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Nanoscale Three-Dimensional Charge Density and Electric Field Mapping by Electron Holographic Tomography

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We have combined off-axis electron holography in the transmission electron microscope (TEM) with electron tomography and model-based iterative reconstruction (MBIR) to determine the 3D charge density in an electrically-biased C fibre needle with a spatial resolution of ∼5 nm. The reconstructed 3D charge distribution was then used to infer the 3D electrostatic potential and electric field.

Figure 1a shows a low magnification bright-field TEM image of the setup. The distance between the needle and a Au counter-electrode is ∼4.5 µm. A higher magnification bright-field TEM image is shown in Fig. 1b. Two tilt series of electron holographic phase images were recorded over a tilt range of −52° to +48° with a tilt increment of 4°. The first tilt series was recorded without an electrical bias applied to the needle. The second tilt series was recorded with +40 V applied between the needle and the counter-electrode. The mean inner potential contribution to the phase was removed by aligning and subtracting corresponding phase images at each tilt angle with and without the electrical bias applied to the needle. Figure 1c shows a resulting phase difference image with equiphase contour lines superimposed. 3D reconstruction of the charge density in the needle was carried out by applying the MBIR approach to the tomographic dataset of phase difference images. By varying the positions and magnitudes of charges in the reconstruction volume and using them to obtain predicted phase images, the algorithm attempts to minimise the residual with the experimental phase difference images at each sample tilt angle.

Figure 2a shows a visualisation of the resulting reconstructed 3D charge density, which is greatest at the apex of the needle. The maximum charge density is 2.94×10^{18} cm^{-3}. Slices extracted from the reconstructed 3D charge density are shown in Figs 2b, c. It is surprising that the charge penetrates several tens of nm into the surface, perhaps because the needle has a disordered or poorly conducting surface layer. Figure 3 shows a combination of a streamline plot of the electric field and the electrostatic potential in the central xy plane calculated from the 3D reconstructed charge density [1].

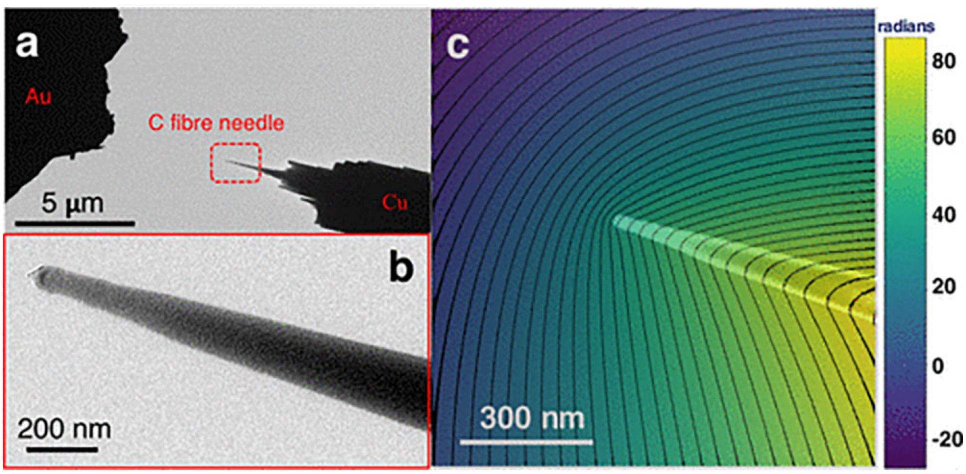

Fig. 1. (a) Bright-field TEM image showing the setup for electrical biasing of a C fibre needle in the TEM. (b) Higher magnification image of the end of the needle. (c) Electron holographic phase difference image with +40 V applied between the needle and the counter-electrode. The mean inner potential contribution to the phase has been removed by subtracting a phase image recorded without a bias applied to the needle. Equiphase contour lines are superimposed. The phase contour spacing is 2π radians. A TEM image of the C fibre needle is overlayed to guide the eye.

