Anode Manufacturing through Ultra-Thin Li Deposition

2021 Vehicle Technologies Annual Merit Review Project ID: Bat 495-Thin Li Deposition

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Overview and Relevance

Timeline

- Start: 05/25/2020
- End: 05/24/2023
- Duration: 36 Months
- ~33% Complete

Budget

- Project Total: $24,184,504
- DOE Share: $12,000,000
- Industrial Cost Share: $12,184,504

Barriers Addressed

- Operating hardware for Li deposition
- High volume manufacturing system
- Large format high energy density cells
- Low-cost manufacturing

Partners

- Saft America, Inc.
- Zenlabs Energy, Inc.
- Pacific Northwest National Laboratory
- Lawrence Berkeley National Laboratory
- Argonne National Laboratory

Objectives

1. Advance batteries with pre-lithiated SiO_x-C anodes with energy density >337Wh/kg from TRL 5 to TRL 7
2. Advance batteries with Li-metal anode with energy density >375Wh/kg from TRL 4 to TRL 6
3. Develop a Li deposition system to meet high volume mfg. (HVM) requirements, TRL 4 to TRL 8

Impacts

1. High Volume Manufacturing (HVM) system required to manufacture high energy density anodes, enabling US leadership in Li-ion manufacturing equipment
2. Proven high energy density Li-ion battery performance to enable US leadership and market share gains for US Li-ion battery manufacturing partners

Milestones: Budget Period 1

Milestone	Type	Description	Status as of 04/30/2021
Gen2 Lithium Deposition Source Design Completed	Technical	Complete Design of Gen2 lithium deposition source	**Design Completed.** Intermediate HW with key features to be tested
Test Stand for Lithium Deposition Source Design Completed	Technical	Complete Design Test Stand for lithium deposition source	**Design Completed.** Test stand installed in dry-room, ready for HW tests and S2S samples
Protective Layer Hardware Design Completed	Technical	Complete design of protection layer hardware for Sheet to Sheet (S2S) testing	**Design Completed.** HW upgrade in progress
Polymer selected	Technical	Selection of a polymer for testing subsequent tasks.	**On Track.** Leading high temperature binder candidates identified and being evaluated for further down-selection in PQ4
Go/No Go Decision	Go/No Go	**S2S tool** fabricated planned samples for program	**On Track.** S2S tool installed. HW & process validation in progress - Li/Cu and pre-lithiated anode samples being generated for testing fromS2S and R2R tools
	Go/No Go	**R2R signed off** by AMAT safety	**Safety Sign-off Completed.** AMAT safety approved R2R operation. R2R operations continue
	Go/No Go	**SiOx-C anode:** Meet R&D Demonstration cell performance (300Wh/kg and 600 Cycles)	**Met.** 4.6Ah pouch cells, 305Wh/kg and >700cycles
	Go/No Go	**Li-metal anode:** Meet R&D Demonstration cell performance. (300Wh/kg and 200 Cycles)	**On Track. Achieved >200 cycles** for both coin and single layer pouch cell. Multilayer pouch cells to be built in PQ4

Program on Track for BP-1 Milestones / Deliverables

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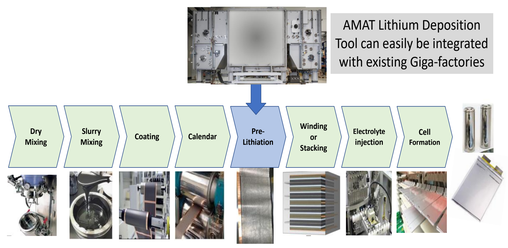
Approach: Technology Development in 3 Phases

- **Budget Period 1 (BP-1):** Hardware and Process Baselining and Pathfinding
  - Design, procure and operationalize hardware for Li deposition and surface protection
  - Establish hardware and process baseline
  - Generate deposited samples for pathfinding and initial cell baseline and testing

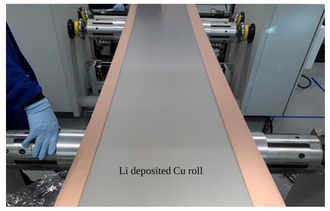
Drop-in Integration with Manufacturing Process



- ✓ Controlled Li delivery
- ✓ Process development
- ✓ Li deposition efficiency
- ✓ Tension control
- ✓ Process metrology developments
- ✓ Closed loop process control
- ✓ Web handling of thin Cu foil
- ✓ Double side Li deposition on Cu
- ✓ Graphite anode roll prelithiation
- ✓ R2R prelithiation safety assessment and approval

Roll-to-Roll Li Deposition System Installed and is Operational

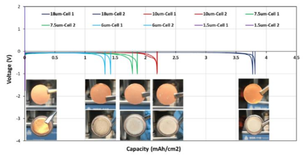
Accomplishment: Li Metal Anode

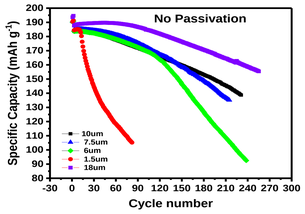


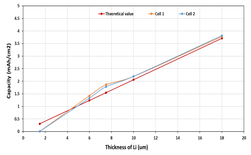
- ✓ Li thickness non-uniformity <7% achieved
- ✓ Double side Li deposition work started
- ✓ Li samples sent to partners for cell build and tests

Roll-to-Roll Li Deposition Li Deposition Demonstrated

Li Thickness and Cycling







Cathode:NMC622, 3.75mAh/cm² (4.4V to 2.7V at C/3)

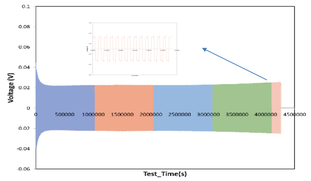
AMO Li: Bare 1.5/6/7.5/10/18um

Electrolyte: PNNL, 100uL.

