Developing Next-Generation 3D Microbatteries, via Two-Photon Lithography

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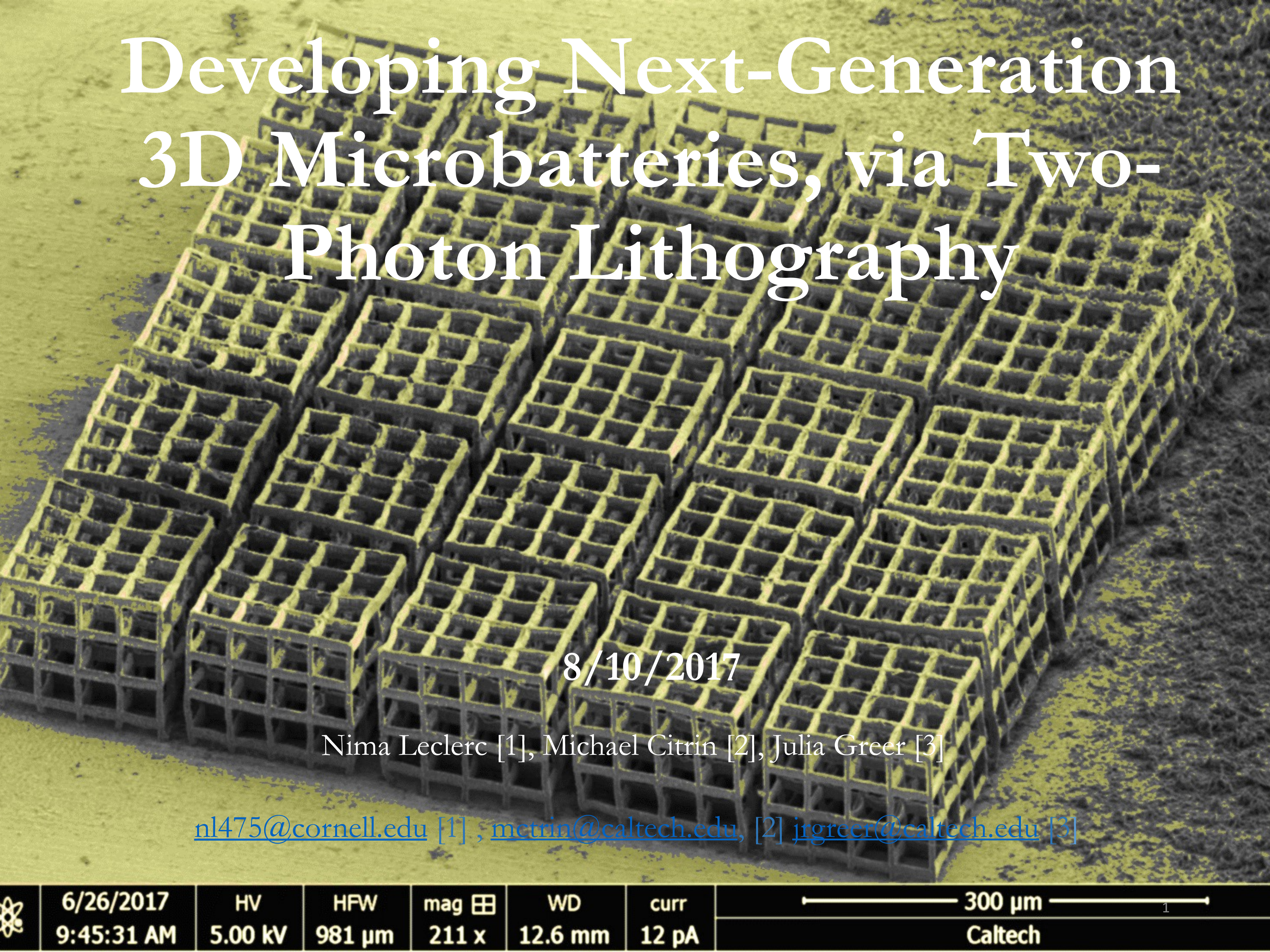


Outline:

