Static and Dynamic Electric and Magnetic Imaging

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Electrostatic properties of insulators in three-dimensions using transmission electron holography tomography.

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Electron holography tomography (EHT) [1,2] is applied here to measure quantitatively in three-dimensions inside and outside one sample of sapphire (Al_2O_3) the electrostatic potential, the electric field, the charge density and the accumulated charge. Sapphire is an insulator and when electron bombarded during transmission electron microscopy observation the sample will emit secondary electrons; if there is not external supply of electrons through a conductive path the sample accumulates an electric charge and an electric potential and electric field can be measured inside and outside the sample [3].

The electrostatic potential for insulating specimens has in first approximation two terms $V(x,y,z) = V_o(x,y,z) + V_c(x,y,z)$ where $V_o(x,y,z)$ in the so-called mean inner potential [4] and $V_c(x,y,z)$ is the potential that accounts for the contribution of the accumulated net charge (both free and bound charge). In our experiments we have made the assumption that the potential is time-independent, i.e., that the sample accumulates a constant charge, supported by the fact that the reconstructed data obtained are coherent with the physical properties expected.

EHT can be used to recover the modulation of the phase of the electron wave of a sample in three-dimensions, $\Delta\phi(x,y,z)$. Furthermore, the potential can be calculated like $|V(x,y,z)| = \Delta\phi\,(x,y,z)/C_E$, where C_E called the interaction constant is a specimen-independent value.

From the electrostatic potential, other electrostatic properties can be easily calculated using Maxwell equations.

The electric field can be computed with the equation

$$\vec{E}(x,y,z) = -\vec{\nabla}V(x,y,z)$$

Neglecting polarization effects the associated volume charge distribution obeys Poisson's equation

$$\nabla\cdot\vec{\nabla}V(x,y,z) = \nabla^2V(x,y,z) = -\frac{\rho(x,y,z)}{\varepsilon}$$

where $\rho(x,y,z)$ is the charge density, ε is the permitivitty of the material (approximately $8.85\cdot10^{-11}$ [F/m] for alumina), $\nabla\cdot$ is the divergence operator and ∇^2 the Laplacian operator. In vacuum there is not charge, $\rho_{vacuum}(x,y,z) = 0$ and Laplace's equation

$$\nabla^2V(x,y,z)_{vacuum} = 0$$

Finally, the total charge Q_R accumulated in the samples is computed as the volume integral over the region *R* of observation.

$$Q_R = \iiint_R \rho(x,y,z)\,dxdydz = -\varepsilon_o \iiint_R \nabla^2V(x,y,z)\,dxdydz$$

Figure 1 shows the experimental results obtained applying EHT to a tip of sapphire. Using the binding approximation as described in [4] the mean inner potential of neutral sapphire V_o is estimated to be 14 Volts.

The total potential $(V = V_o + V_c)$ reaches a maximum value of 12.5 Volts inside the tip and decreases towards the surface to a minimum value of 8 Volts. V_o of an homogeneous sample must be spatially invariant but the experiment here shows that the potential is not constant. $V(x,y,z)$ is lower at every point than the calculated V_o for neutral sapphire and decreases at the surface of the sample. The accumulation of a positive electric charge induced by the electron beam adding a potential $V_c(x,y,z)$ that decreases V_o [5]. The electric charge dsitribution is not homogeneous and accumulates closer to the surfaces of the sample (see Figure 1C).

The total charge is of 0.098 fC (equivalently to removing 614 electrons from the sample) confirmed by the presence of an electric field surrounding the sample. This electric field is always perpendicular to the surface and reaches a maximum value of 0.7 V/nm or 7MV/cm at the end of the tip which is lower than the breakdown voltage of sapphire.

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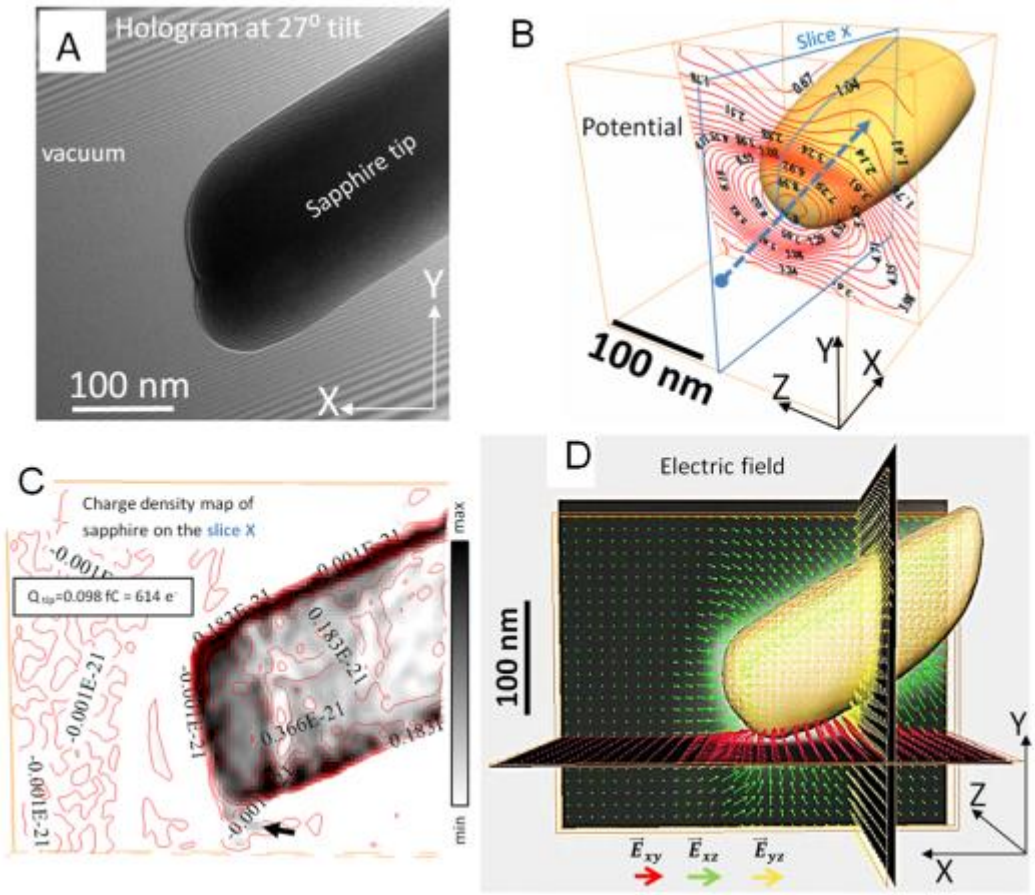

Figure 1. (A) Hologram of a tip of sapphire tip acquired in a microscope FEGTEM Titan and using a biprism. (B). Orthoslice of the three-dimensional distribution of electrostatic potential (in Volts) inside and outside the tip shown in (A). (C) Charge density distribution (C/nm^2) corresponding to the otrhoslice *Slice x* shown in (B). (D) Vectorial representation of the three-dimensional electrostatic field outside the tip.