Nanostructured materials for energy storage applications

The need for energy storage continues to grow due to our increasing use of consumer electronics, and adoption of electrical vehicles and renewable energy sources, which necessitates grid storage. Unfortunately, fast charging capabilities and cycle life remain problematic in current lithium-ion batteries. In this thesis, we aim to: 1) develop novel materials with good rate capability and define design rules for fast charging materials, and 2) use nanoporous metal to hinder degradation and extend the lifetime of high capacity alloying anodes and utilize operando X-ray diffraction and imaging studies to understand the mechanisms that underpin the performance of these materials.

Thus far, we have identified a number of key requirements for optimized battery performance. 1) With our highly defected MoS2 nanocrystal, mesoporous LiMn2O4 and LiVPO4F, we have found that the key to producing fast charging is nano-structuring a battery material to increase the maximum charge and discharge rate by shortening the diffusion path length for lithium and sodium-ions and in some cases allowing ions to intercalate into the channels or layers of the redox-active material in a non-diffusion controlled manner. At the root of this behavior is suppression of the phase transition that often occur upon ion intercalation.

For long cycle lifetime, we used nanoporous tin and antimony tin as platforms to show that nanoporous metals, intermetallics and surface coatings are effective in alleviating the volume expansion that causes material degradation and impedes the lifetime of these alloying anodes. Operando transmission X-ray microscopy shows that porosity and protective coatings are critical in reducing stress and strengthening the structural integrity during cycling. Through our experimental approaches, we hope to establish a set of materials and architectural guidelines for the next generation electrochemical energy storage.

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Thursday, Nov. 29th, 2018
2033 Young Hall
12:00 PM