High Throughput Laser Processing for Enhanced Battery Performance and Manufacturing

AMMTO

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Abstract

For widespread adoption of electric vehicles, lithium-ion batteries (LiBs) need to achieve energy densities of >275 Wh/kg, cell costs less than $100/kWh, and charge to more than 80% capacity within 15 minutes.[1] Recently, it has been shown that introducing a secondary pore network in thick battery electrodes enables higher extracted capacity without a severe reduction in charge/discharge rate performance. Secondary pore networks consisting of ordered arrays of microstructures reduce tortuosity of Li^+-ion transport deep into the thick electrodes, diminishing detrimental concentration gradients within the cell. Ultrafast (femtosecond)-pulsed laser ablation is a promising method to introduce such micro pores or channels in thick battery electrodes as it allows for precise control of pattern geometries, results in minimal damage to the electrode, and can be introduced into existing roll-to-roll electrode manufacturing lines. We have explored laser patterning to create secondary pore networks in a variety of battery electrode materials for both anode and cathode applications and characterized the laser-material interaction parameters. In addition, advanced materials characterization techniques (SEM-EDS, XRD) were used to explore whether ultrafast laser ablation affects the remaining electrode materials' morphology and structure. Furthermore, we have translated lab-scale laser ablation to high-throughput roll-to-roll processing at industrially relevant scales. Finally, we worked with Argonne National Laboratory, developers of the battery cost-analysis package BatPac, to estimate the additional manufacturing costs (CapEx and OpEx) for incorporation of laser-ablation processing to current battery electrode manufacturing. We estimate that ultrafast laser processing will add only ~$1kWh, which for considerable improvements in cell performance, creates a compelling case for industry adoption.

Alignment with Office Mission

Our project has been focused on AMMTO goals to establish public-private partnerships that address manufacturing challenges for Li-ion battery materials/devices, with a focus on de-risking, scaling, and accelerating adoption of new technologies.

Challenges and Impact

- **Cost:** Scale laser processing for high throughput roll-to-roll processing
- **Performance:** Identify and manufacture laser-ablated 3-D electrode architectures for enhanced battery performance
- **Life:** Engineer micro-structured electrodes to reduce lithium plating and extend cell life

Project Outline

Innovation: High-Throughput Laser Ablation for Battery Electrode Processing
Project Lead: NREL
Project Partners: Clarios, Liminal Insights, Amplitude Laser Group

Timeline: Start: 10/1/20; End: 9/30/23, 85% complete
Budget: DOE: $1.44M; Cost-share: $1.44M

	FY21 Costs	FY22 Costs	FY23 Costs	Total Planned Funding
DOE Funded	$360,003	$443,756	$636,241	$1,440,000
Project Cost Share	$240,000	$450,00	$750,000	$1,440,000

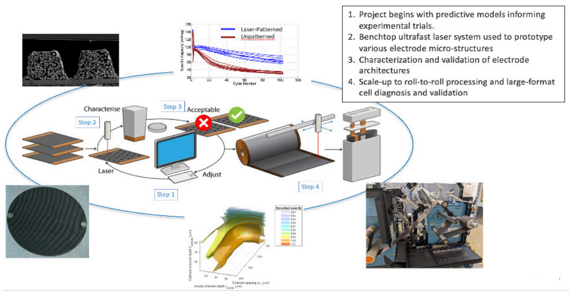
End Project Goal: Demonstrate roll-to-roll laser ablation processing of battery electrodes at rates up to 10 m/min (electrode width up to 160mm) with laser pattering optimized to produce >40% increase of practical cell capacity (Wh/kg) in 27Ah cells.