I. Motivation

II. 3D Microbattery Fabrication

III. Electrodeposition Results and Discussion

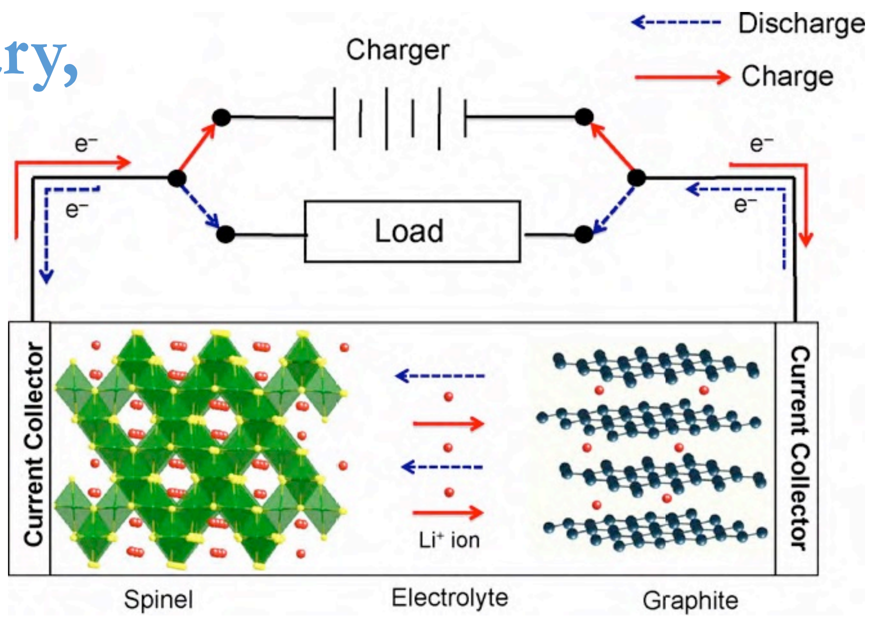
IV. Side Projects, Summary, and Future Work

What's in a battery? How does it operate?

- Primary vs. Secondary

-Cathodes, anodes, electrolytes

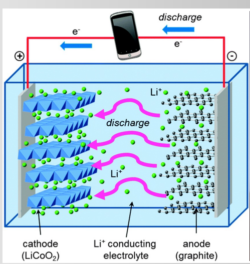
-Power vs. energy density

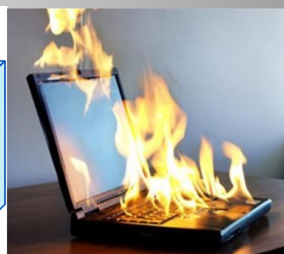


M. Park, et al., J. Power Sources (2010)

Problem: Current Batteries sacrifice Energy Density w/ Increased Power Density

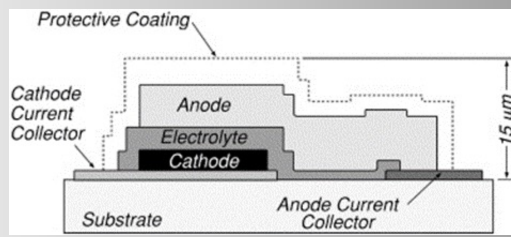
Li Ion Battery





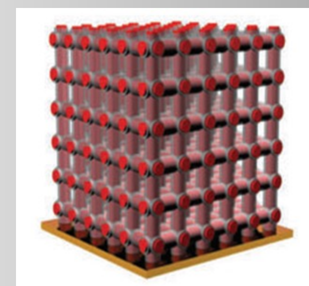
- Organic solvent electrolyte
- Low E/P densities
- Dendrite failure mechanism
- Large transport lengths