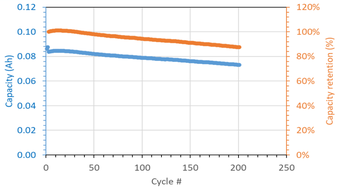
Separator: PE 20um

Cycling:0.33C discharge to -1.0 V, 30min rest after discharge.

Li Anode Thickness Impact Characterized



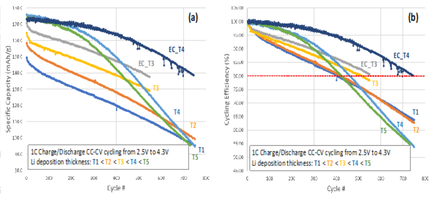
- Li/Li symmetric cell, cycled at 10mA >500 cycles



Single layer pouch cell achieved >200 cycles with capacity retention of 87.4%, exceeding the goal set for BP1 (80% after 200 cycles)

R&D Demonstration Cells with Li-metal Anode exceeded BP-1 Performance Goal

Accomplishment: Pre-Lithiation



- ✓ SiO_x pre-lithiation with different target thickn (T5>T4>T3>T2>T1)
- ✓ Samples delivered to partners for cell build characterization

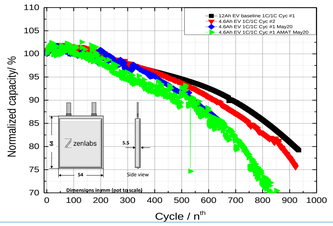
- ✓Improved cycling and higher capacity are observed for the samples with higher Pre-Li dose (T4 and T5)
- ✓Lower Pre-Li doses (T1, T2 and T3) show lower capacity indicating a deficit in Li to compensate the SiO_x IRCL
- ✓Pre-Li dose T4 looks the best based on electrochemical performance

Prelithiation Dose Deposition Control Demonstrated

R&D Cells with Pre-Lithiated SiO_x Anode

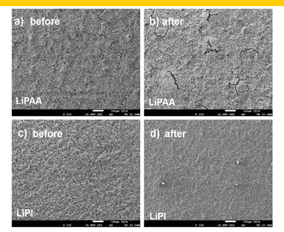
Pouch cell performance:

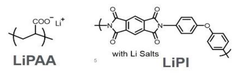
- **4.6 Ah** capacity at (C/3 rate)
- **305 Wh/Kg** specific energy (at C/3 rate)
- Pre-Lithiation using Applied Materials process
- SiO_x-C anode and NCM622 cathode
- Voltage window of 4.3V to 2.5V



R&D Demo Cell Performance Met the BP-1 Goal of >300Wh/Kg and 600 cycles

Accomplishment: High Temperature Binders





Two High Temperature Binder Candidates Down-selected for BP-2 Work

Remaining Barriers / Next Budget Period Focus

- High volume manufacturing (HVM) system design, scale up and operation
- Li deposition and protection hardware and process for high volume manufacturing (HVM)
- Large format high energy density cells
- Lower cost of manufacturing

Roll-to-Roll (R2R) HVM Test Preparations

- Complete scale up design for the Li deposition and protection equipment
- Procure and operationalize scaled up components
- Large format cells to meet or exceed interim performance goals towards high volume manufacturing (HVM)

R2R HVM Validation

- Validate the Li deposition and protection hardware and process
- Meet the equipment and cell performance goals for high volume manufacturing (HVM)
- Establish a cell and pack level technoeconomic model incorporating these advanced anodes

Summary

Four out of Four milestones for BP-1 have been completed, meeting the target performance.

- ✓Gen2 Lithium Deposition Source Design: **Completed. Parts on order.**
- ✓Test Stand for Lithium Deposition Source Design: **Completed. S2S system operational.**
- ✓Protective Layer Hardware Design: **Completed. Hardware Upgrades complete at Vendor site.**
- ✓Polymer Selected: **Down-selected two candidates.**

Three out of four Go/No-Go decision criteria have been met as of April 30, and the last one is on track to be accomplished by the end of BP-1

- ✓S2S tool fabricated planned samples for program: **R&D Cells fabricated using S2S system generated samples.** Ongoing
- ✓SiO_x-C anode: Meet R&D Demonstration cell performance: **Met.** (4.6Ah pouch cells, 305Wh/kg and >700cycles)
- ✓Li-metal anode: Meet R&D Demonstration cell performance: **On Track.** Achieved >200 cycles for both coin and single layer R&D demonstration pouch cell. **Awaiting** projected Specific Capacity information. Multilayer pouch cells being built and tested in PQ4.

Collaborators

Pre-lithiated cell manufacturing: zenlabs	HVM solution: APPLIED MATERIALS make possible	Li metal cell manufacturing: SAFT
Metrology support Polymer development	Cell & sub-component cost model development	Electrolyte and Prototype cell development