1.6 Neutron Imaging for Li-Ion Batteries

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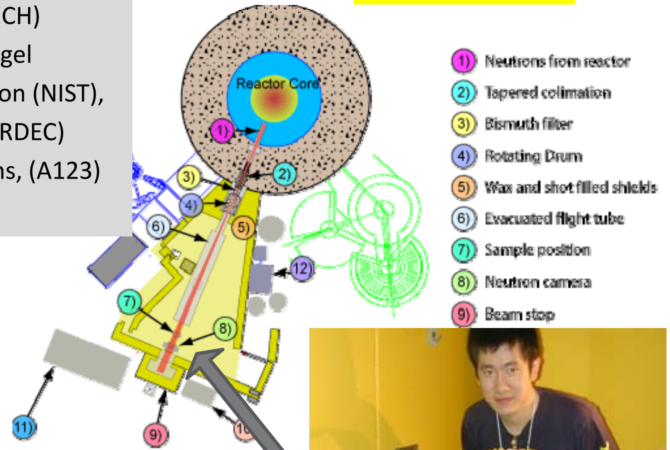
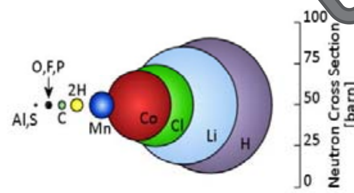
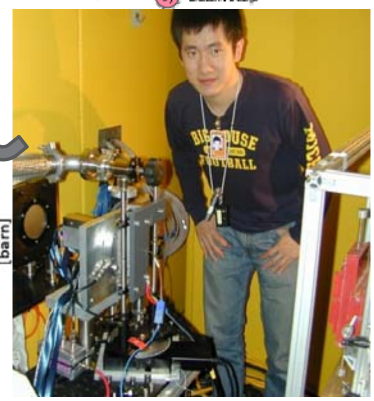
David Gorsich, Yi Ding (TARDEC)
Industry Quad: Danny King, Patrick Hagans, (A123)
Steven Harris (GM)

Start Date: Jan 2010







Motivation and Needs:

Spatio-temporal variations in Li concentration are important for the life and the utilization of a battery.

- Need to model and predict distributions along the electrode to verify the applicability of the single-particle solid diffusion modeling approach
- "Unobserved large variations" may cause battery degradation or failure
- Implications for both supervisory control design and sizing

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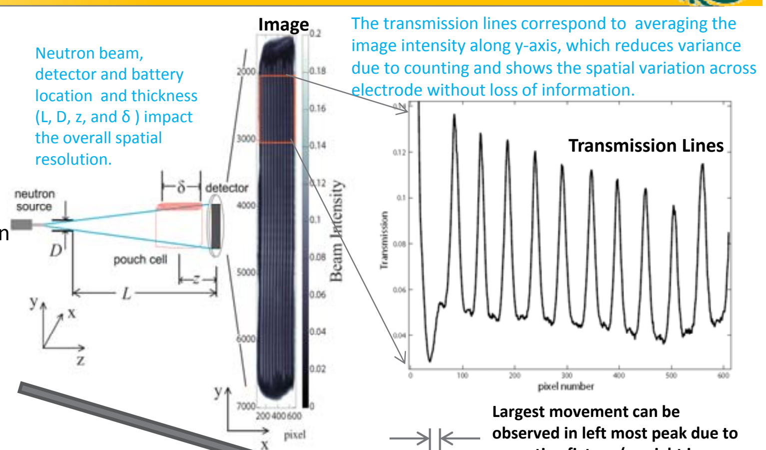
Challenges, Approach and Results

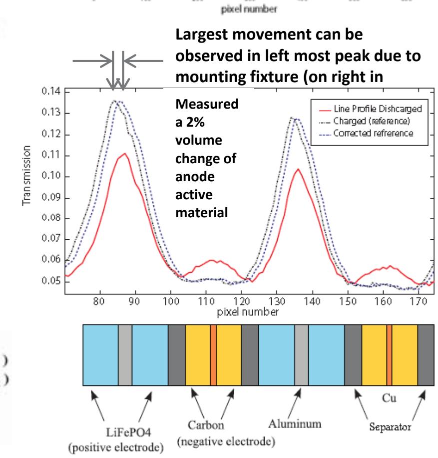
Goal: Measure change in spatio-temporal lithium concentration across the battery electrodes of an operational battery (*in situ)*

