OPTODOT *Energy Storage Solutions Through Nanotechnology*

Innovative Manufacturing and Materials for Low-Cost Lithium-Ion Batteries

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Optodot Corporation

Project ID# ES136
Monday, May 13, 2013

Overview

Timeline

- Start date – October 2011
- End date – September 2014
- Percent complete - 30%

Barriers/Targets

- Cost reduced to $300/kWh by 2014
- Energy density to 300 Wh/kg by 2015

Budget

- Total Funding: $2,999,127
  - DOE Share $2,249,127
  - Contractor Share $750,000
- Funding Received:
  - FY12: $382,875 (10/1-9/30)
  - FY13: $190,820 (10/1-current)

Partners

- **Interactions/Collaborations**
  - *Madico, Inc*. – Electrode Stack Mfg.
  - *Dow Kokam, LLC* – Battery Mfg. and Testing
  - *University of Rhode Island* – Electrolyte
  - *Ashland* –Solvents & Polymers
- **Project Lead – *Optodot Corporation***

Thank you to the DOE Vehicle Technologies Program for their support and funding of this project!

Project Objectives

Project Long-term Objective

- Reduce the cost, weight, and volume of the cell's inactive components by at least 20%, and preferably by at least 40%, while maintaining cell performance

Project Immediate Objectives (Mar-12 to Mar-13)

- Complete initial prototype with much thinner separator and current collector layers

Project Milestones for FY12

Month/Year	Milestone	Status
Jan-12	Initial ceramic separator design	Complete
Jan-12	Initial anode coated stack design	Complete
April-12	Initial cathode coated stack design	Complete
April-12	Initial low cost electrolyte design for lithium salt	Complete
June-12	Initial current collection and termination design	Complete
June-12	Initial low cost electrolyte design for solvents complete	Complete

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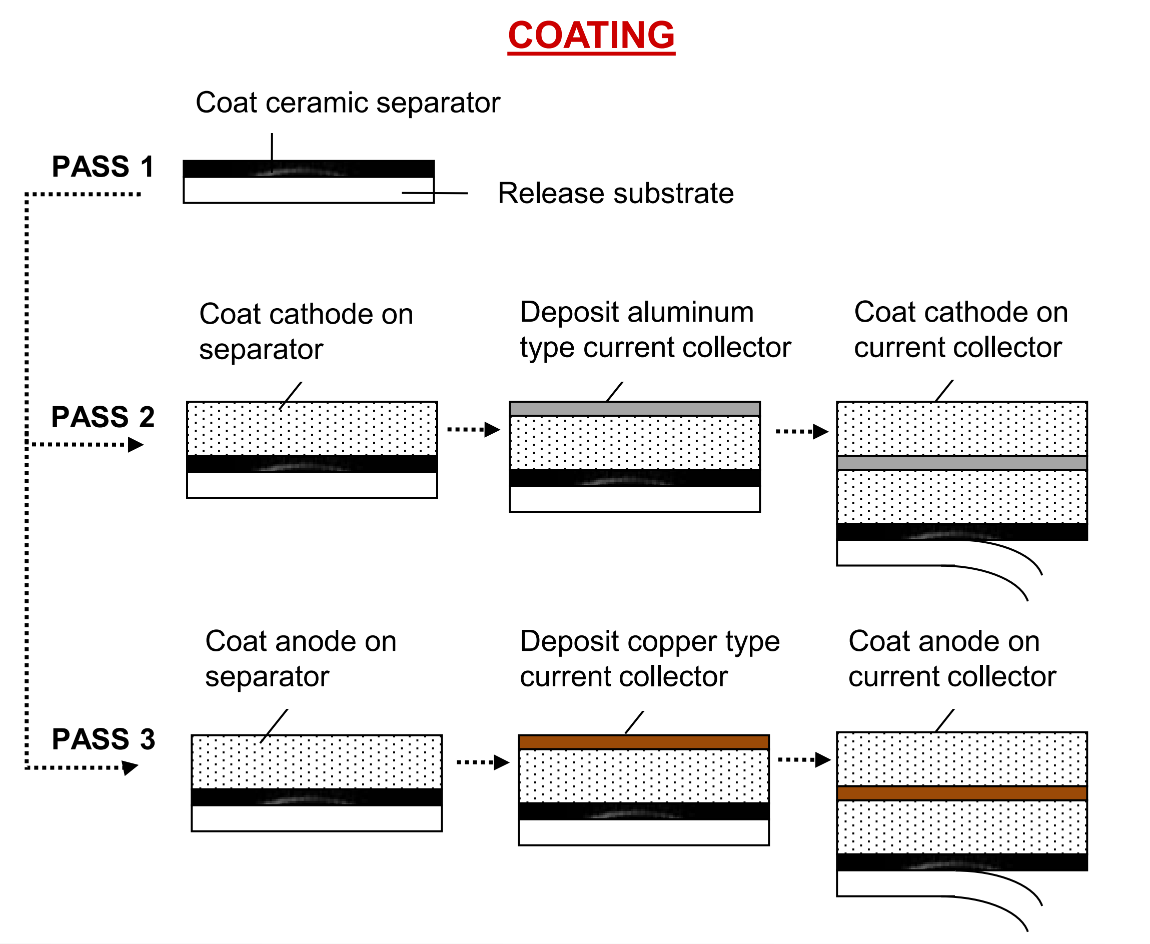
Project Milestones for FY13

