U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

AMMTO & IEDO JOINT PEER REVIEW

May 16th-18th, 2023

Washington, D.C.

Acoustophoretic Additive Manufacturing for Scalable 3D Battery Electrodes | AMMTO

Dr. Corie L. Cobb, University of Washington

DE-EE0009112 | September 1, 2020 – December 31, 2023

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Project Overview

- **Overview**: We have developed a next generation manufacturing technology to rapidly control and pattern materials on a micron-scale over large-areas for high performing energy technologies to drive US domestic manufacturing for energy products and decarbonization. Our process is material agnostic – no specific chemistry is required.
- **Barriers Addressed**:
  - Performance: Current Lithium-ion batteries (and other energy storage technologies) are low in power density and lack the ability to support fast charging and discharging
  - Manufacturing: Lack rapid, large-area manufacturing for 3-dimensional (3D) patterning of functional materials that are critical for energy technologies
- **Impact**: This is a new manufacturing process with many cross-cutting clean energy applications. We have solved the critical physics that makes acoustic processing possible for patterning materials over a micron- to cm-scale at rapid timescales (seconds).
- **Relationships (Industry-National Laboratories)**:
  - Vehicle Technologies Office (co-managed)
  - Arkema USA, Argonne National Lab (CAMP & MERF), Oak Ridge National Lab

Project Outline

Innovation: Use acoustic focusing forces to rapidly pattern (in seconds) thick, micron-scale features in electrodes over large areas for higher performing energy storage devices

Project Lead: University of Washington (PI: Dr. Corie L. Cobb)

Project Partners: University of California, Santa Barbara (co-PI: Dr. Matthew Begley)

Timeline: September 1, 2020 – December 31, 2023; 75% complete

	FY21 Costs	FY22 Costs	FY23 Costs*	Total Planned Funding
DOE Funded	$120,108	$115,157	$258,758	$494,023
Project Cost Share	$52,253	$42,587	$28,666	$123,506

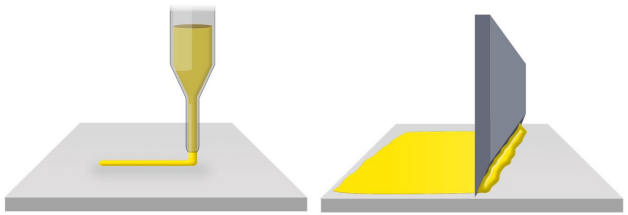
**Includes FY24Q1 costs to project end date; Cost share is met on a budget period basis*

End Project Goal: Develop a fundamental understanding of acoustic processing for functional materials and successfully demonstrate 3D patterned Lithium-ion battery electrodes made with $LiNi_{0.6}Mn_{0.2}Co_{0.2}O_2$ (NMC-622). Demonstrate a path to **> 15%** improvement in energy/power density and much larger improvements in manufacturing competitiveness.

Background & Strategic Approach

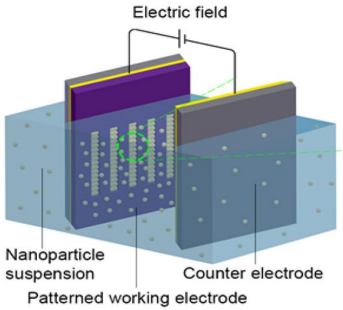
State-of-the-art is inadequate for micron-scale 3D patterning

Current Additive Manufacturing



Issue: Slow speeds or micron-scale features unobtainable

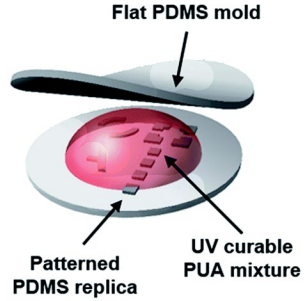
Electric Field Assembly



Issue: Specific material chemistry required

Image from Z. Chai, A. Childress, and A. Busnaina, ACS Nano (2022), licensed under CC BY 4.0

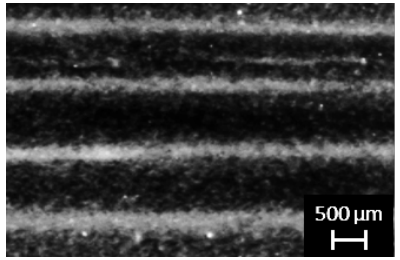
Imprinting & Templating



Issue: Material damage during mold removal

Image from S. Joo, J. Kim, and S. Seo, RSC Adv. (2017), licensed under CC BY 3.0

How do we develop processes that are independent of material chemistry?



