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Application of in-situ electron microscopy in nanoscience and energy research

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Transmission electron microscopy (TEM) is a powerful tool for structural characterization of materials. However *in-situ* studies of the mechanical, electrical and electrochemical properties of materials at a nanometer scale are still challenging. A scanning probe microscopy (SPM), including scanning tunneling microscopy (STM), atomic force microscopy (AFM), and nano-indentor, explores the physical and mechanical properties of materials down to a single atom level but without internal structural information. A combined TEM-SPM platform, which integrates a fully functional SPM into a TEM, takes advantage of both the SPM and the TEM capabilities and provides unprecedented opportunities to probe the structural, mechanical, electrical, and electrochemical properties of materials *in-situ* down to a nanometer scale. This allows for direct correlation of the physical, electrochemical and mechanical properties to the atomic-scale microstructure.

In the first part of my talk, I will review our recent progress in using TEM-SPM platform to probe the electrical and mechanical properties of carbon nanotubes, nanowires and graphene. First, individual multiwall carbon nanotubes are peeled off layer-by-layer by electric breakdown inside the TEM. This provided new insights into the transport property of nanotubes. Second, plastic deformation, such as superplasticity, kink motion, dislocation climb, and vacancy migration, was discovered in nanotubes and graphene for the first time. Third, We induced sublimation of suspended few-layer graphene by in-situ Joule-heating inside a TEM. The graphene sublimation fronts consisted of mostly {1100} zigzag edges. Under appropriate conditions, a fractal-like "coastline" morphology was observed. In the second part of my talk, I'll review our recent progress in in-situ studies lithium ion batteries. We created the first nano-battery inside a transmission electron microscope, allowing for real time atomic scale observations of battery charging and discharging processes. Two types of nano battery cells, one ionic liquid based, and the other all solid based, were created. The former consists of a single nanowire anode, an ionic liquid (IL) electrolyte and a bulk $LiCoO_2$ cathode; the latter uses Li_2O as a solid electrolyte and metal Li as anode. Several case studies of nanobattery will be presented.

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