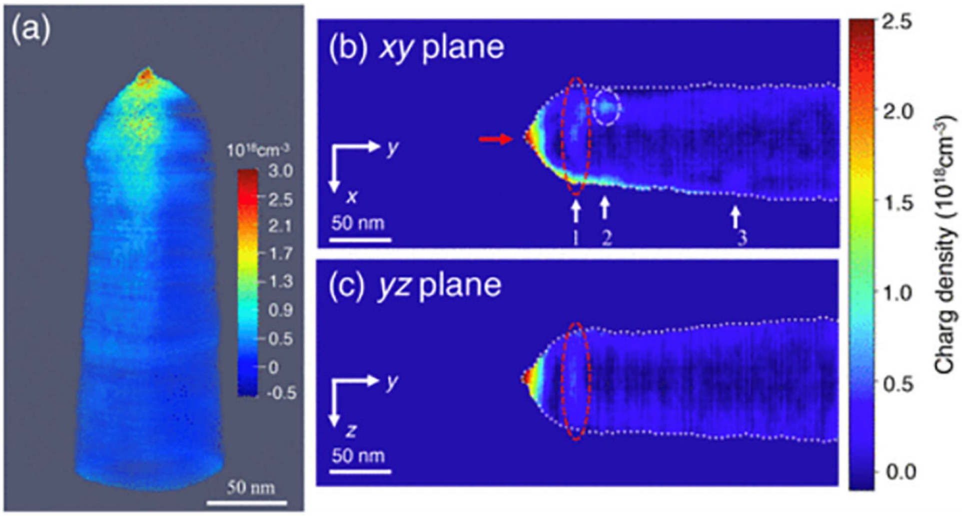

Fig. 2. 3D charge density in the C fibre needle reconstructed using electron holographic tomography and the MBIR approach. (a) Side view. (b, c) xy and yz slices extracted from the 3D charge density.

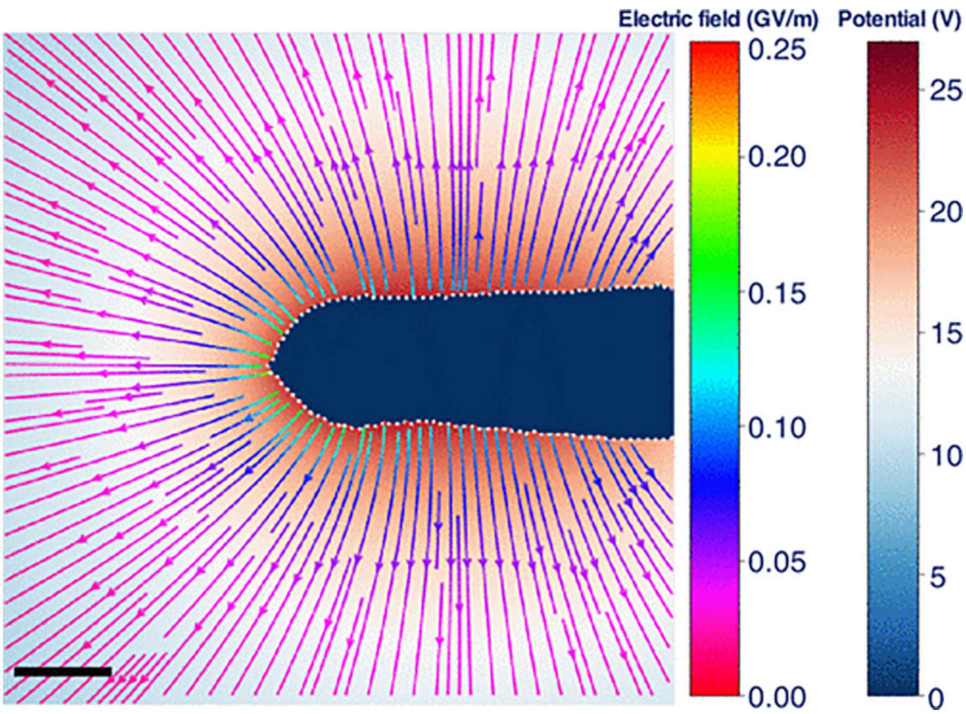

Fig. 3. Combination of a streamline plot of electric field and electrostatic potential in the central xy plane determined from the reconstructed 3D charge density of the C fibre needle. The scale bar is 50 nm.

Reference

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