Thin-film SSBs



- LiPON solid electrolyte
- All solid-state!
- Small transport lengths

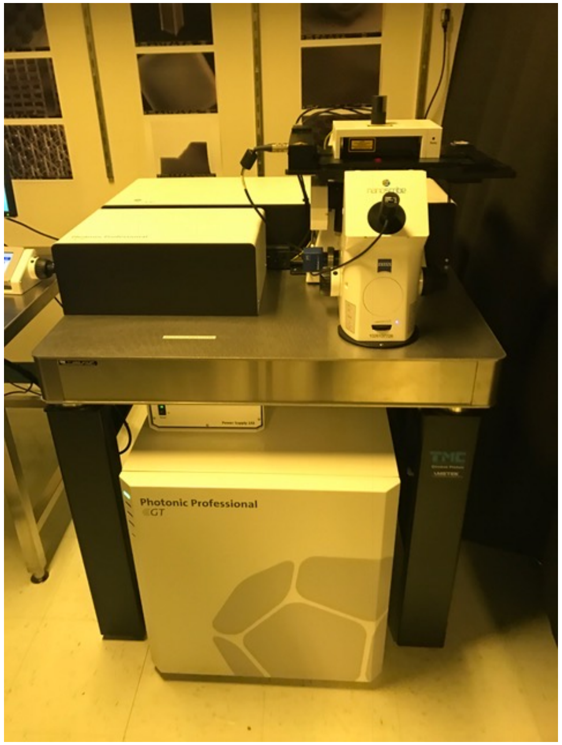
3D SSBs

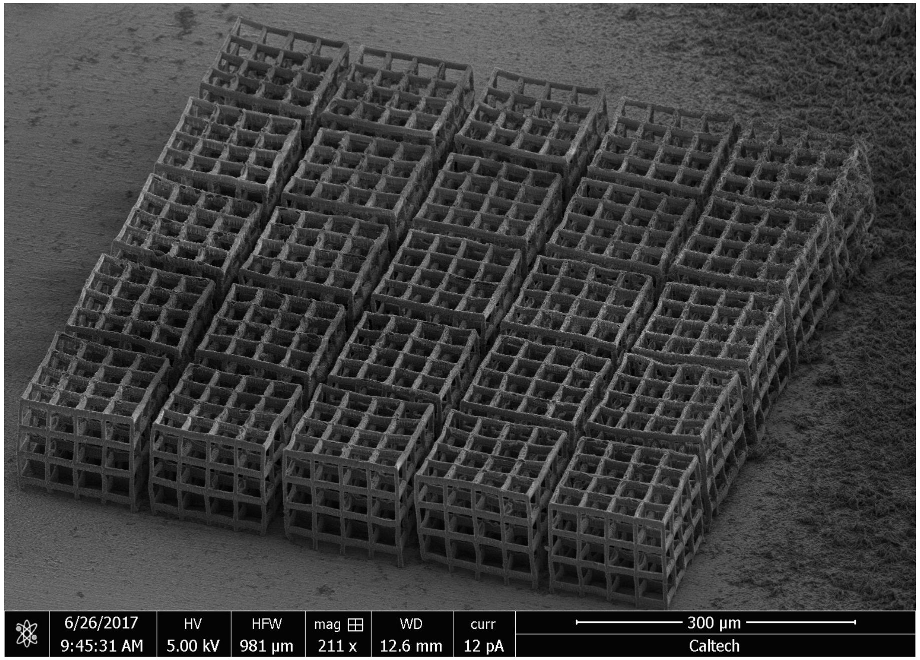


- High E/P densities
- All-solid state !
- Uses height to increase E density
- Small size → biomedical devices

Chem. Soc. Rev., 2014, **43**, 185-204
Materials Sci. and Engi., 2005, **116**, 245-249

Nanostructure Fabrication





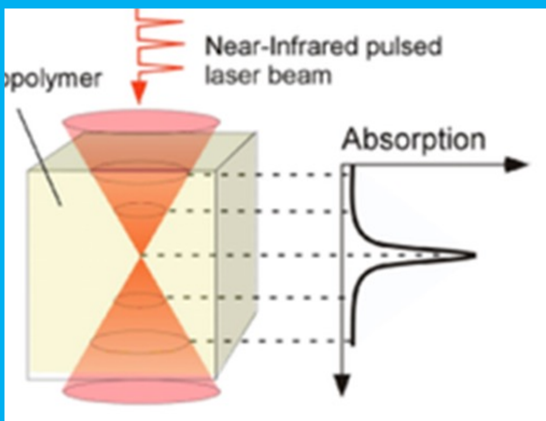
-*Nanoscribe* two-photon lithography used to create trusses, with cubic unit cells with 30 μm unit cells, arrays of 4x4x4 trusses

-Cubic geometry: open structures and fast to write

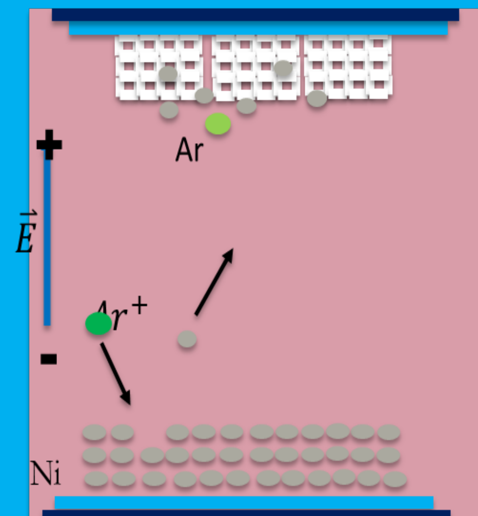
- Geometry increases surface area with about 1 order of magnitude

Fabrication Process

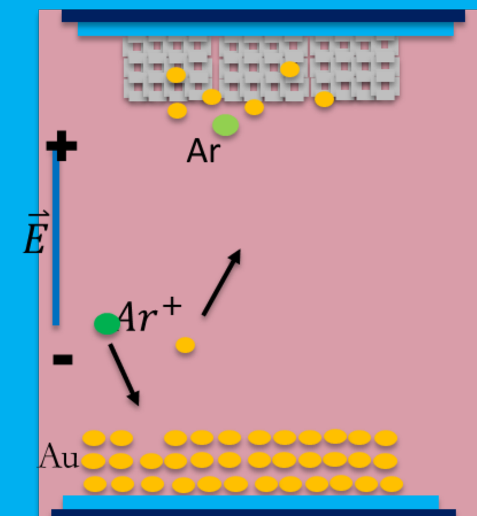
Nanolattice Fabrication, via Two-Photon Lithography