Acoustophoretic Additive Manufacturing

How do we develop processes that rapidly pattern micro-scale (< 100 µm) features?

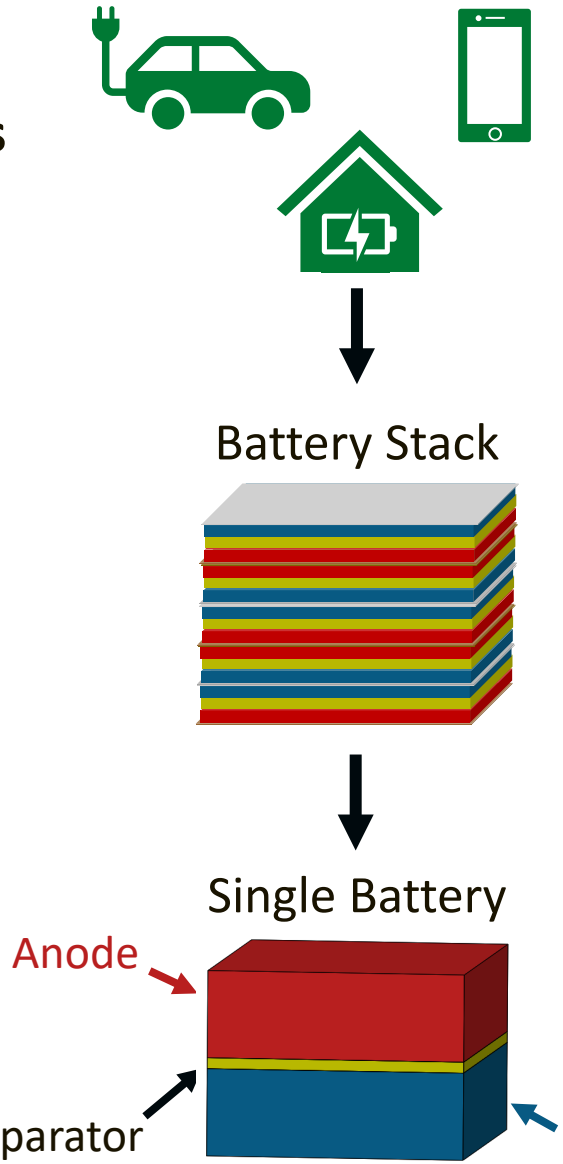
Research innovation under this project (DE-EE0009112)