Month/Year	Milestone	Status
Dec-12	Initial coated stack cell development and testing	To be completed May-13
Dec-12	Initial electrolyte for energy cell design	To be completed May-13
Mar-13	Anode coated stack optimization and scale up for energy cells	To be completed June-13
June-13	Optimized low cost and/or safer electrolyte for energy cells	On schedule
June-13	Cathode coated stack optimization and scale up for energy cells	On schedule
Sep-13	Initial anode coated stack design for power cells	On schedule
Sep-13	Current collection and termination design optimization and scale up	On schedule

Approach: Battery Stack Manufacturing Process



- **Utilizes a roll-to-roll process**
  - Lower cost
  - Higher efficiencies
  - Wider Widths
- **Electrode coatings can be in lanes to provide electrode-free current collector zones for termination**
- **Release substrate is removable, enabling interleaving of anode and cathode coated stacks**

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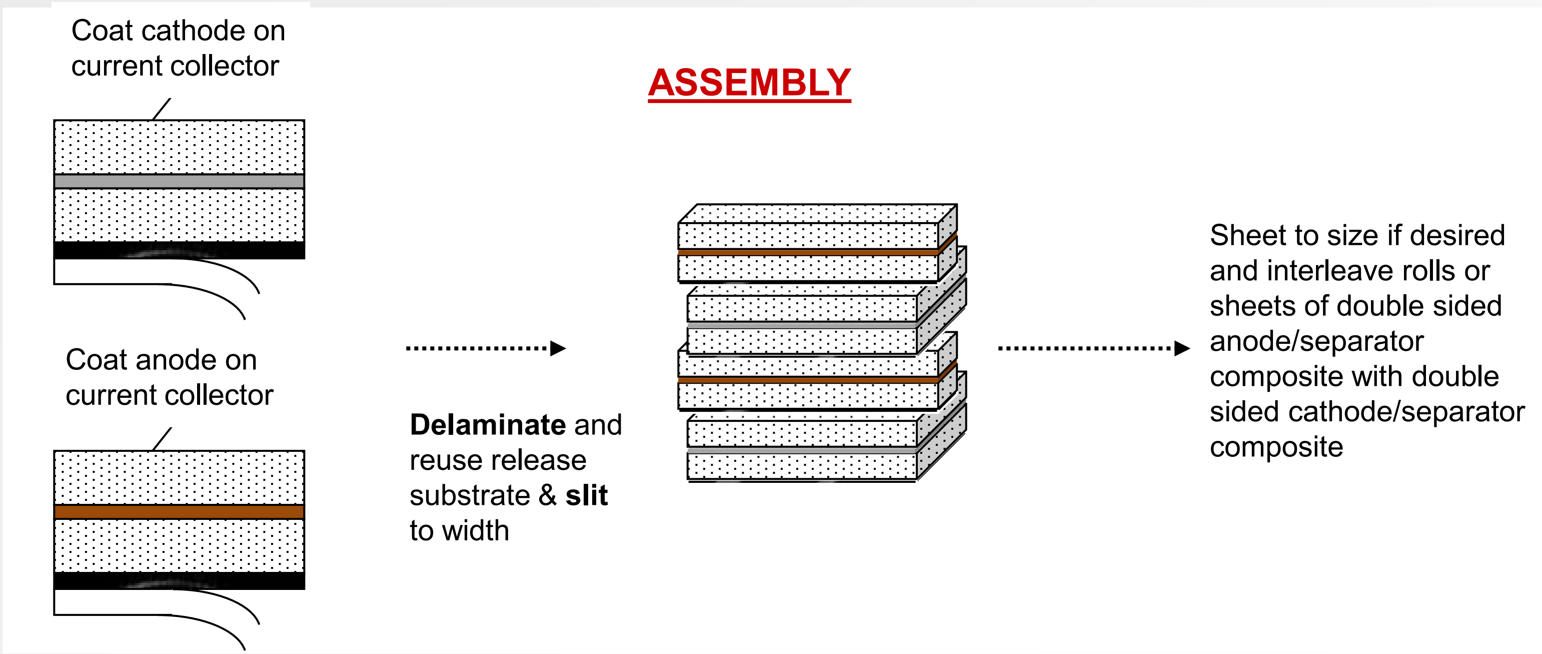
Approach: Battery Stack Manufacturing Process



