Northwestern | McCORMICK SCHOOL OF ENGINEERING
Materials Science and Engineering

COHEN Lecture

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Wednesday, May 31St
4:00pm
Panoce - Abbott Auditorium

Nanoscale Imaging of Structure and Ion Distributions during Electrochemical Cycling by Electron Microscopy

Much of what we know about the structure-property relationships of energy conversion and storage materials during their operation is inferred indirectly through bulk measurements or post-mortem studies. To observe electrochemical processes in their native environment on the nanometer scale, we developed a liquid cell incorporating electrodes on the viewing membrane in a transmission electron microscope [1,2]. This geometry allows us to image the microstructure of an electrode, in liquid and under bias, and further perform spatially-resolved spectroscopy to determine composition and bonding. Using this cell, we have studied the degradation and coarsening of Pt/Co fuel cell cathode electrocatalysts during electrochemical cycling. We also show how valence electron energy-loss spectroscopy (EELS) can be used to observe the lithiation and delithiation dynamics of individual LiFePO4 nanoparticles, as well as the lithium ion distribution in the liquid using energy-filtered transmission electron microscopy (EFTEM). We also consider fundamental limits on this imaging approach imposed by the liquid thickness and maximum allowable beam dose.These studies are supplemented by an air-operational scanning electron microscope (airSEM) that leaves the sample outside of vacuum – in air or liquid [3]. The sample can be placed on a simple optical microscope slide or even the surface of a liquid. The spatial resolution is 5-10 nm, and the absence of a specimen vacuum chamber simplifies the construction of custom detectors, liquid and electrochemical cells [4].

[1] M. E. Holtz, Y. Yu, J. Gao, H. D. Abruña, and D. A. Muller, "In Situ Electron Energy-Loss Spectroscopy in Liquids". Microscopy and Microanalysis 19, 1027-1035 (2013)
[2] M. E. Holtz, Y. Yu, D. Gunceler, J. Gao, R. Sundararaman, K. A. Schwarz, T. A. Arias, H. D. Abruña, and D. A. Muller, "Nanoscale Imaging of Lithium Ion Distribution During In Situ Operation of Battery Electrode and Electrolyte". Nano Letters 14, 1453-1459 (2014).
[3] K. X. Nguyen, M. E. Holtz, J. Richmond-Decker, and D. A. Muller, "Spatial Resolution in Scanning Electron Microscopy and Scanning Transmission Electron Microscopy Without a Specimen Vacuum Chamber". Microscopy and Microanalysis 22, 754-767 (2016).
[4] In collaboration with Elliot Padget, Megan Holtz, Yingchao Yu, Kayla Nguyen, Barnaby Levin and Héctor D. Abruña

Bio: David Muller is a professor of Applied and Engineering Physics at Cornell University, and the co-director of the Kavli Institute at Cornell for Nanoscale Science. He is a graduate of the University of Sydney, received a PhD from Cornell University and worked as a member of the technical staff at Bell Labs for six years before returning as faculty to Cornell. His current research interests include the development of a new generation of high-speed imaging electron detectors, and the atomic-scale control and characterization of matter for applications in energy storage and conversion.