Background & Strategic Approach

Better batteries and energy storage technologies with existing materials

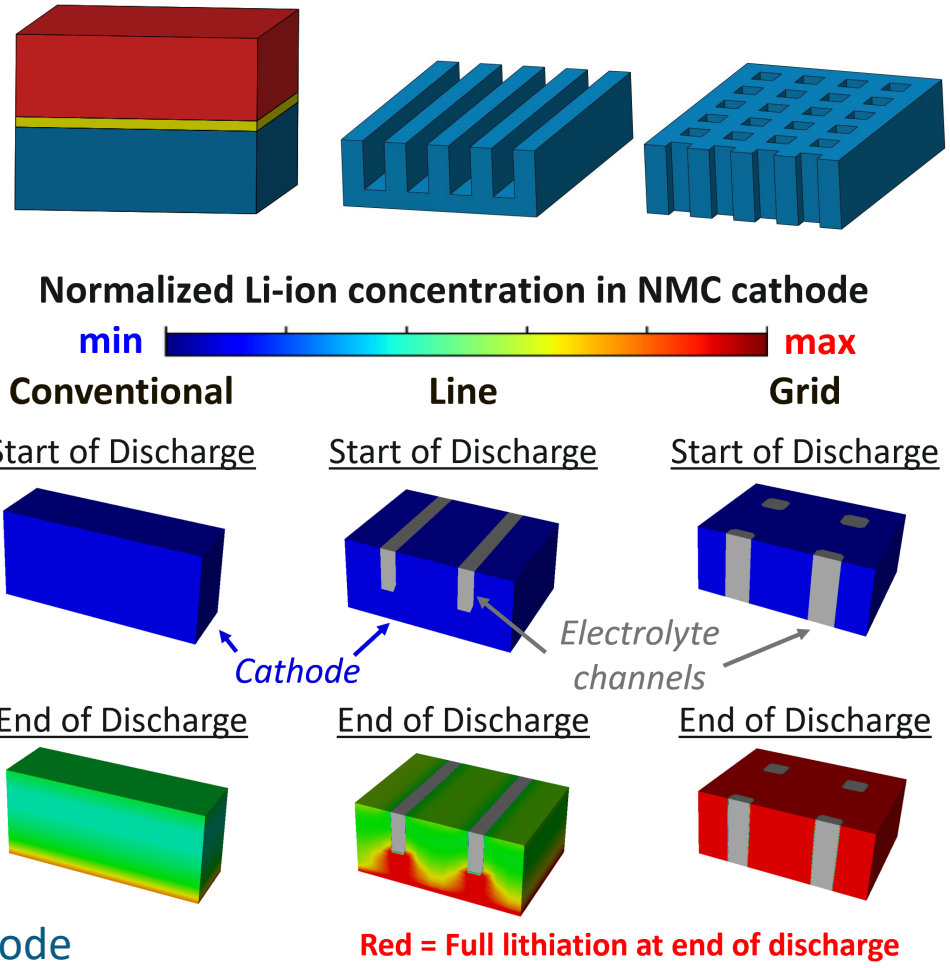
Metric	DOE Target	Our Impact
Materials	Low or no cobalt materials	Material agnostic (works with any material)
Fast charge	< 15 min with 80% capacity retention*	10 min with 85% capacity retention*
Performance	Increase to 300 miles+	Increase over baseline with >15% capacity increase

*500 charge/discharge cycles



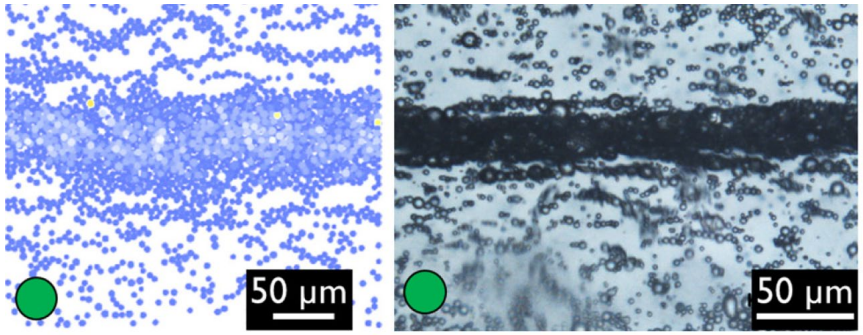
3D Li-ion Battery Electrodes

Improved range and fast charge

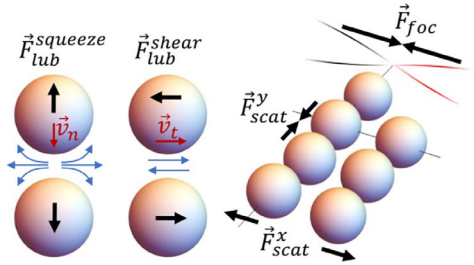


Background & Strategic Approach

- Develop models and experiments to determine how acoustic processing parameters impact 3D electrode formation in battery slurries
- **Material Agnostic – no specific chemistry is required, driven by particle size and density**
- Manufacture 3D structured electrodes to increase power and energy in NMC-622 battery electrodes