Ni deposition, via sputtering



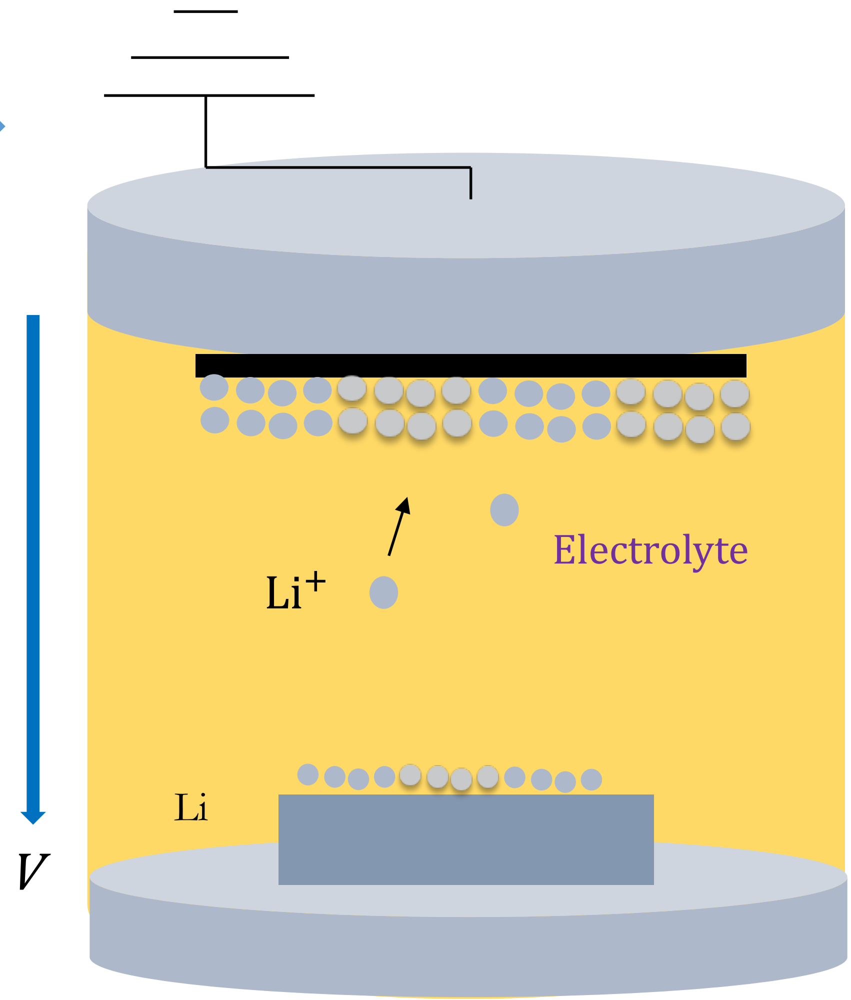
Au deposition, via sputtering



Maruo, S. and Fourkas, J. (2008), Recent progress in multiphoton microfabrication. Laser & Photonics Reviews, 2: 100–111.

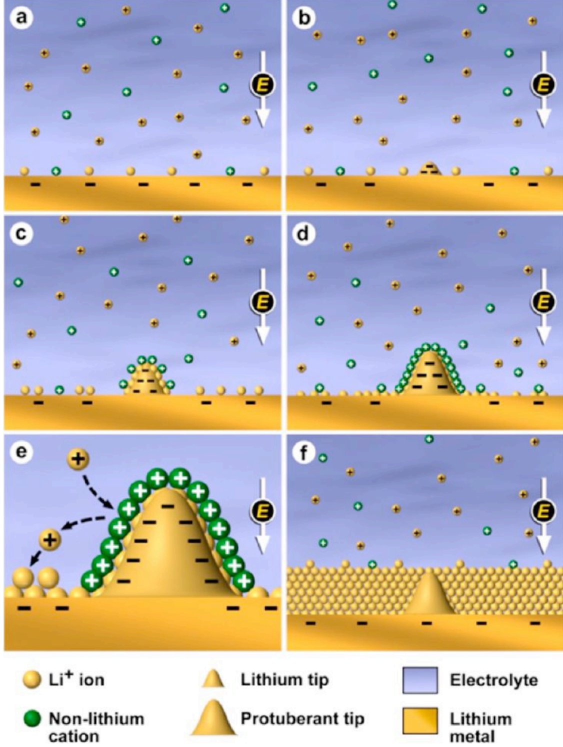
Electroplating Li anode

- Containment: beaker cell and EL-CELL
- Less electrolyte → less impurities → ☺
- Electrolyte: Propylene carbonate, $CsPF_6$, $LiClO_4$