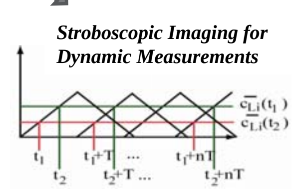
Challenges: spatial resolution, counting noise (uncertainty) requires long exposure time limiting imaging at high c-rates

Results:

- ✓ Q1-4 from 2010: Quantify Li-Concentration measurement resolution, accuracy, and tradeoffs for low c-rate (steady-state)
- ✓ **Q1,2 from 2011:** Observe swelling of electrode material during cycling; potential source of degradation; correlate with material properties
- ✓ **Q3,4 from 2011**: Measure local lithium concentration changes during high C-rates in commercial pouch cells. Perform stroboscopic image processing.
- ✓ **Q1- from 2012**: Model the spatially distributed lithium concentration along the battery electrode using both electrolyte and solid diffusion dynamics.
- ❑ Q2-4 from 2012: Tune model parameters to match the observed voltage data for iron-phosphate cells and compare modeled and measured Li-ion profiles







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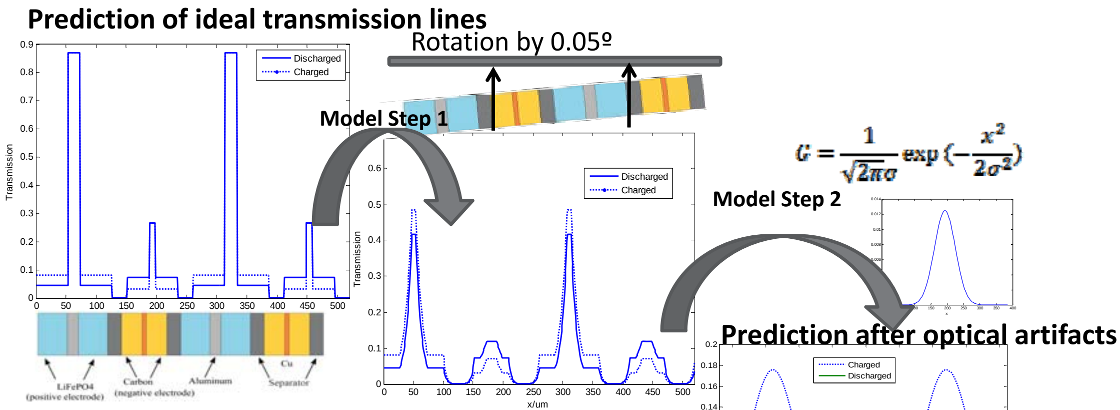
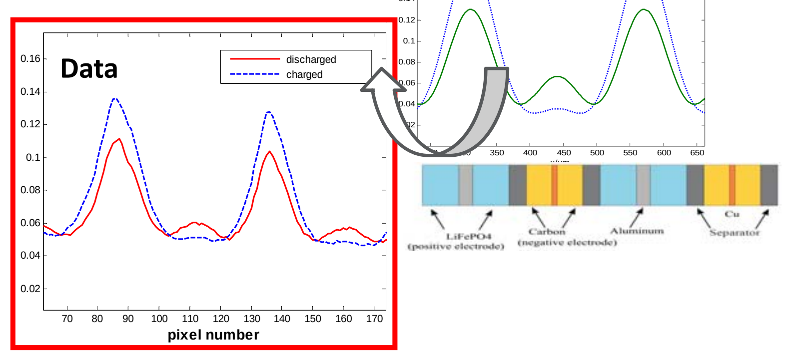
Results (Year 1): Model of Battery & Optical Artifacts and Comparison with Steady State Data



Progress Report: Year 1

- Measured pouch cell with commercial (very thin) electrodes.
- Quantified the uncertainty (2.5% after 60 min) in Lithium concentration with 13μm spatial resolution.