- Lower cost and lighter inactive components
  - Nanopore nature and compressive strength of ceramic separator enables overcoating with anode and cathode layers followed by calendering
  - Thinner separator reduces inactive components and cell level cost significantly
  - Thinner & lighter current collector layers

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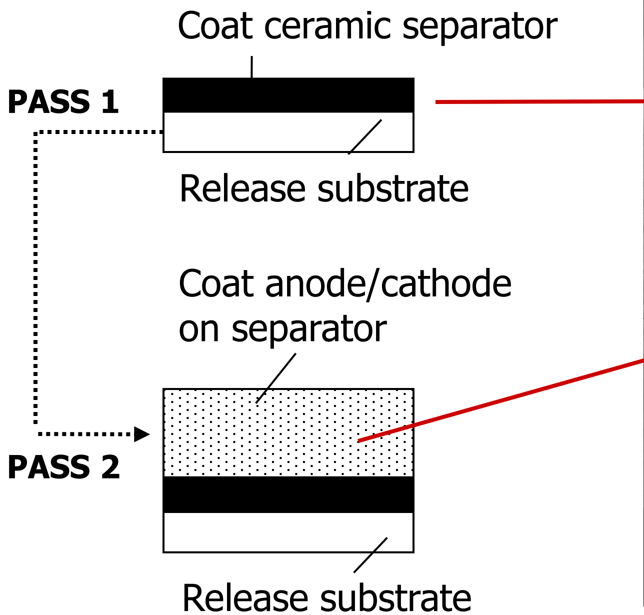
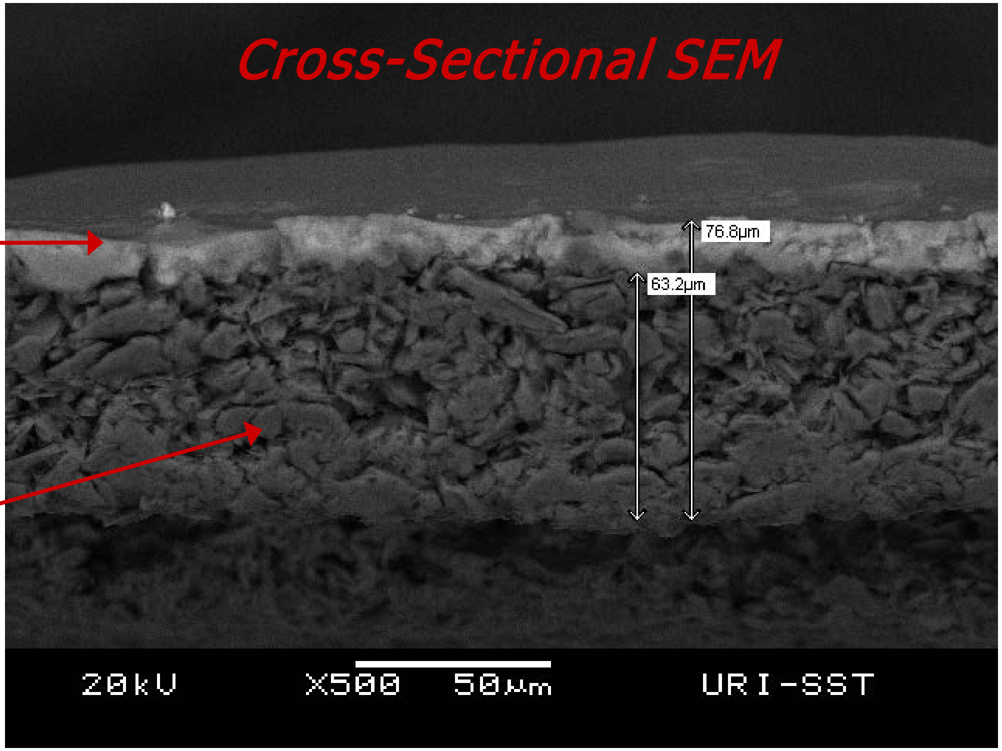
FY12/13 Accomplishments

