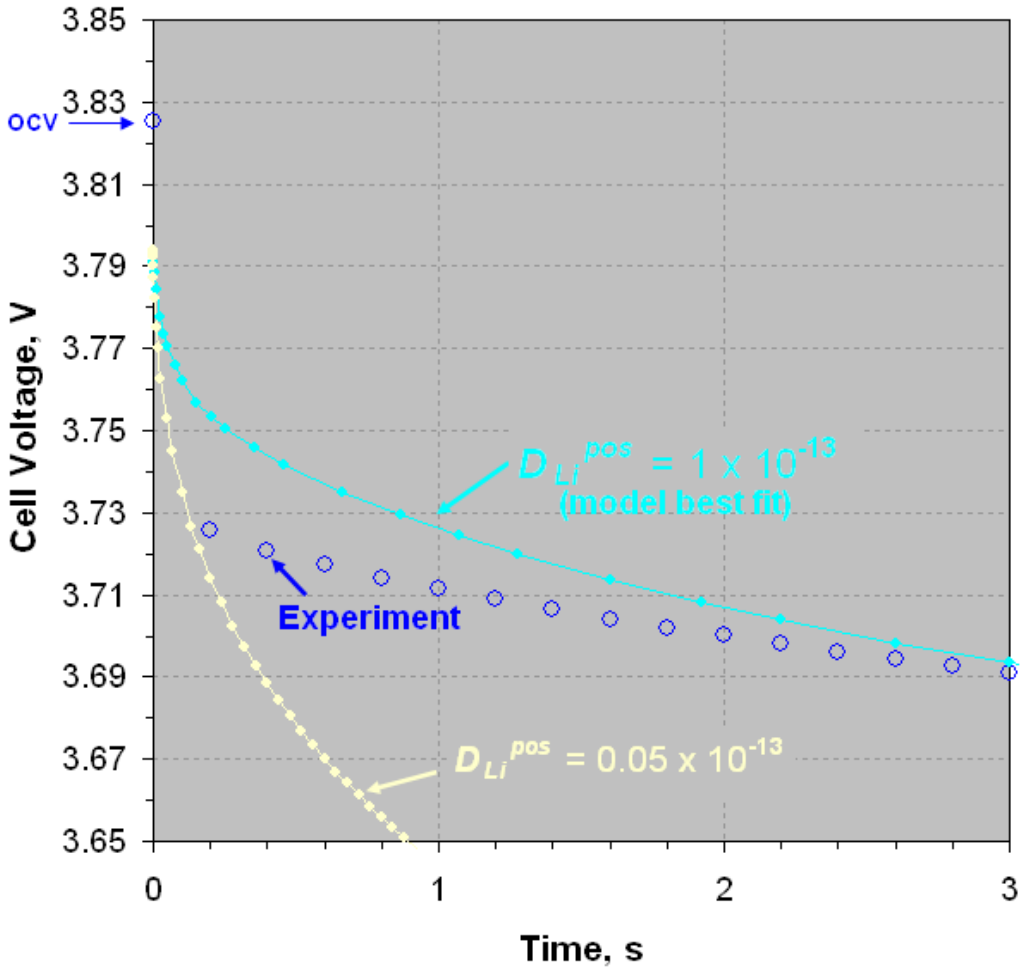
Calculations: 2-Dimensional Animation of Solid-Phase Li Composition Throughout Positive and Negative Electrodes



Calculations: Voltage relaxation time as a function of positive-electrode particle characteristics