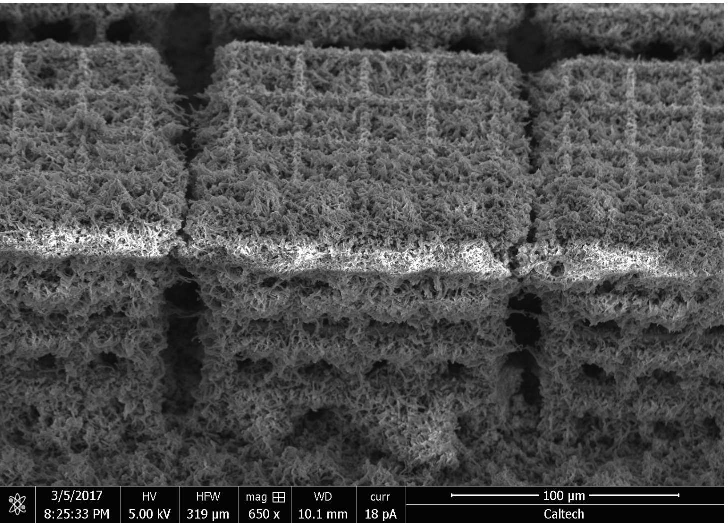


Minimizing Dendrite Formation

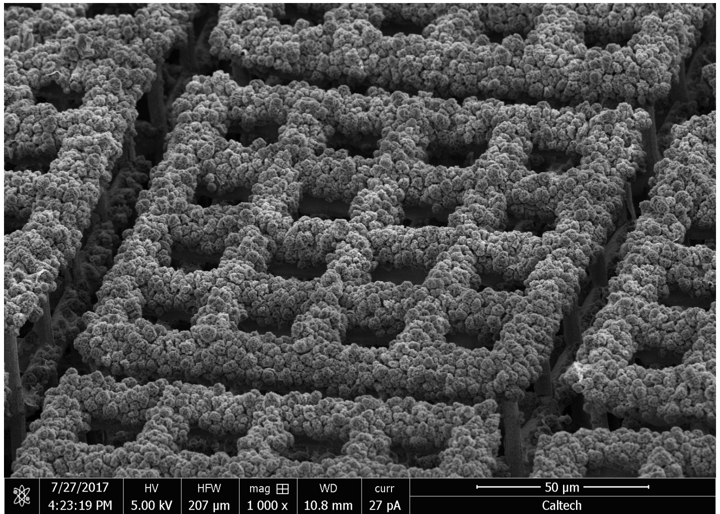
- **Cesium additive, forms Self-Healing Electrostatic Shield (SHES)**
- **Low currents**
- **Increased temperature**