(Mar-12 – Mar-13)

- Demonstrated first example of an anode coating onto a separator layer followed by calendering and showed good cycling results for this coated anode stack in half cells

Separator/Electrode Composite
(not to scale)

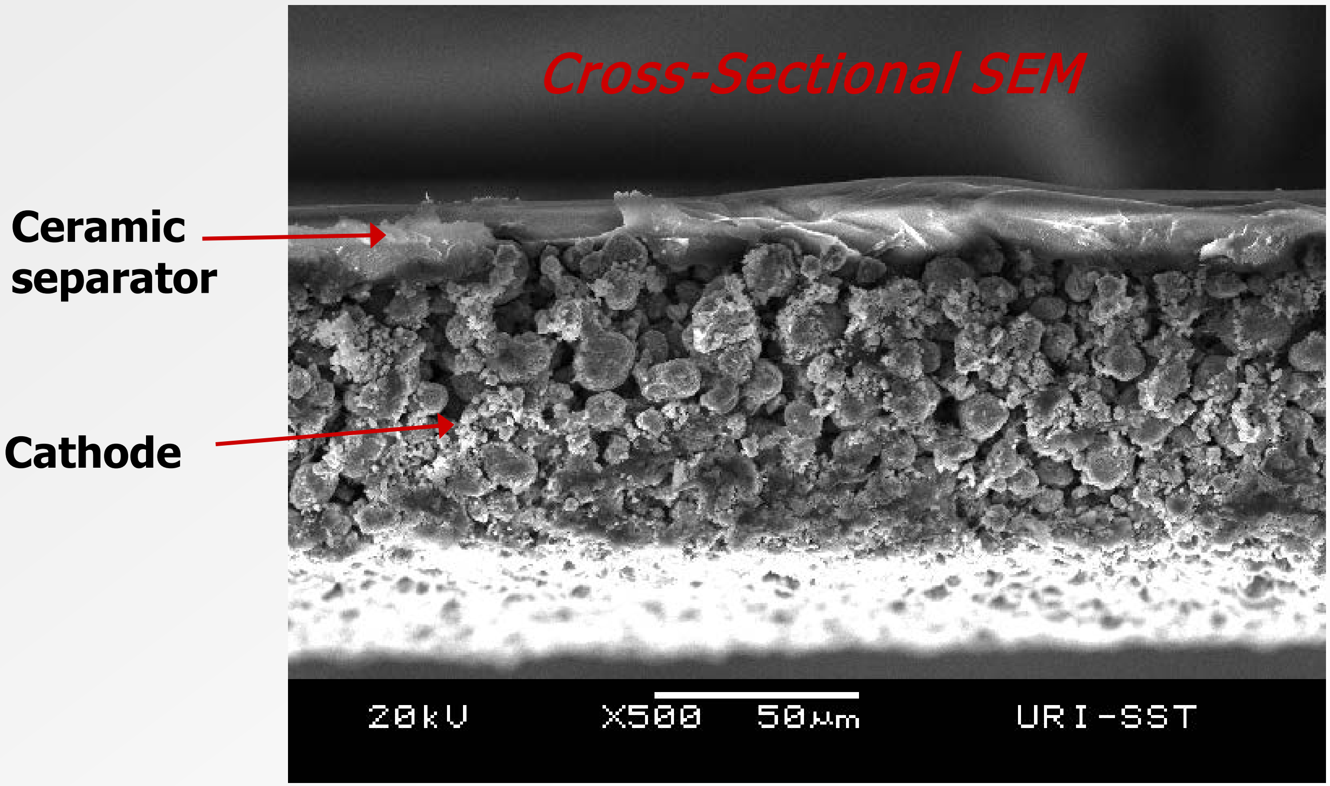




NOTE: Release substrate was removed prior to cross-sectional SEM

FY12/13 Accomplishments
(Mar-12 – Mar-13)

