In-Situ Transmission Electron Microscopy Observations of the Charging and Discharging Processes of Lithium Ion Batteries

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We created the first nano-battery inside a transmission electron microscope, allowing for real-time atomic scale observations of battery charging and discharging processes. The nano-battery consists of a single SnO$_2$ nanowire anode, an ionic liquid electrolyte and a bulk LiCoO$_2$ cathode [1]. Upon charging, a reaction front propagates progressively along the nanowire, causing the nanowire to swell, elongate, and spiral. The reaction front is a “Medusa zone” containing a high density of mobile dislocations, which are continuously nucleated and absorbed at the moving front. This dislocation cloud indicates large in-plane misfit stresses and is a structural precursor to electrochemically-driven solid-state amorphization. In charging Si nanowires, the nanowires swell rather than elongate. We found unexpectedly the highly anisotropic volume expansion in lithiated Si nanowires, resulting in a surprising dumbbell-shaped cross section which developed due to plastic flow and necking instability. Driven by progressive charging, the stress concentration at the neck region led to cracking, eventually splitting the single nanowire into sub-wires. These experimental results and associated theoretical models uncover the previously unknown anisotropic deformation mechanism and highlight the critical role of plastic flow in electrochemically induced failure of Si nanostructures. Because lithiation-induced volume expansion, plasticity and pulverization of electrode materials are the major mechanical effects that plague the performance and lifetime of high capacity anodes in lithium-ion batteries, our observations provide important mechanistic insight for the design of advanced batteries for powering electrical vehicles and devices.

References

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Brief Bio

Dr. Jianyu Huang is a staff scientist at the Center for Integrated Nanotechnologies at Sandia National Laboratories. He received his Ph. D. from the Institute of Metal Research, Chinese Academy of Sciences in 1996. He then moved to Japan as a COE (Center-of-Excellence) Fellow and a JSPS (Japanese Society for the Promotion of Science) Fellow. From 1999 to 2001, he worked at Los Alamos National Lab. as a postdoc, and from 2002 to 2006, he was a research faculty at the Physics Department of Boston College. He has been working in the area of electron microscopy and its applications in materials science for over 20 years. His current interests focus on in-situ structure and property correlation of carbon nanotubes, nanowires, and graphene by using transmission electron microscopy – scanning probe microscopy platforms. He is also involved in developing micro-electro-mechanical devices to enable in-situ thermal/thermoelectric, and electrochemical (battery) studies. The goal is to understand how the size, defects and surface affect the electron, phonon, ion, and mass transport processes in nanomaterials. He has published over 140 peer reviewed journal papers, including such distinguished journals as Nature, Science, Physical Review Letters, Nature Nanotechnology, Nature Communications, Nature Methods, PNAS, and Nano Letters. He has given over 50 invited talks in a number of academic conferences, including the Materials Research Society, the Microscopy Society of America, TMS, AVS. Some of his works are featured in New York Times, Nature, Nature Nanotechnology, New Scientists, Chemical Engineering News, EETimes, Science News, Sandia Lab. News.