J. Am. Chem. Soc. 2013, **135**, 4450−4456

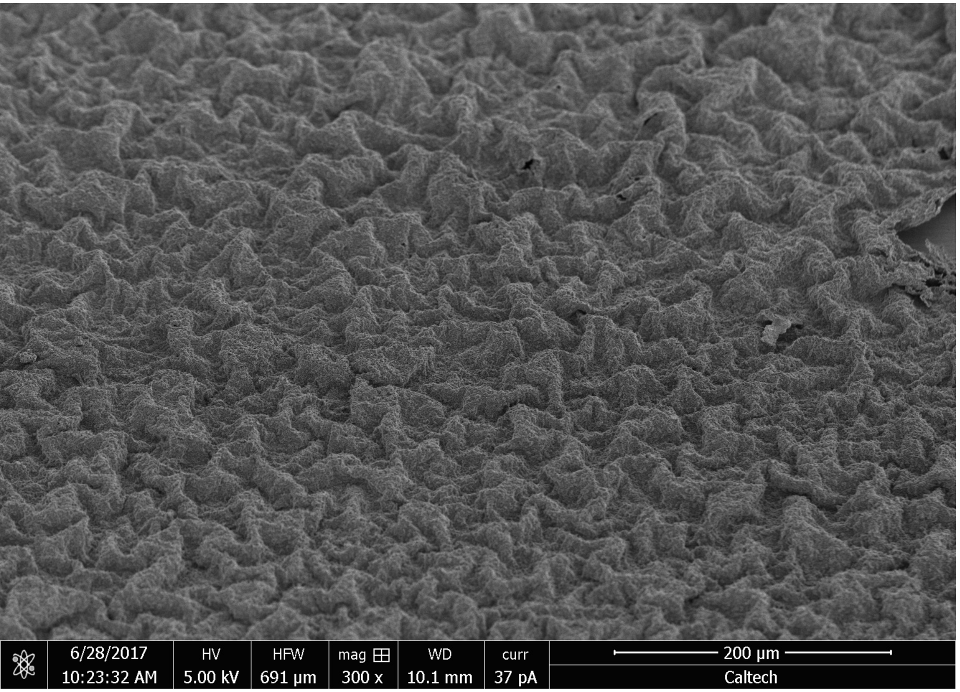


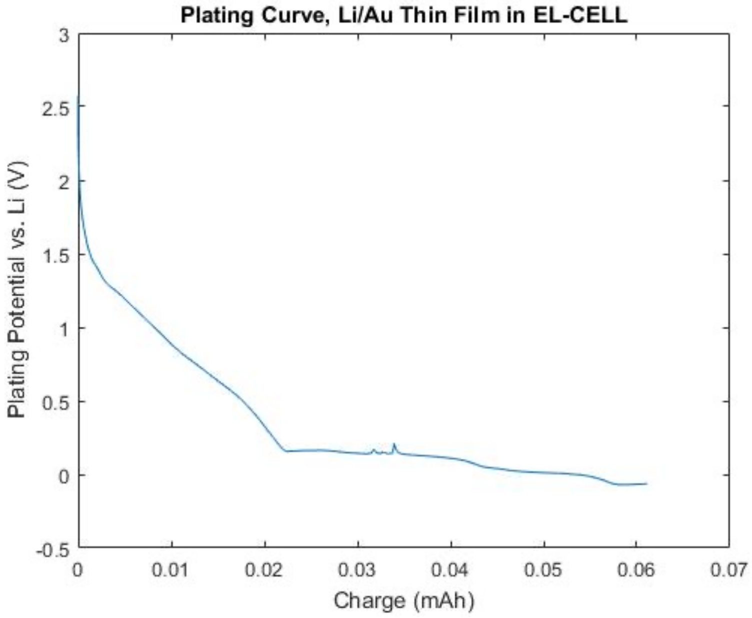
Cs^+

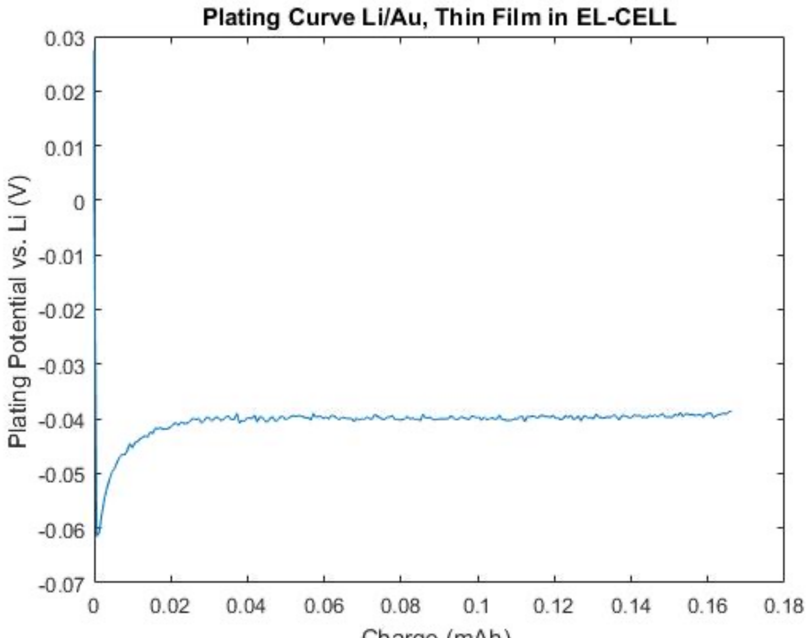


Thin Film Electrodeposition

EL-CELL

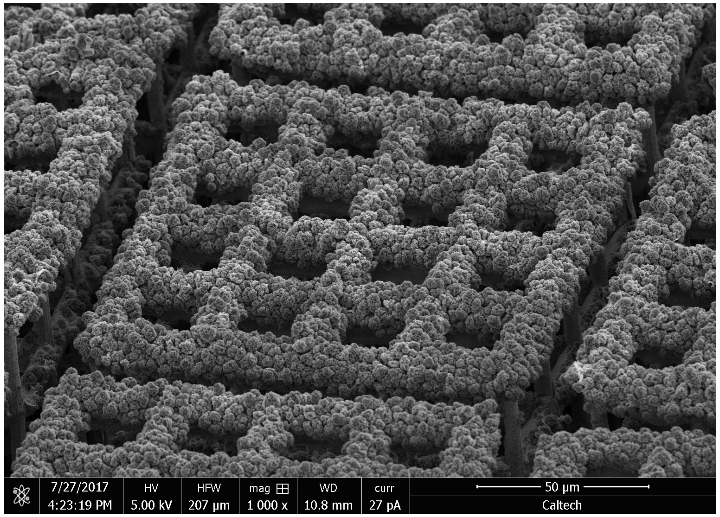


