SAND2018-12355C

Sandia National Laboratories

Electrochemical ion insertion: mechanisms and applications in energy and computing

Yiyang Li
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Present: Harry Truman Fellow, Sandia National Laboratories
2016: PhD, Materials Science and Engineering, Stanford University
2011: BS, Electrical Engineering, Olin College of Engineering

Research Vision

Combine **electrochemical materials** with **microfabrication** to enable more accurate measurements of redox processes and design novel devices for **energy** applications

Select Awards and Honors

2017: Young Scientist Award, International Solid State Ionics
2016: Walter J. Gores Teaching Award, Stanford University
2016: Daniel Cubicciotti Award, Electrochemical Society
2015: Ross Tucker Award, Electronic Materials Symposium
2015: Gold Graduate Student Award, Materials Research Society
2013: Graduate Research Fellowship, NSF

Teaching Experiences

2015: Lecturer, Principles of Batteries
Course Evaluation: 4.6/5.0
2012-14: Teaching Assistant, Thermodynmaics
Interests: thermodynamics, transport, electrochemistry, materials, semiconductor processing and devices

Research Mentees

2018: Jane Edgington*, RPI
Andrew Gilbert, West Point
2016: Rachel Lee*, National Chiao Tung University
2014-15: Norman Jin*, Stanford University
2013-14: Sophie Meyer#, Stanford University
2013: Sebastian Galvez, Belmont HS
*Currently PhD Student
#Published first-author paper in **Adv. Mater.**

Funding and Proposal Writing

2017: Sandia National Laboratories, Laboratory Directed Research & Development, PI: Y. Li. Successful/Accepted
2017: Office of Naval Research, Broad Agency Announcement. Successful/Accepted
2014-16: Advanced Light Source User Proposal, 80 percentile review score. Successful/Accepted

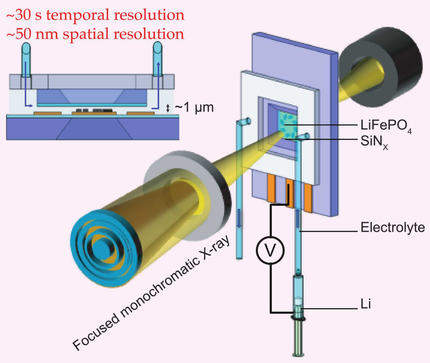
References

William Chueh, Stanford <wchueh@stanford.edu>
A. Alec Talin, Sandia <aatalin@sandia.gov>
Martin Bazant, MIT <bazant@mit.edu>
Mark Brongersma, Stanford <brongersma@stanford.edu>

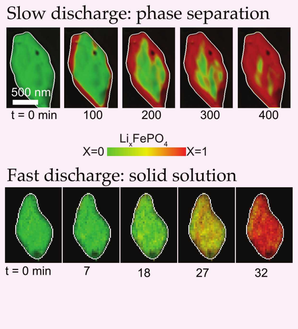
Reaction, diffusion, and phase transformations in Li_XFePO_4

Presentation Title: Autocatalytic Reactions and Surface Diffusion Control Phase Separation in Li_XFePO_4
Presentation Time: 4:00 PM - 4:15 PM , Sunday Oct 28, 2018
Location: David L. Lawrence Convention Center, 324

Imaging battery cycling in operando using X-ray absorption spectroscopy and microscopy

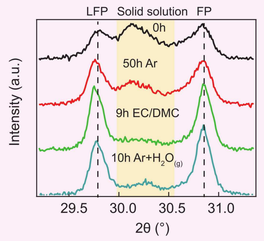


Phase separation in Li_xFePO_4 is suppressed at elevated cycling rates



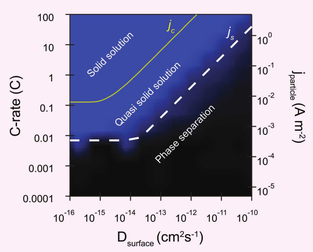
Y. Li et al. **Nat. Mater.** 13, 1149(2014)
J. Lim*, Y. Li* et al. **Science**, 353, 566(2016)
*equal contribution
Y. Li et al. **Nat. Mater.** 17, 915(2018)

Phase separation rate depends on environmental conditions

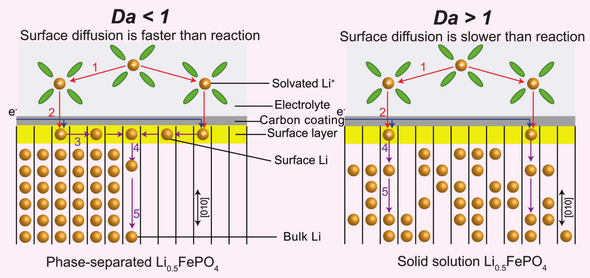


Phase-field reaction-diffusion model

$$\frac{\partial X}{\partial t} = \nabla\left[\frac{D_{surf}}{k_B T} X(1-X)\nabla\mu_{Li}\right] + r(X, \mu_{Li}, \mu_{ext})$$



The Damkohler number governs solid solution vs phase separation



(1) Electrolyte diffusion (2) Desolvation (3) Surface diffusion (4) Incorporation (5) Bulk diffusion

Neuromorphic computing using non-volatile electrochemical memory

Presentation Title: The Effect of Electrochemical Lithium Insertion on the Electronic Conductivity of TiO_2 (anatase)
Presentation Time: 5:40 PM - 6:00 PM , Sunday Oct 28, 2018
Location: David L. Lawrence Convention Center, 330

Artifical neural networks use training data to learn tasks without specific instructions.

