New approaches for measuring electrostatic potentials and charge density distributions in working devices in the transmission electron microscope

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Abstract

The use of advanced specimen holders with multiple electrical contacts, in combination with off-axis electron holography, allows electrostatic potentials in nanoscale working devices to be measured quantitatively in the transmission electron microscope (TEM).

Figures 1 and 2 illustrate recent results obtained by applying off-axis electron holography to measure the electrostatic potential and electric field around an electrically-biased Fe atom probe tomography needle. The experiment involved applying a voltage between the needle and a counter-electrode that was placed at a distance of ~400 nm away from it. The phase shift recorded using electron holography was analyzed both by fitting the recorded phase distribution to a simulation based on two lines of opposite charge density and by using a model-independent approach involving contour integration of the phase gradient to determine the charge enclosed within the integration contour [1]. In the present study, both approaches required evaluation of the *difference* between phase images acquired for two applied voltages, in order to subtract the mean inner potential and magnetic contributions to the phase. On the assumption of cylindrical symmetry, the three-dimensional potential and field around the needle were determined from the results, as shown in Fig. 1. Charge density profiles along the needle measured using both approaches are shown in Fig. 2 and are consistent with each other.

The coherence of the transmission electron microscope that was used to record Figs. 1 and 2 also allowed other interesting electron-optical phenomena to be observed. When two metallic tips similar to that shown in Fig. 1 were placed at a separation of ~1 μm and a potential difference was applied between them, the combined effect of the fields from the needles resulted in the formation of highly complex interference patterns in bright-field TEM images acquired out-of-focus, as shown in Fig. 3 for a nominal defocus of 9.5 mm and a potential difference between the needles of 130 V. We are presently developing new techniques to allow off-axis electron holography to be used to obtain results similar to those shown in Figs. 1-3 during ultrafast switching processes in the electron microscope [2].

References

[1] M. Beleggia, T. Kasama and R. E. Dunin-Borkowski, *Ultramicroscopy,* **100** (2010), 425.
[2] We are grateful to M. Beleggia, T. F. Kelly and D. J. Larson for valuable discussions.

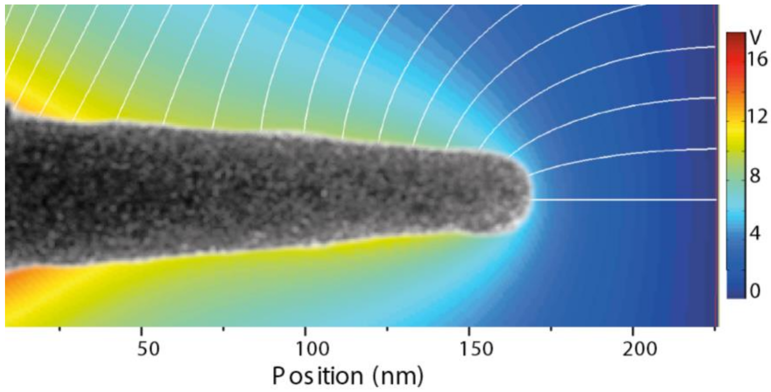

Figure 1 – Central slice of the 3D electrical potential (colors) and electric field (white lines) between an Fe atom probe tomography needle and a Au counter-electrode, determined from the charge density distribution in the needle measured from the *difference* between phase images recorded using off-axis electron holography at applied bias voltages between the needle and the counter-electrode of 0 and 5 V.

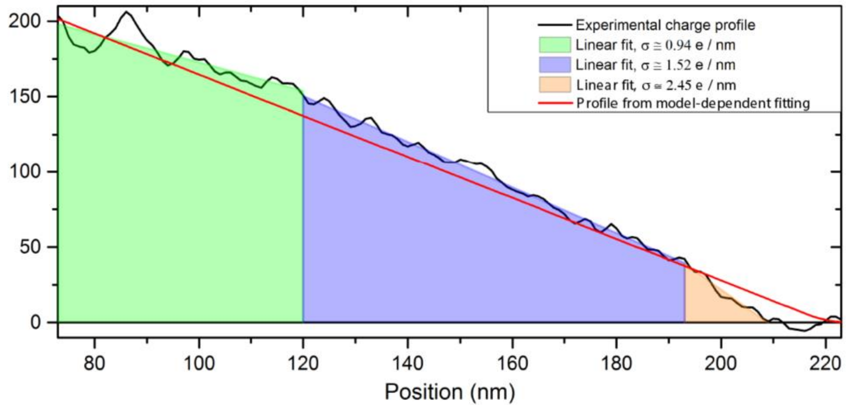

Figure 2 – Cumulative charge profiles along the needle shown in Fig. 1, measured by off-axis electron holography in units of electrons using model-independent (black) and model-dependent (red) methods.

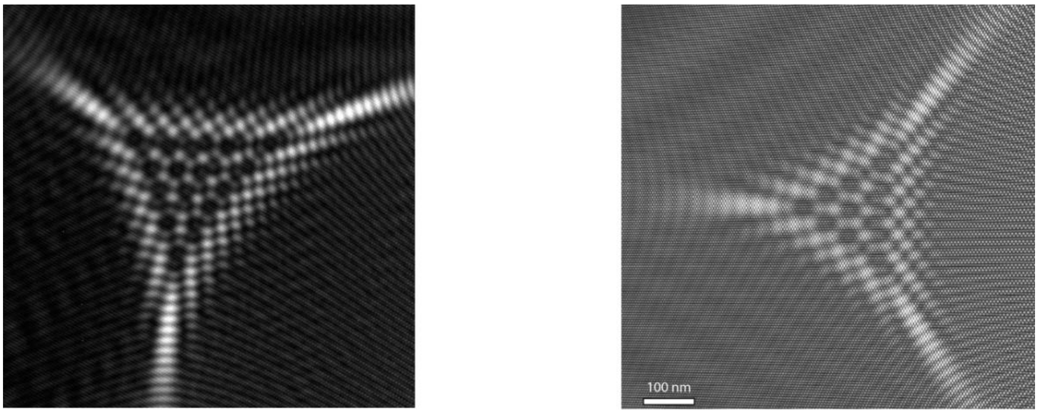

Figure 3 – Left: Bright-field TEM image recorded at a defocus of 9.5 mm from two metallic needles similar to that shown in Fig. 1, with a potential difference of 130 V between them, showing hexagonal-like spots in a caustic. Right: Simulation performed for the experimental conditions used to acquire the experimental image on the left.