Background

Overcoming challenges with traditional Li-ion battery electrodes:

- Need: More capacity needed from current battery electrodes. Increasing their thicknesses (> 150 μm) is one proposed solution. [2]
- Problem: Slurry-processed thick electrodes are challenged by poor electrolyte wetting and poor rate capabilities during operation.
- Proposed Innovation: Femto-second laser ablation is a cost-effective and scalable method for high-throughput manufacturing of structured electrodes for improving wetting, fast charge performance, and lifetime of Li-ion cells. [3]

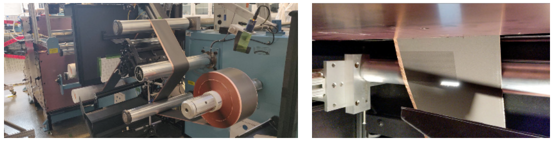
Our Approach:



Results

Ultrafast laser ablation was implemented in high-throughput roll-to-roll electrode processing:

- Femtosecond-pulsed laser (from project partner Amplitude Laser Group) with custom scanning optics was successfully integrated into NREL's R2R processing line
- Demonstration of laser processing up to **10 m/min** of electrodes up to **160 mm** wide. Successfully processed **> 1200 m** of electrode roll.



NREL's demonstration R2R Laser Processing

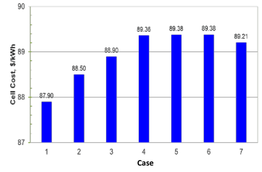
Laser-ablation electrode processing is scalable with minimal added cost:

- Cost estimation in collaboration with Shabbir Ahmad (Argonne National Lab) using **BatPaC model**
- Estimated additional cost when scaled to production: **<$1.50/kWh or < 1.7 %**

Case No.	
1	Baseline
2	6% Ablated
3	Porosity increased from 25% to 30%
4	Porosity increased from 30% to 35%
5	Equipment Cost increased by $300K
6	Equipment Cost increased by $500K
7	Electrolye Filling reduced to 1/7th of Baseline

Model Assumes:

- 50 MWh plant
- Anode ablation only
- 4 mAh/cm^2 NMC811 loading
- Cost of 2x 600 W laser at ~$500k each
- 2 m^2 additional floor space
- Additional 1200 W of continuous power consumption
- 0.2 FTE service engineer
- $40k/year service contract
- Steps above are sequential where each step includes condition of previous steps



Conclusions

We have demonstrated that femto-second laser ablation is a cost-effective and scalable method for high-throughput manufacturing of structured electrodes for improving wetting, fast charge performance, and life of Li-ion cells. Numerical and multi-physics models were developed to identify optimal laser-ablated patterns and predict improvement of cell performance. In prototype trials, laser-ablated electrodes demonstrated considerable improvements in capacity (**up to 2x**) and cycle life for fast charging **at 4C**. Microstructural characterization using X-ray nano- and micro-computed tomography (CT) revealed continued added benefit of the laser-ablated electrodes. (**see AMMTO poster by Donal Finegan** for additional details) Electrode laser patterning was successfully implemented in industry-relevant high-throughput roll-to-roll processing.

Key Achievements

Patents and Publications:

1. Dunlap et al., Laser ablation of Li-ion electrodes for fast charging: Material properties, rate capability, Li plating, and wetting, Journal of Power Sources, 2022.
2. US Patent App. 17/651,093, Laser ablation for Li-ion batteries
3. US Provisional patent 22-19, "Sensor-guided Adaptive Laser Ablation of Battery Electrodes

Future Work

Laser-ablated electrodes will be evaluated in large format 27Ah prismatic cells and compared to baseline (non laser ablated) cells to quantify the performance changes (capacity, rate capability, lifetime, etc.) of laser-processed electrodes.

Spatial mapping of wetting and solid-electrolyte interphase (SEI) inhomogeneities during electrolyte filling and cell formation of laser-patterned cells will be collected using acoustics sensing (Liminal Insights) to compare the dynamics of wetting, gas evolution, and SEI formation with baseline cells.

Technology Transfer

Throughout the project, there has been close collaboration with all our industrial project partners, Clarios, Liminal Insights, and Amplitude Laser Group, to ensure successful demonstration of the ultrafast-laser ablation processing method in a commercial-relevant fashion.

References

[1] USCAR – USABC, Low-Cost/Fast-Charge EV Goals (cell level) – 2023; https://uscar.org/usabc/
[2] Wood, D. L., et al., "Prospects for reducing the processing cost of lithium ion batteries." Journal of Power Sources, 2015.
[3] Dunlap et al.," Laser ablation of Li-ion electrodes for fast charging: Material properties, rate capability, Li plating, and wetting", Journal of Power Sources, 2022

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