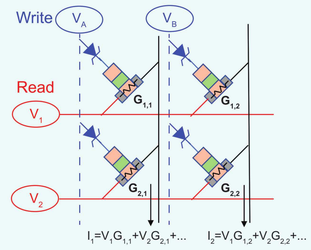
Example: Image recognition

Inference and learning require manipulation of large matricies, but are extremely energy intensive.

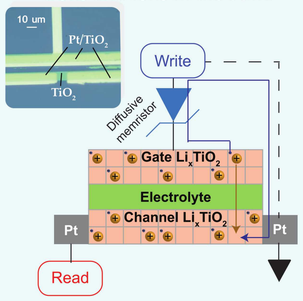
$$\begin{bmatrix} V_1 & V_2 & V_3 \end{bmatrix} \begin{bmatrix} w_{11} & w_{12} & w_{13} \\ w_{21} & w_{22} & w_{23} \\ w_{31} & w_{32} & w_{33} \end{bmatrix}$$

$$I = V^T W$$

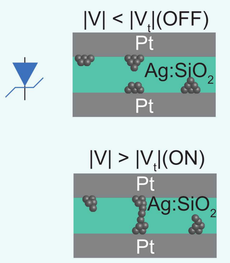
Non-volatile memory directly conduct matrix multiplications, and can reduce energy consumption by 1000X.



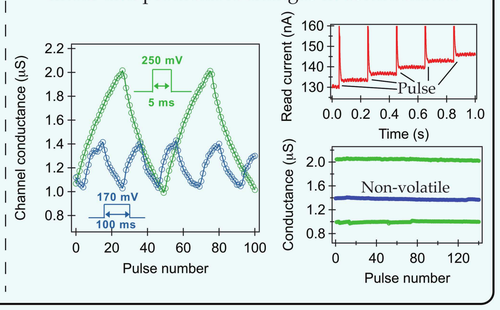
Ion insertion transistors store electrons and ions in the bulk.



Diffusive memristor switches provide non-volatility.

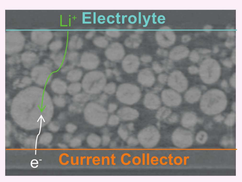


The combination enables non-volatile memory at record low programming voltages, with highly linear and predictable changes in conductance.



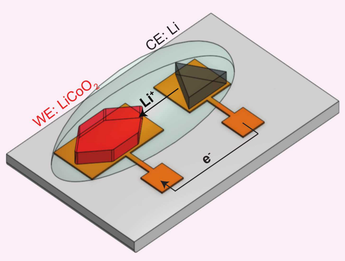
Future work: precise measurements of Li-ion batteries using microfabrication

Heterogeneous porous electrodes make precise measurements

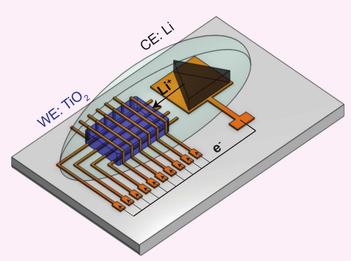


Ebner et al. **Adv. Ener. Mater.**, 8, 245 (2013)

Single particle measurements eliminate the heterogeneity of porous electrodes

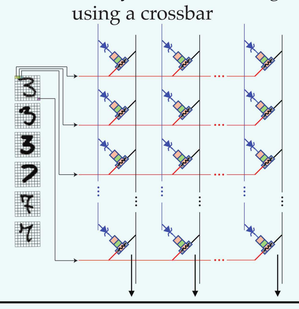


Particle crossbar for in situ lithium mapping with higher spatial and temporal resolutions



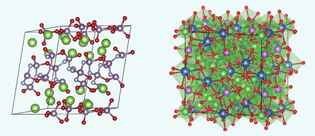
Future work: develop the ion insertion transistor into a hardware training accelerator

Learn to identify handwritten digits using a crossbar



Identify the fastest programming speed, aiming for ~ 1 MHz

More conductive electrolytes will be essential towards this goal

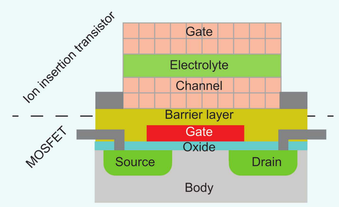


Current LiPON
$\sigma_{Li^+} = 10^{-6}$ S/cm

Future Garnet LLZO
$\sigma_{Li^+} = 10^{-3}$ S/cm

Sicolo & Albe. **J. Power Sources.**331, 382 (2016)

Design barrier layers for compatibility with CMOS processes



The views expressed in the presentation do not necessarily represent the views of the U.S. Department of Energy or the United States Government.
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