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LETTER TO THE EDITOR

Potential screening effects from support films in electron microscopy

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Abstract. Preliminary calculations indicate that it may be possible to utilise the screening action of suitably chosen dielectric support films in electron microscopy to reduce the primary ionisation damage, particularly to organic molecules, and thus perhaps to obtain satisfactory images at rather higher resolution than would be obtainable otherwise.

Ionisation damage is the dominant factor in limiting the resolution which can be obtained in transmission electron microscopy, particularly of organic specimens (e.g. Stenn and Bahr 1970, Glaeser 1975). Frequently these specimens are placed on some kind of thin film support which is usually chosen with reference to its elastic scattering properties or convenience in fabrication. Here we draw attention to the possible significance of the dielectric screening properties of the support material in modifying the initial damage event, particularly in the case when the objects of interest are organic molecules of some kind lying on the surface of the support film or possibly embedded in it. Direct experimental evidence of these screening effects is not currently available for the damage problem, but their influence on the inverse problem of radiative de-excitation of molecules on conducting supports has been observed (Chance *et al* 1978).

The ionisation damage process in electron microscopy arises from the electronic excitations generated (both directly in the molecule concerned and indirectly in the surrounding specimen regions) by the action of the impulsive electric field created as the fast electron passes. For an electron with velocity v and impact parameter ρ, the classical expressions (Jackson 1975) for the time dependence of the field components parallel and perpendicular to the trajectory are $E_\parallel = -evt(\rho^2+\gamma^2v^2t^2)^{-3/2}$, $E_\perp = e\gamma\rho(\rho^2+\gamma^2v^2t^2)^{-3/2}$, where $\gamma=(1-v^2/c^2)^{-1/2}$. In the case of the incident electron energies of 100 keV typically used in electron microscopy, and molecular excitations of between 5 eV and 20 eV, the range of significant impact parameters can extend up to 10 nm. $E_\perp$ is appreciably larger than $E_\parallel$ over most of this range.

We now consider the case where the fast electron passes normally through a thin slab of dielectric constant ϵ as shown in figure 1. A standard static calculation (Jackson 1975) for the case of a point charge and a semi-infinite slab shows that when $E_\perp$, the field component perpendicular to the trajectory and parallel to the surface, is measured at a point either just outside or just inside the surface it will be found to be reduced (for all positions of the point charge) by a multiplicative factor $f=2/(\epsilon+1)$ relative to the corresponding value *in vacuo*. The same reduction factor applies to $E_{\parallel}$, the field component normal to the slab, when this is measured at points lying just on the opposite side of the interface to the point charge. For surface points lying just on the same side of the interface as the point charge, the corresponding factors are $f=2\epsilon/(\epsilon+1)$ and $f=1/\epsilon(\epsilon+1)$ according to whether the point charge is outside or inside the slab. For molecules lying on, or better just inside, the surface of the dielectric slab with a reasonably large value of ϵ, these results therefore suggest that useful screening effects might occur, particularly in the major field component $E_{\perp}$. We could expect that the excitation probability of the molecule would to a first approximation be changed by a factor of f^2 as a result of screening.

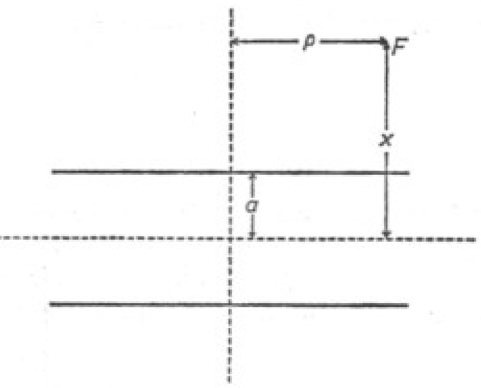

Figure 1. Coordinates of the field point F relative to the trajectory of the electron passing through a slab of thickness $2a$. ρ is the impact parameter.

A somewhat more realistic calculation of the screening effects, taking account of the finite thickness of the support, the electron velocity and retardation effects can be carried out using the results of Kröger (1968), who gives explicit expressions for the Fourier components of the fields. The model used automatically includes both bulk and surface dielectric properties. Kröger's expressions are functions of the arguments $(x, k_{\perp}, \omega)$ where $k_{\perp}$ is the vector component normal to the electron beam direction. Doing the Fourier transform on $k_{\perp}$ we have converted these expressions for the field components to functions of (x, ρ, ω). Values of the ratios of the field components $E_{\parallel}$ and $E_{\perp}$ have been computed as functions of ρ for a point x on the surface and just outside a slab of thickness $t=10$ nm. Two different frequencies have been employed corresponding to $\hbar\omega_1=\Delta E_1=5{\cdot}4$ eV and $\hbar\omega_2=\Delta E_2=30{\cdot}6$ eV. Values of $\epsilon=1$, 2, 5 and 10 have been used in each case and assuming Im $\{\epsilon\}=0$ the computations confirm several predictions of the simple static calculation. The real and imaginary parts of $E_{\perp}$ are reduced by factors similar to $2/(\epsilon+1)$ at large values of ρ but the factor increases towards 1 for small impact parameters. For the components of $E_{\parallel}$, which behave in a more complicated way, the screening factor can be considerably larger than unity for points outside the slab and at small impact parameters, but is less than 1 for points inside the slab.

