In situ Observation of Lithiation of Ge Nanowires using Electron Holography

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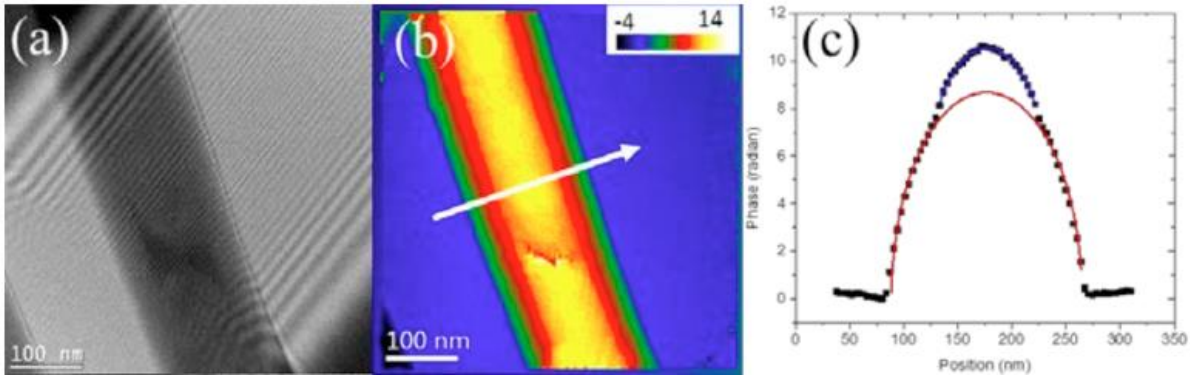
The successful operation of rechargeable batteries relies on reliable insertion/ extraction of ions into/from the electrodes. The battery performance and the response of the electrodes to such ion insertion and extraction are directly related to the spatial distribution of the charge and its dynamic evolution. However, it remains unclear how charge is distributed in the electrodes during normal battery operation. In this work, we have used off-axis electron holography to measure charge distribution during lithium ion insertion into a Ge nanowire (NW) under dynamic operating conditions.

Off-axis electron holography in the transmission electron microscope provides a unique and powerful approach to visualizing electric and magnetic fields within materials with resolutions approaching the nanometer scale. The ability to image phase shifts at medium resolution opens up a wide range of interesting and important materials problems. In this work, an important extension of our holography studies has involved observations of *in situ* lithiation of Ge nanowires.

For example, we measured charge distribution during lithium ion insertion into a Ge nanowire (NW) under dynamic operating conditions [1]. Figure 1(a) is a hologram recorded while lithiation was taking place, while Figure 1(b) show the corresponding phase image. Profile measurements, combined with simulations, enabled the Li component of the NW to be estimated and the amount of trapped charge to be quantified. We discovered that the surface region of the Ge core was negatively charged during the core-shell lithiation of the Ge NW, which was counterbalanced by positive charge on the inner surface of the lithiated Li_xGe shell. The remainder of the lithiated Li_xGe shell was free from net charge, consistent with its metallic characteristics. In the figure below, 1(a) shows a hologram of Ge/Li_xGe core/shell NW structure during litigation; (b) reconstructed phase image; (c) phase profile (dotted) and simulation (solid) along indicated arrow in (b). The present work provides a vivid picture of charge distribution and dynamic evolution during Ge NW lithiation and should form the basis for investigating the response of these and related materials under real electrochemical conditions.



References

[1] Z. Gan, *et al.*, Nano Lett., **16** (2016) 3748.

[2] M.M acknowledges support from DoE Grant DE-FG02-04ER46168 and the J.M. Cowley Center for High Resolution Electron Microscopy at ASU. The biasing experiments were performed at PNNL under the LDRDP program.