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Considerations for Secondary Electron Imaging of Dielectric Materials in Low-Vacuum and Environmental SEM

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Many secondary electron (SE) contrast effects observed during the imaging of dielectric substances in low vacuum scanning electron microscopes can be attributed to the electric fields that exist above and below the specimen surface. This paper will review the origins of these fields and examine their consequences for imaging and microanalysis.

If we consider a sample oriented such that the *z* direction is normal to the surface (*i.e.*, the *x,y* plane at z=0), the net field $\vec{E}_{net}(x,y,z)$ at any given point is the sum of three contributions:

$$\vec{E}_{net}(x,y,z) = \vec{E}_{bias}(x,y,z) + \vec{E}_q(x,y,z) + \vec{E}_{ion}(x,y,z). \qquad (1)$$

where E_{bias} is the contribution due to the detector bias V_0, E_q arises from trapped charge in the specimen, and E_{ion} is due to the presence of gaseous ions above the specimen surface. The significance of each contribution will be discussed.

Many of the SE detectors developed for poor vacuum environments use a positively biased detector located either above or near the specimen. The specimen is usually situated on a grounded support, thus creating an electric field from the detector, through the dielectric specimen, and terminating at the support. (Alternatively, the support may have a negative bias, establishing a field of the same sign, but terminating on the grounded pole-piece.) The intensity of the field above and below the specimen surface will be determined by the capacitance of the specimen, which in turn is a function of the specimen geometry and dielectric constant. It can be shown that the fields above and below the specimen surface are given respectively by

$$\vec{E}_{bias}(x,y,z>0) = V_0 \frac{\varepsilon_s}{d_g \varepsilon_s + d_s \varepsilon_g}; \vec{E}_{bias}(x,y,z<0) = V_0 \frac{\varepsilon_g}{d_g \varepsilon_s + d_s \varepsilon_g}. \qquad (2a,b)$$

The dielectric constants of the gas and specimen are given by ε_g and ε_s respectively, while the thicknesses of the gas region and specimen are given by d_g and d_s. The surface potential V_s of the specimen can be found similarly:

$$V_s = V_0 \frac{\varepsilon_g d_s}{\varepsilon_g d_s + \varepsilon_s d_g}. \qquad (3)$$

Thus, as experience supports, the change in surface potential due to the detector bias is negligible for most specimens, but could become an issue if bulk dielectrics are examined (*i.e.*, when $d_s > d_g$). In most cases, the detector field induced in the specimen is too weak to affect SE emission. Significantly, the field strength between the surface and detector determines the amplification efficiency of the gas cascade, and thus the SE signal intensity.

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The field effects on SE emission due to implanted charge in the specimen have been treated rigorously by Cazaux.[1] In this case, the field in the region between the centre of mass of the implanted charge and the specimen surface [$\vec{E}_{q}(z<0)$] is of interest, as is the field that extends into the region above the surface[$\vec{E}_{q}(z>0)$]. In high vacuum, the (negative) surface potential can easily reach thousands of volts, resulting in deflection of the primary beam and other classic charging effects. Similarly, the associated internal fields are strong enough to result in enhancedSE emission. The associated field strength will depend on the amount of trapped charge, which in turn depends on the nature and density of available charge traps.

With the addition of a low pressure of gas and an ionization cascade to amplify SE signals, positive ions become an important factor. Ions created in the cascade accumulate above the surface of insulators. The field $\vec{E}_{ion}$ radiates outward from the centre of mass of the ion cloud and terminates on the detector and the grounded specimen support. The field intensity in the gas and specimen regions and the surface potential are determined by similar considerations that went into driving equations (2) and (3). The ions give rise to several effects[3,4]: The surface potential of the specimen can actually be shifted positive by a few hundred volts, which reduces the primary electron landing energy and reduces the cascade amplification field. Also, ions that accumulate at the surface can capture secondary electrons and diminish the SE signal. Conversely, a strong dipole field is set up between the positive ions at the surface and the implanted negative charge. Because the charge density can be fairly high and the charge separation (*i.e.*, the penetration depth of the deposited primary electrons) is small, the local field can be very great. This reduces the SE escape barrier at the surface, resulting in enhanced emission.

Inhomogeneities in trap/defect distribution, and therefore stored charge and resulting field $\vec{E}_{q}(x,y,z<0)$, can give rise to contrast via this mechanism. It should also be noted that not all defects behave in the same way. Depending on trap depth and density, some regions may be able to store more charge than the bulk material while others may in fact be more conductive, therefore storing less charge. Similarly, anything that perturbs the net electric field at the surface $\vec{E}_{net}(x,y,z>0)$ results in inhomogeneous ion flux, also allowing the possibility of differential contrast.[5]

In the final analysis, any intrinsic differences in SE emission from the specimen will be modulated by all of these effects. Image contrast will then be a net result of all the contributing factors. Different widows in the operating parameter space where each effect dominates make it possible to diagnose the probable origin of a particular contrast feature.

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