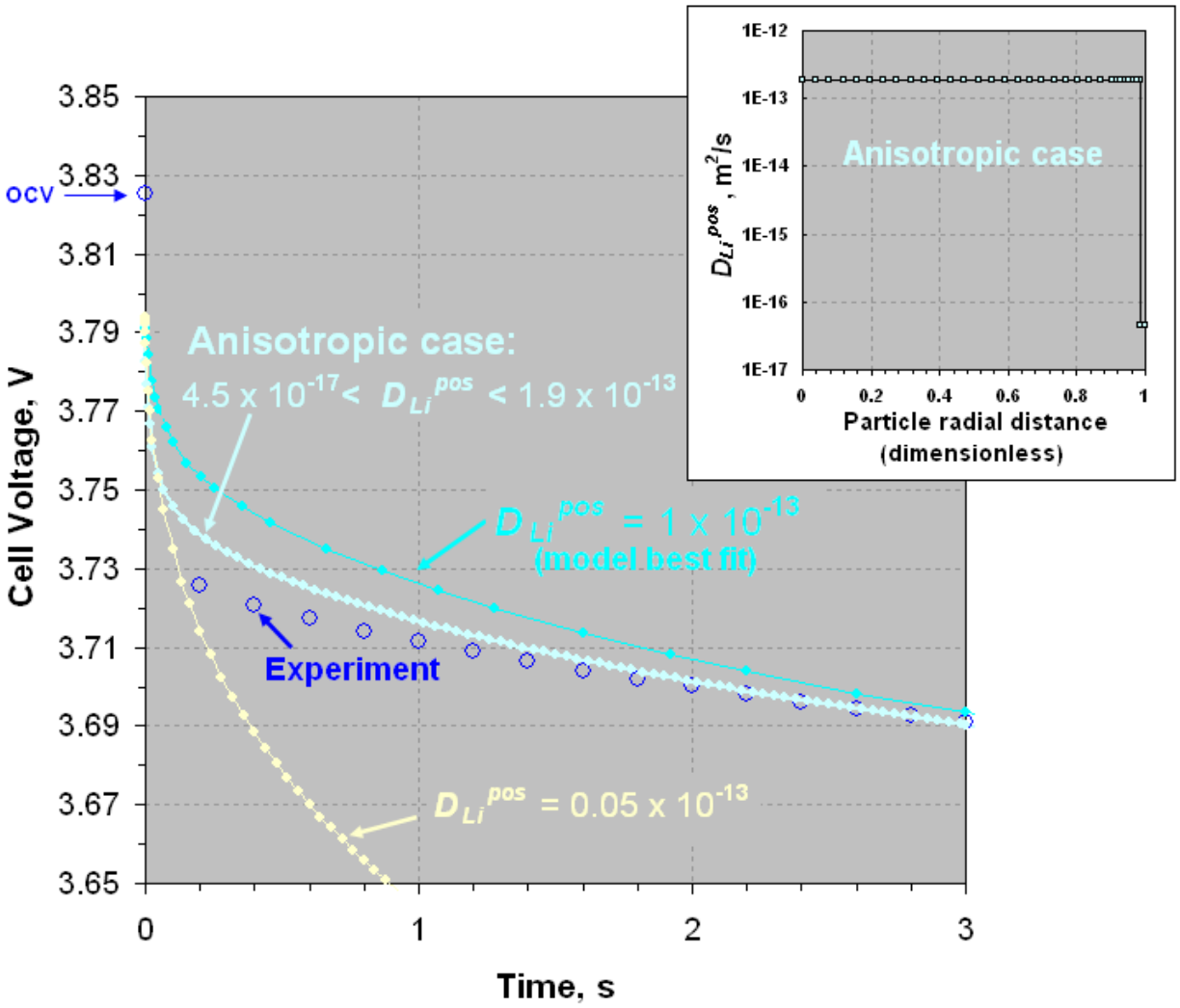
Current Pulse: Model vs. Experiment
(in the first 3 seconds)



Could anisotropy of D_{Li}^{pos} explain the experimental behavior?

Current Pulse: Model vs. Experiment

(in the first 3 seconds)



"Fixing" the diffusivity at the particle periphery would reduce overvoltage.

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Summary and Future Directions

- Weight, volume, and cost are driving the shift from nickel/metal-hydride to lithium-ion battery technology for automotive propulsion.
- Battery models can implicate resistive factors that reduce fuel economy.
  - Positive electrode: electronic resistance of active material
  - Positive electrode: solid-state lithium transport
- Low lithium diffusivity at particle peripheries may explain the initial steep voltage descent
- When compared to behavior throughout life, models can implicate life-limiting mechanisms.

Thank you for your attention!

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Back-up slides

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From Nickel/Metal Hydride to Lithium-Ion Batteries