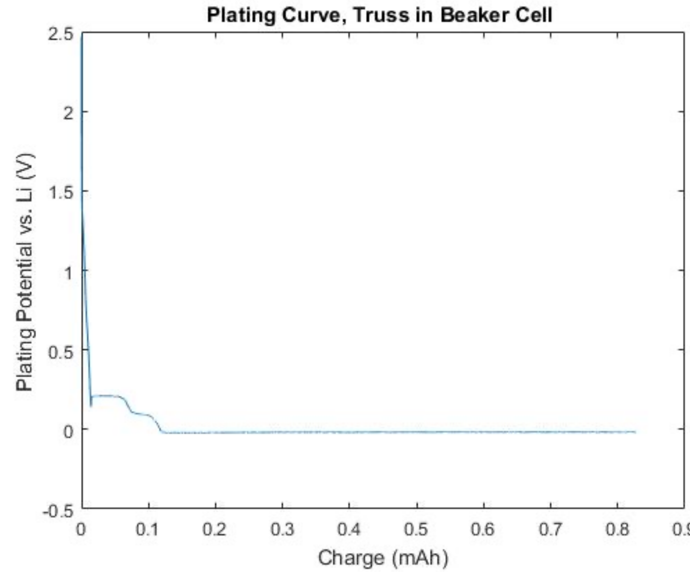




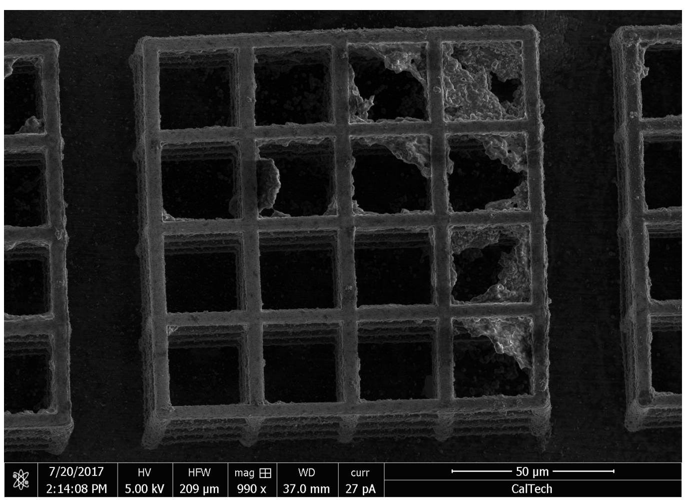
Nanotruss Electrodeposition

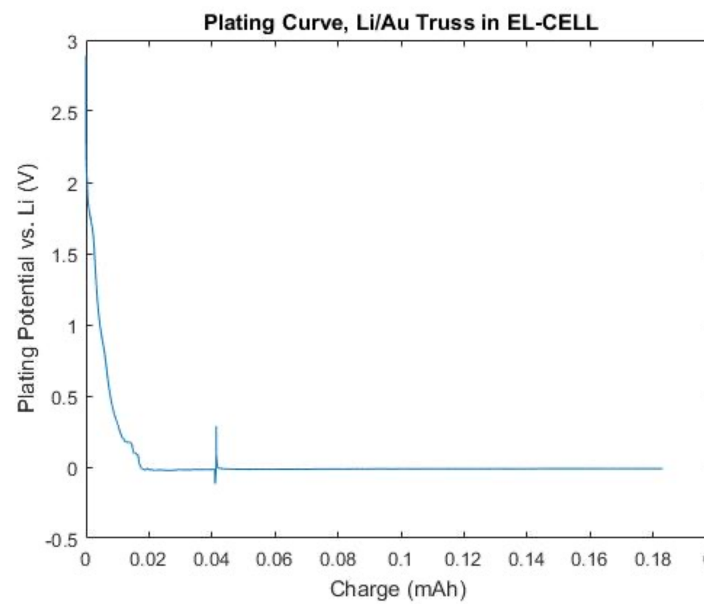
Beaker Cell





EL-CELL

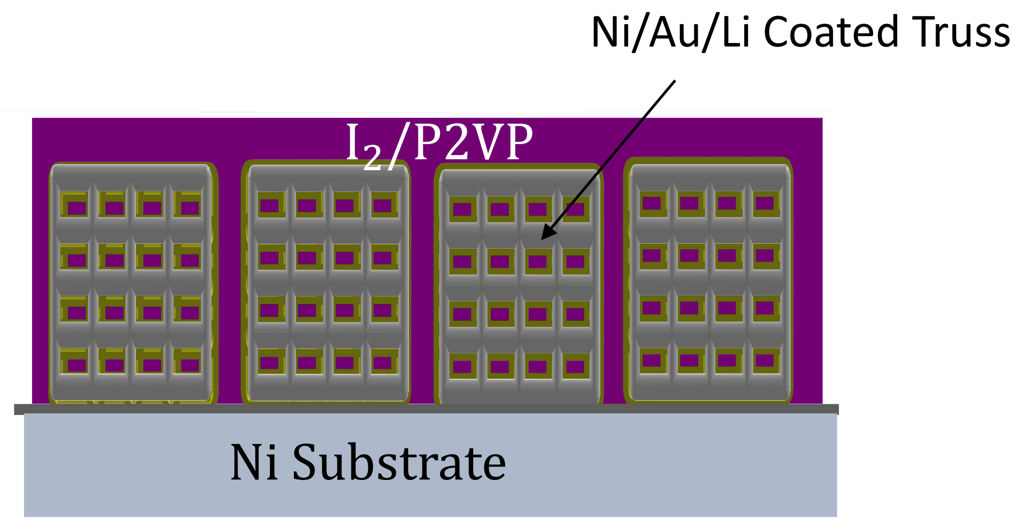




Future and Ongoing Steps...