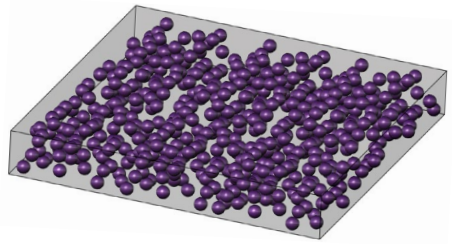


Model Experiment



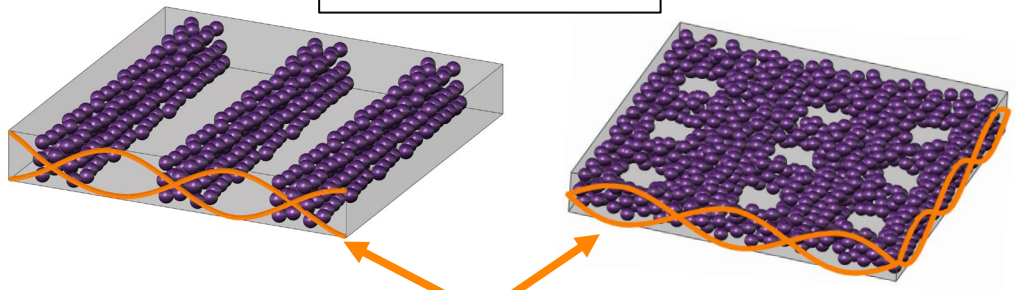
D.S. Melchert, *et al.* Materials & Design, Vol. 202, pp. 109512 (2021). (CC BY-NC-ND 4.0)