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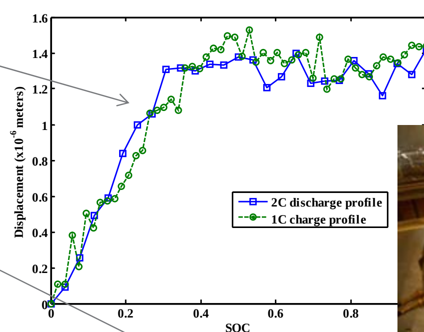
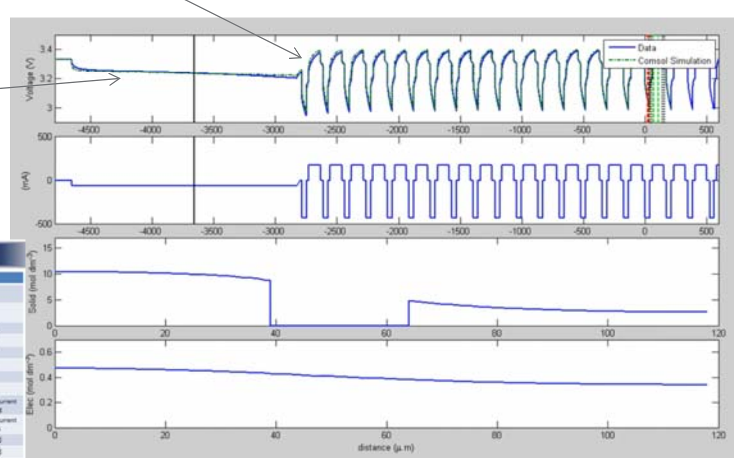
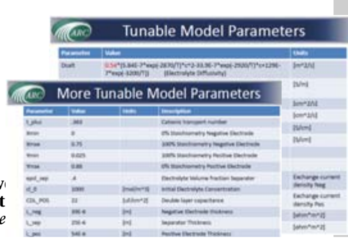
Results (Year 2): Model Li Concentration along the Electrodes (Solid+Electrolyte) and Stroboscopic Experiments at high C-rate

- ✓ Q1,2 from 2011: Observe swelling of electrode material during cycling; potential source of degradation; correlate with material properties
- ✓ Q3 from 2011: Imaged Li-concentration along electrode at high C-rates (1C/2C) and pulses (5C/10C) and
- ✓ Q4 from 2011: Perform stroboscopic image processing.
- ✓ Q1- from 2012: Model the spatially distributed lithium concentration along the battery electrode using both electrolyte and solid diffusion dynamics.
- ❑ Q2-4 from 2012: Tune model parameters to **match the observed voltage data** for iron-phosphate cells and compare modeled and measured Li-ion profiles







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Project Output & ARC Participation

- Education & Training (project started in 2010)
  - Jason Siegel (postdoc), XinFan Lin
- Publications

[J1] "Neutron imaging of lithium concentration in battery pouch cells," J. B. Siegel, X. Lin, A. G. Stefanopoulou, D. S. Hussey, D. L. Jacobson, and D. Gorsich, J. Electrochem. Soc., 158 (5), 2011.

[J2] "Parameterization and Estimation of Surrogate Critical Surface Concentration in Lithium-Ion Batteries," International Vehicle Design, ARC Special Issue, in print

[C1] Jason B. Siegel et al, "Neutron Imaging of Lithium Concentration in Battery Pouch Cells," Proceedings of the American Controls Conference, Invited, San Francisco, CA, June 2011.

[C2] Jason B. Siegel et al, "NEUTRON IMAGING OF LITHIUM CONCENTRATION FOR VALIDATION OF LI-ION BATTERY STATE OF CHARGE ESTIMATION," in Army Science Conference, Orlando, FL, December 2010.

[C3] Jason B. Siegel et al, "Quantifying Lithium Concentration in a Li-Ion Battery Using Neutron Radiography," presentation invited in Battery Congress, Ann Arbor, MI, April 2011.

[C4] Jason B. Siegel et al, "On the Accuracy and Simplifications of Battery Models using In Situ Measurements of Lithium Concentration in Operational Cells" Proceedings of the American Controls Conference, Montreal, CA, June 2012.

[A1] Jason B. Siegel et al, "Neutron Radiography of LIB Electrodes," abstract/presentation ECS Meeting, 2011

[A2] Jason B. Siegel et al, "Neutron Imaging of Degraded LFP Pouch Cells Illustrate Dendrite Formation and Internal Shorts," abstract/presentation ECS Meeting, 2012

[A3] Gordon Conference (Poster) Mar 2012.