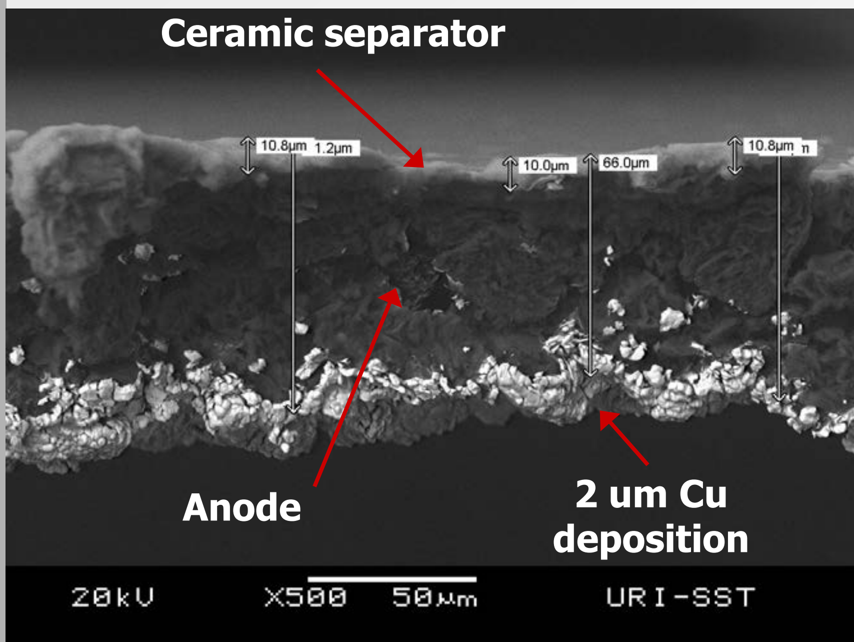
- Demonstrated first example of a cathode coating onto a separator layer and showed good cycling results for this coated cathode stack in half cells

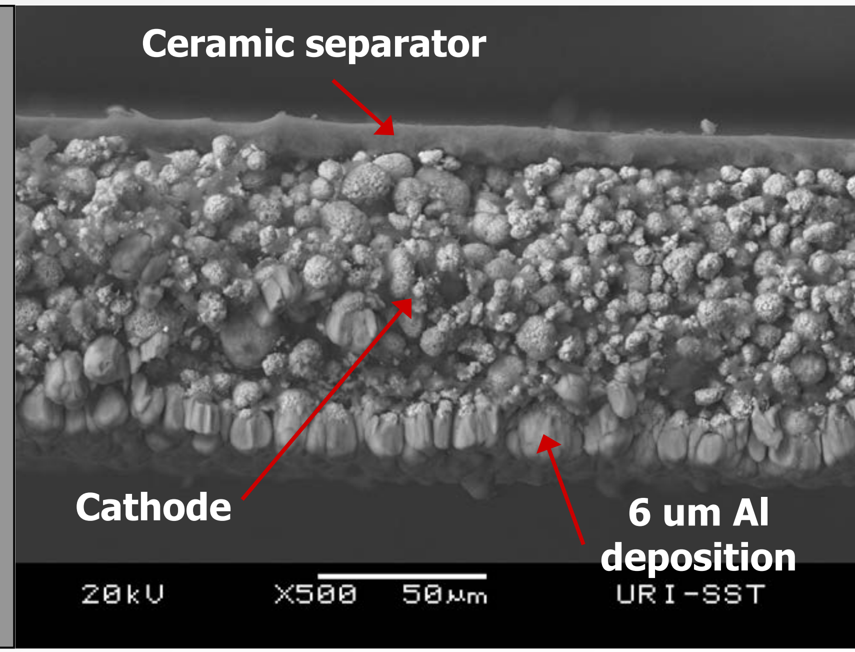


Cathode/Separator Stack

FY12/13 Accomplishments
(Mar-12 – Mar-13)

- Demonstrated first example of depositing copper and aluminum current collector layers onto coated anode and cathode stacks, respectively, and successfully cycled these stacks in coin cells