- Electroplate Li onto truss w/ coin cell
- Fabricate a full cell
- Implement design in secondary battery (LiPON w/ALD)

$$2Li_{(s)} + I_{2(s)} \rightarrow 2LiI_{(s)}$$

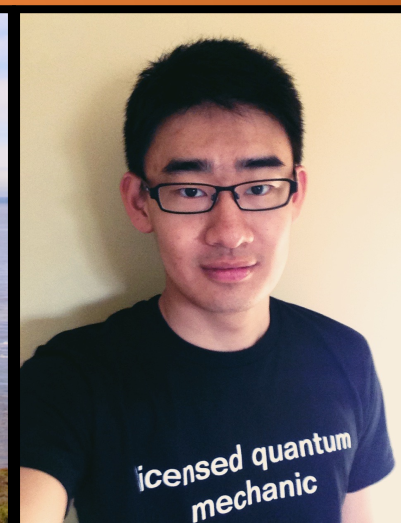


Courtesy of Mike Citrin

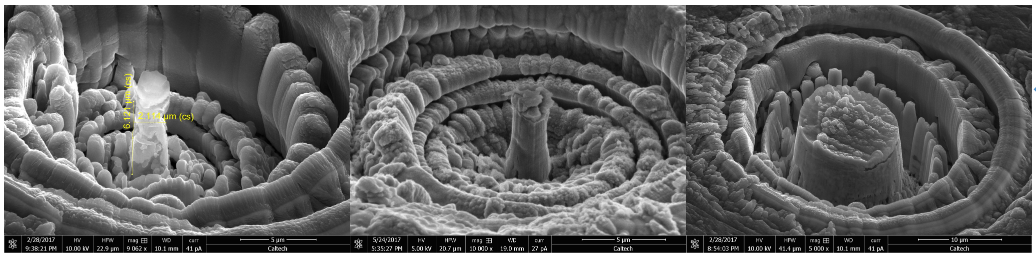
THANK YOU!!

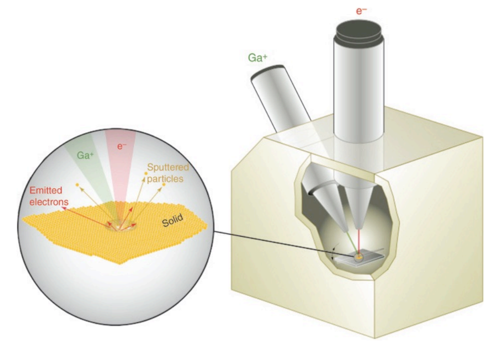
- Mentors: Julia Greer, Mike Citrin
- Heng Yang, Xiaoxing Xia

- SURF Program
- The Greer Group



Understanding Ga^+ interactions with Nanoscale Li, via *ab-initio* Methods



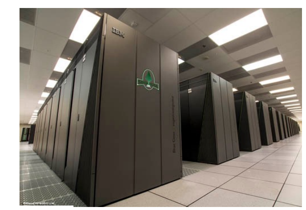


Materials Sci. and Engi., 2007, **32**, 389-399

Increasing *J* → Smoother surface

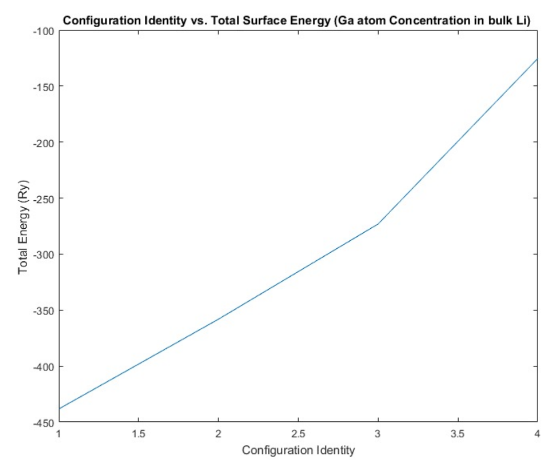
Hypothesis: Rough surface = higher surface energy.
Increased *J* → Increased Ga surface concentration

Approach $[-\nabla^2 + \hat{V}]|\Psi\rangle = \epsilon|\Psi\rangle$ ✚



$$E_{surface} = \langle\Psi|\hat{H}|\Psi\rangle$$

computed for varied Ga configurations at surface



Hypothesis verified! But, is this a valid hypothesis??