- Keynotes, invited talks
  - o Battery Congress, April 2011
  - o NASA, GM, CMU, OSU, PHM, …
- Copyrights, Patents
  - Transferred the model to other teams within ARC
  - Data for battery validation will be posted and accessible from the ARC website
- ARC case study: 1 in 2010, 2 in 2011, 1 2012
- ARC- Seminars: Jan 2010, Feb 2011, April 2012
- ARC@TARDEC: TA1 review, and quarterly reviews with GVPM quad membs
- Supported by NIST (facility), A123 (batteries), and Yokogawa (cyclers)

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Relation with other ARC Activities:

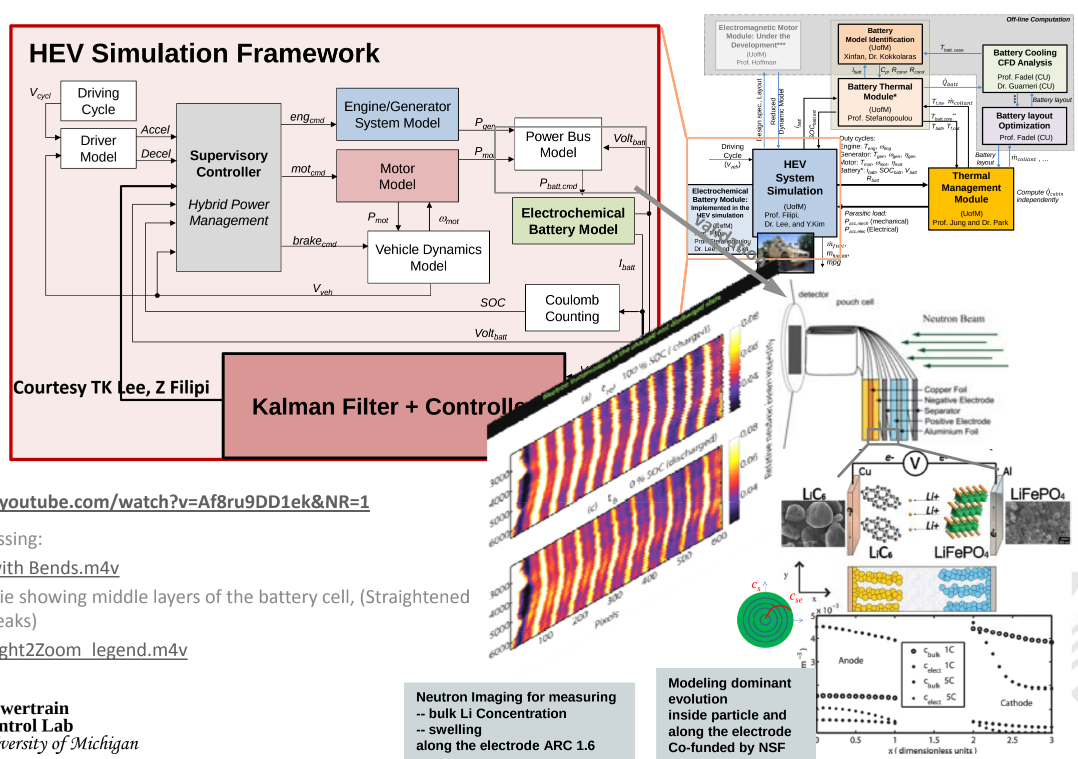
This effort is providing data for validating battery models of various fidelity for powertrain design, sizing, power split strategies and thermal management

HEV Power Sizing ARC 5.2

Supervisory Control and HEV Power Management ARC 4.4

Capacitor Power-Boost ARC 1.10

Synthesizing Asymmetric Capacitors ARC 4.8



Neutron Imaging for measuring
-- bulk Li Concentration
-- swelling
along the electrode ARC 1.6

Modeling dominant evolution inside particle and along the electrode Co-funded by NSF

http://www.youtube.com/watch?v=Af8ru9DD1ek&NR=1

Before processing:

Raw Movie with Bends.m4v

Zoomed movie showing middle layers of the battery cell, (Straightened by aligning peaks)

Transm_Straight2Zoom_legend.m4v

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