Focusing **OFF**



Dispersed particles battery slurry

Focusing **ON**



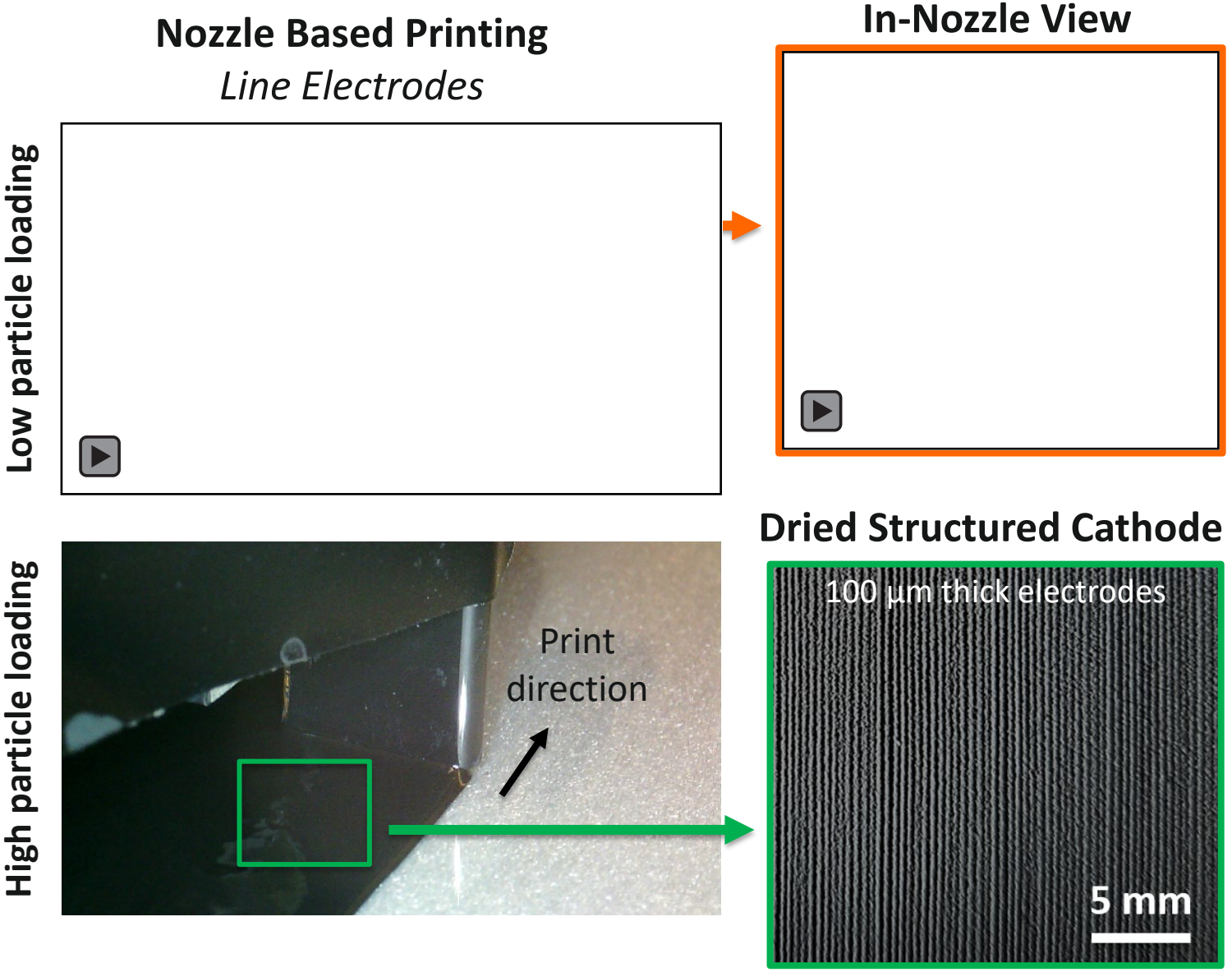
Structured lines *Structured grid*

Acoustic Forces

Results and Achievements

- To our knowledge, this is the first demonstration of large-area, multi-line material patterning with acoustic focusing in high viscosity slurries, opening the door for new energy applications
- Testing of NMC-622|Graphite battery cells in progress; manuscript and **invention disclosure underway**

Emilee Armstrong
Ph.D. Student



Results and Achievements

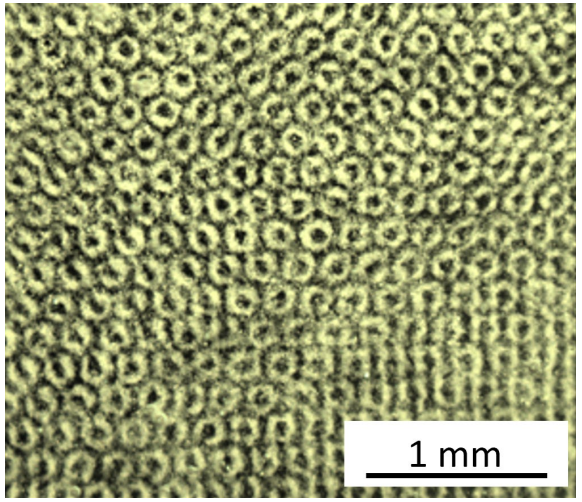
- Developed new predictive process models and an initial hardware prototype to enable acoustic patterning of grid and pillar electrode geometries
- Validation with battery material is underway and two manuscripts are in progress

Outcome: New AMMTO funding (DE-EE0010226) to scale up our acoustic manufacturing technology with in-situ process characterization

Lead: University of Washington

Partners: University of California, Santa Barbara, Arkema USA & Oak Ridge National Lab

Keith Johnson
Ph.D. Student



Future Work, Technology Transfer, & Impact

Future Work:

- Process refinement and electrochemical testing of 3D electrodes to attain data that shows a > 15% improvement in battery energy and power density; Manufacturing scale-up analysis underway.

Technology Transfer:

- We have fostered new relationships with Arkema and Argonne National Laboratory's Materials Engineering Research Facility (MERF) for guidance on material and process scale-up; With our manufacturing concept proven, future efforts will focus on higher TRL engineering - partnerships with material suppliers is key.
- Scale-up is promising (no new physics), but time and resources are needed for development. UW's focus is on patents and licensing to enable technology transfer.

Impact:

- This is a new manufacturing process with many cross-cutting clean energy applications. We have solved the critical physics that makes acoustic processing possible for patterning materials over a micron- to cm-scale at rapid timescales (seconds).

Questions?

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