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ELECTRON-BEAM-INDUCED DYNAMIC CHARGING OF THIN FILMS

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Abstract

Primary electrons that are inelastically scattered generate electron-hole pairs in the illuminated area of a thin film, thereby enhancing its charge-carrier density and conductivity. The charge density gradient near the rim of the illumination patch triggers a drift-diffusion process that leads to a steady-state equilibrium with a local bias within a circular region that is larger than the beam diameter. The sign of the potential is dictated by the difference in mobility between electrons and holes and is generally positive. The magnitude of the local bias, which is also dependent on the mobilities, is determined primarily by the ratio between intrinsic and extrinsic carrier densities.

A proportion of the generated electrons that have sufficient energy may escape into vacuum, leaving holes behind and triggering larger-scale drift processes involving neutralizing currents that originate from electrical contacts to ground. This process also affects the steady-state equilibrium, both in the magnitude and in the extent of the local bias. The two effects cannot easily be kept separated.

In order to measure electron-beam-induced dynamical charging, we create a circular patch of illumination on a pristine region of a thin film by using the condenser system of the electron microscope. We then use the imaging lenses to record a time series of Fresnel defocus images of the illuminated area. As the currents start to flow and balance each other out, the out-of-focus appearance of the spot changes, reflecting the evolution of the local bias. We vary experimental parameters such as film composition, temperature, beam energy, beam current and beam current density and compile a comprehensive dataset that can be interpreted on the basis of the drift-diffusion equation. We are interested in characterizing the steady state and the previously observed asymmetry between charging and discharging characteristic times that goes by the name of the "Berriman effect", i.e. the charge footprint of the beam that appears to remain stable once the illumination is turned off.

Our study is relevant for understanding the operating principles of charge-based phase plates for electrons, such as the "hole-free" and "Volta" devices. More generally, the development of an understanding of electron-beam-induced charging processes and resulting local electric fields promises to be beneficial for a wide variety of *in situ* electron microscopy experiments involving gases, liquids, electrochemical processes (beam-assisted electrocatalysis), junctions, etc.