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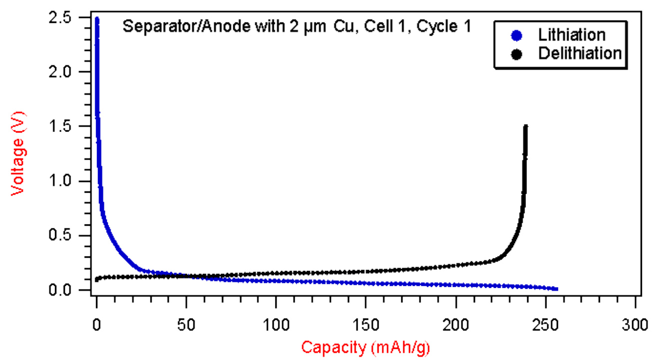
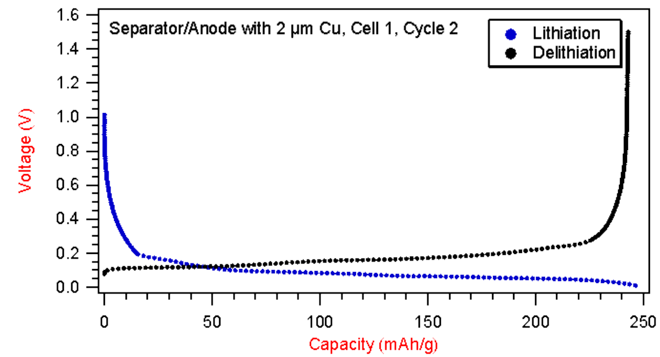
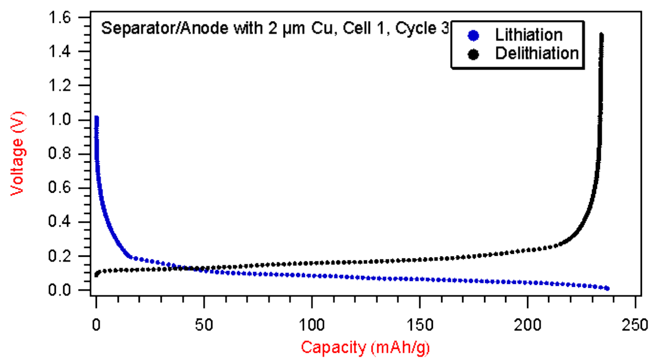
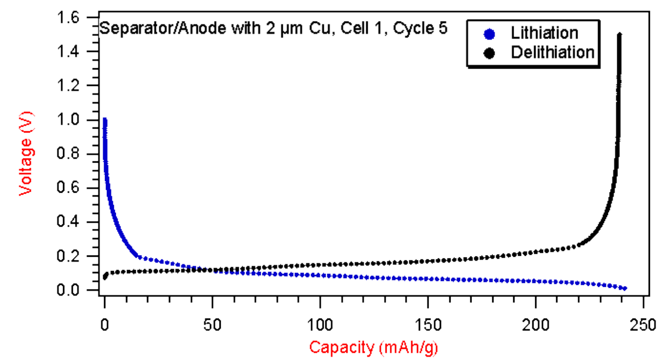
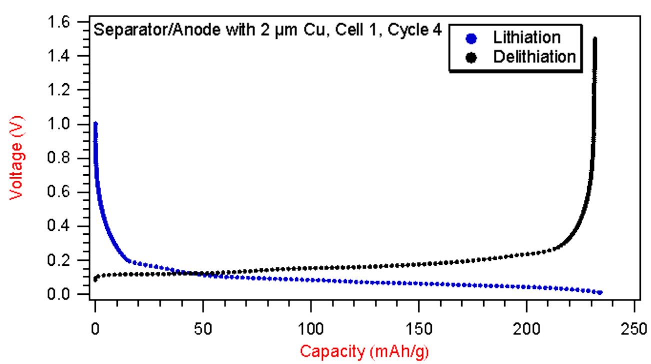
FY12/13 Accomplishments
(Mar-12 – Mar-13)





