APP Brief

Correlating Li-Ion Cathode Conductivity with Battery Performance

Atomic Force Microscopy Accelerates Battery Research

Correlative property mapping using Bruker's Dimension® XR AFM accelerates research in anode, cathode, and separator performance under operando conditions. Uncover new insights in SEI formation, and the influence of nanoscale mechanical and electrical properties on capacity and failure.

AFM is a powerful tool for characterisation of battery systems that integrate materials with distinct mechanical properties, from soft (polymer additives) and loose (conductive additives) to hard (Li metal oxide) and porous (separator) surfaces.

Significant variation in nanoscale surface topography and electrical properties is common for battery electrodes. PeakForce Tapping® and its nanoelectrical variants, such as PeakForce TUNA™, play an important role in AFM-based battery research[1]. Topography, nanomechanical properties, and conductivity variations are tracked simultaneously, without sample damage. Now, new electrical data-cube (DCUBE) modes combine imaging, nanomechanics, and full electrical spectroscopy at every pixel, producing an integrated 3D data set. This big-data approach delivers higher dimensional data that can be sliced along any axis or plane.

Here, the advantages of the DCUBE-TUNA mode using a Dimension XR AFM are illustrated on a battery cathode consisting of Li metal oxide, polymer binder, and conductive carbon nanoparticles. Figure 1 shows 15×15 µm images extracted from a DCUBE-TUNA data set. A few large Li metal oxide grains are easily seen in topography and are marked as areas 1–3 in image 1a. The modulus image (1b) identifies the interstitial material as mostly soft polymer binder. Closer inspection of Figure 1b shows variation in the softer material correlating with the conductivity, map in Figure 1c.

Regions of high conductivity where carbon black particles are embedded in binder material are clearly differentiated. Interestingly, the conductivity image (1c) also shows that the grain marked as number 2 is "dead." It shows no measurable conductivity over the entire -3.5 V to +4 V bias range represented by the image slices extracted in Figure 1d.

This could arise from the carbon black additive distribution failing to provide a conductive channel (no evidence of carbon black is seen near this grain in the conductivity maps), or be due to the nature of this metal oxide grain itself. In a practical battery, "dead" grains

are to be avoided, as they lower available specific and volumetric energy density without a concomitant increase in lifetime or power density.

Thus, DCUBE-TUNA enables new insights into battery cathodes. The reproducible, multidimensional data set not only allows dissection of the spatial component distribution, it also can uncover the presence of "dead" metal oxide grains. Correlative AFM-based electrochemical methods (e.g., PeakForce SECM™) can additionally quantify anode and cathode processes under operando conditions, such as SEI formation.

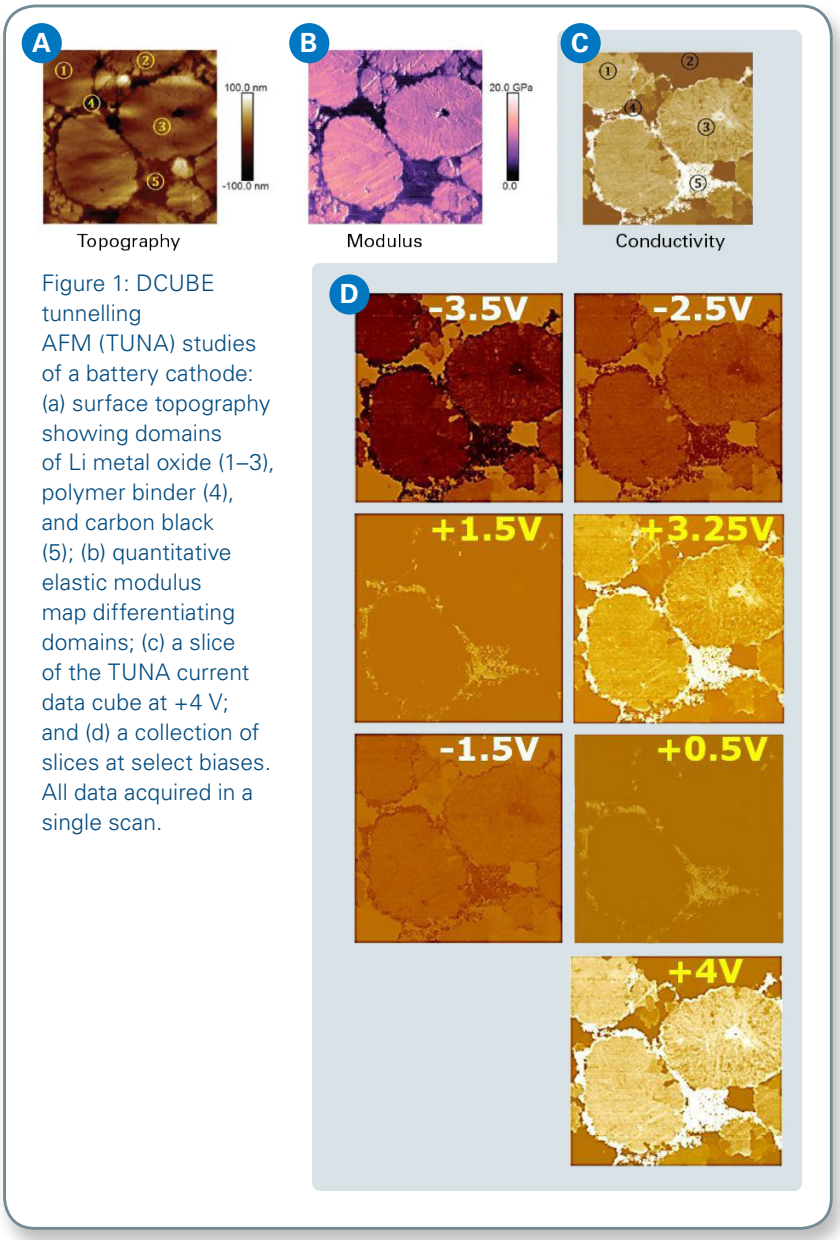

Figure 1: DCUBE tunnelling AFM (TUNA) studies of a battery cathode: (a) surface topography showing domains of Li metal oxide (1–3), polymer binder (4), and carbon black (5); (b) quantitative elastic modulus map differentiating domains; (c) a slice of the TUNA current data cube at +4 V; and (d) a collection of slices at select biases. All data acquired in a single scan.

References

1. B Liu et al., "Enhanced Cyclability of Lithium–Oxygen Batteries with Electrodes Protected by Surface Films Induced via In Situ Electrochemical Process," *Adv Energy Mater* 8 (2018).

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