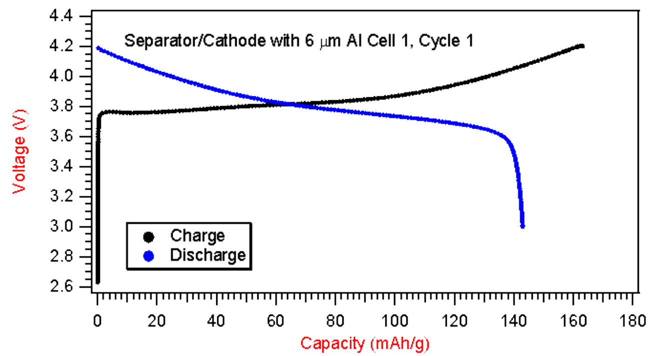


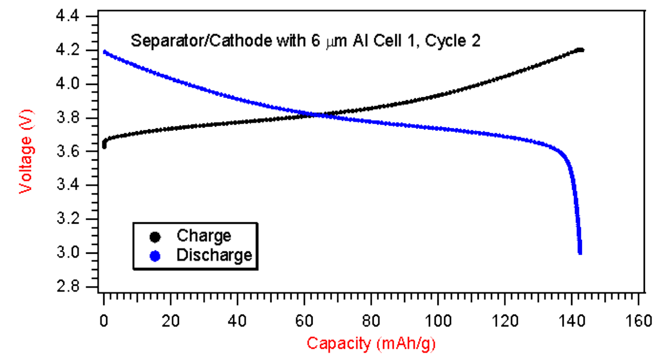


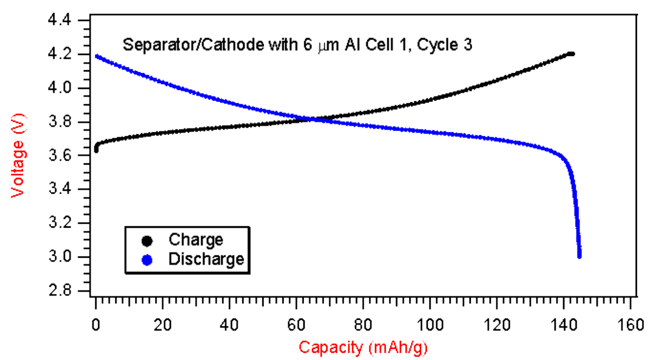


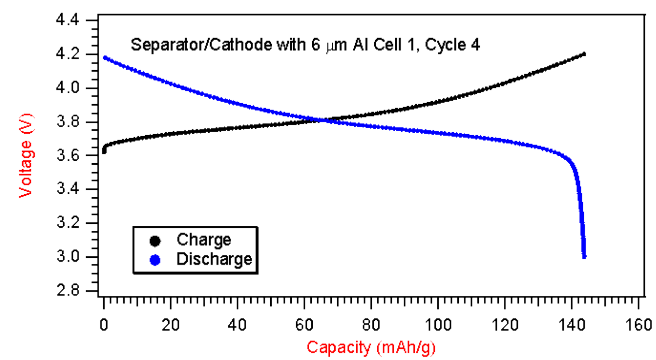
Cycling of separator/anode stack half cells with 2 um Cu deposition on the anode for current collection

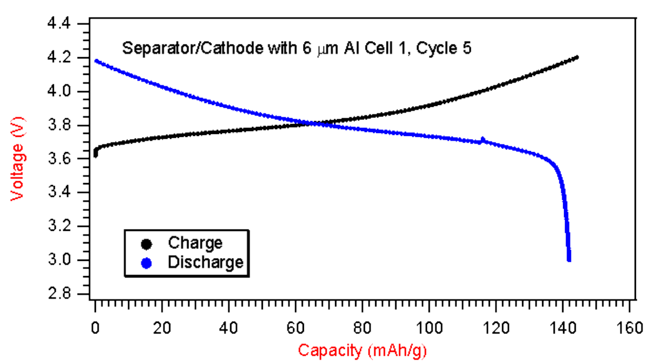
FY12/13 Accomplishments
(Mar-12 – Mar-13)







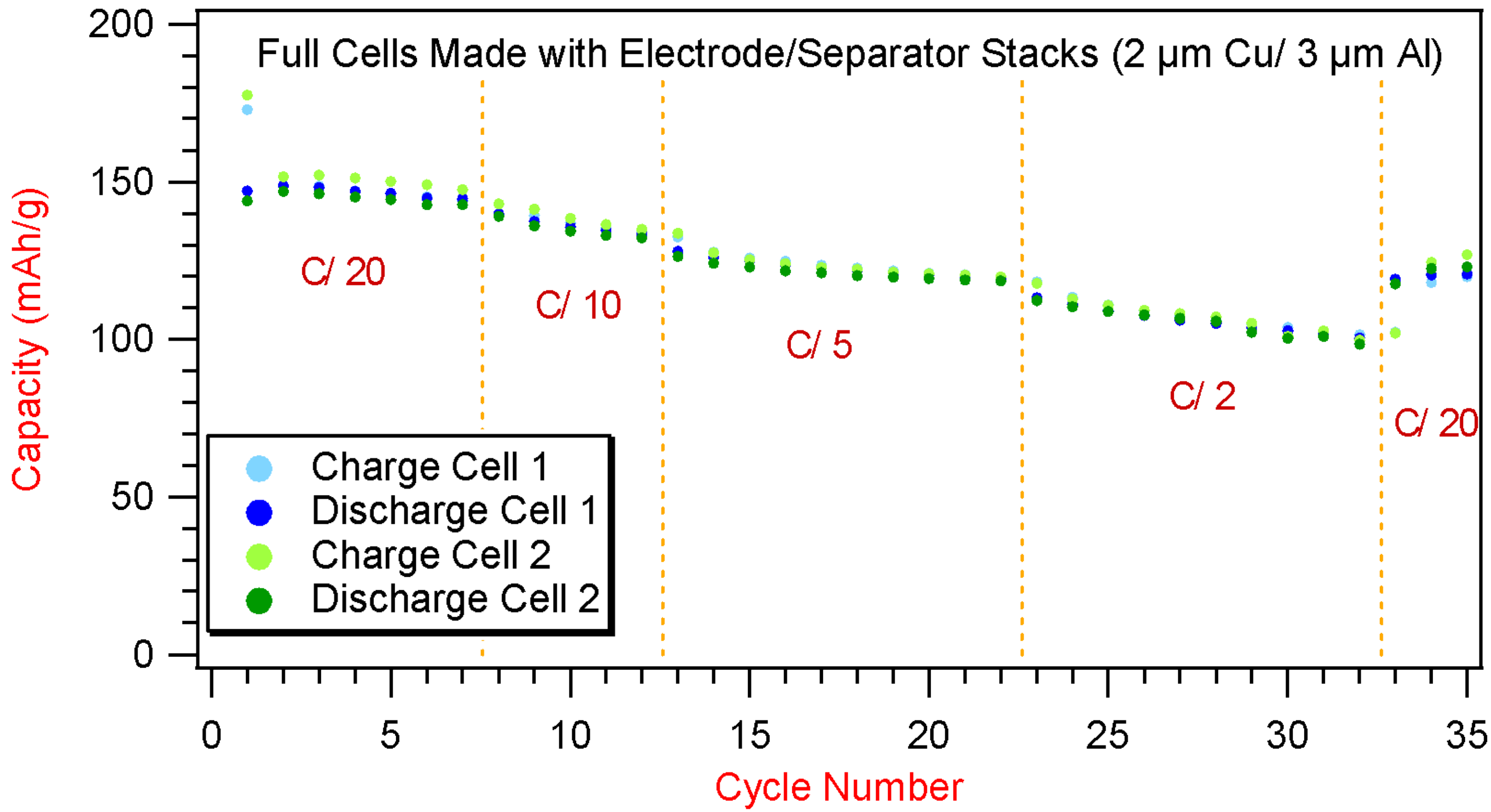




Cycling of separator/cathode stack half cells with 6 um Al deposition on the cathode for current collection

FY12/13 Accomplishments

(Mar-12 – Mar-13)



Cycling of initial prototype separator/electrode stack full coin cells with 2 um Cu and 6 um Al depositions on the anode and cathode respectively

NOTE: Electrodes were not calendered and not vacuum dried in these prototypes

FY12/13 Accomplishments
(Mar-12 – Mar-13)

- Developed new versions of 8-10 micron thick ceramic separator layers with an all-nanoporous design and very narrow pore size distributions ranging from 25-75 nm average pore diameter.

- Using the Argonne National Lab battery cost model, preliminary cost savings from the 8 micron ceramic separator component including the reduced usage of electrolyte were estimated to be greater than 20% cost savings for the inactive components of the cell. This estimated savings meets the cost reduction objectives of this project from the thinner ceramic separator alone.

Collaborations/Subcontractors

- **Madico** (industry) on manufacturing processes of mixing & coating of the ceramic separator
- **Dow Kokam** (industry) on electrode coatings
- **URI** (academic) on cell cycling testing on various ceramic separator and coated stack designs & on new electrolytes
- **Ashland** (industry) on polymer selection for battery coatings

Future Work

Remainder of FY13

- Optimization and scale-up of anode stack, cathode stack, and current collector/termination
- Develop initial designs for anode stack and electrolyte for high rate/power cells

FY14

- Optimization and scale-up of coated stack design with new electrolyte for both energy and power cells

FY14 Final Deliverables

- Cost assessment of Li-ion cell manufactured using the current vs. improved designs
- Deliver 18 cells of baseline design and of new coated stack design with cell test plan and report on performance and abuse tolerance of these cells

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Summary

- Meeting the at least 20% improved cost, volume and weight, as well as the performance requirements, for the key inactive components of Li-ion cells and developing a low cost next generation manufacturing process will help meet the DOE goals of cost reduction to $270/kWh by 2017 for PHEVs and to $150/kWh by 2020 for EVs.
- Demonstrated the first examples of electrode/separator coated stacks by leveraging off of the all-nanoporous ceramic separator, the key enabling technology of this project
- The use of the 8 micron thick ceramic separator alone meets the project's $\geq$ 20% cost improvement objective for the inactive components
- Our 4 partners and subcontractors, Madico, Dow Kokam, URI, and Ashland, are providing coating and converting expertise and equipment, battery assembly and testing capability, electrolyte expertise, and polymer and solvent expertise.

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