These complexities can be avoided by examining the behaviour of the quantity $P(\rho, \omega, \epsilon)=|E_{\perp}(\rho, \omega, \epsilon)|^2+|E_{\parallel}(\rho, \omega, \epsilon)|^2$ which is proportional to the probability of direct excitation or ionisation at frequency ω of an isotropic molecule at impact parameter ρ. The related screening parameter $\overline{f^2}=P(\rho, \omega, \epsilon)/P(\rho, \omega, 1)$ thus measures the reduction in damage and is plotted as a function of impact parameter in figures 2 and 3 for points lying just outside and just inside the surface of the slab, respectively.

It can be seen that for $\epsilon > 1$, $\overline{f^2}$ is always < 1 and is reasonably close to the value $[2/(\epsilon+1)]^2$ for points inside the slab. The results indicate that $\overline{f^2}$ really depends on $\epsilon(\omega)$ and not on the value of ω itself. It was also found that relativistic effects made practically no difference to $\overline{f^2}$ in the range of parameters investigated here.

Thus, although it appears that useful screening factors can be obtained for molecules on the surface of a suitable support, the whole effect is appreciably better for molecules actually embedded in the support. It would be of interest to investigate the dependence

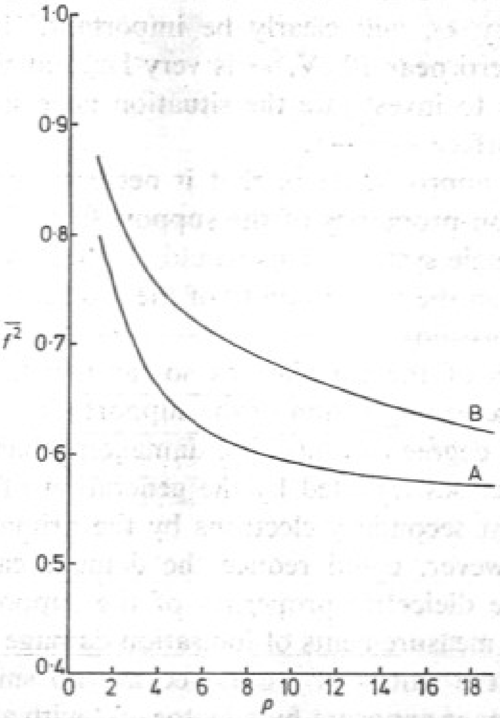

Figure 2. Dependence of the screening factor $\overline{f^2}$ on impact parameter for field point positions just outside the slab surface. A, $\epsilon=2$; B, $\epsilon=10$. In atomic units $a=100$, $x=101$, $\omega=0{\cdot}2$, $v=75$.

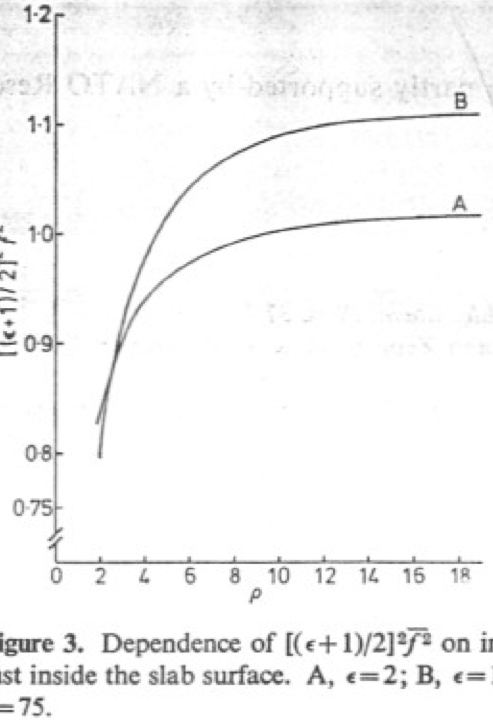

Figure 3. Dependence of $[(\epsilon+1)/2]^2\overline{f^2}$ on impact parameter ρ for field point positions just inside the slab surface. A, $\epsilon=2$; B, $\epsilon=10$. In atomic units $a=100$, $x=99$, $\omega=0{\cdot}2$, $v=75$.

of these results on the thickness of the support. Preliminary calculations indicate that similar screening effects still occur for thicknesses of only 2 nm.

The real and imaginary parts of the dielectric constant $\epsilon_1(\omega)$ and $\epsilon_2(\omega)$ are generally quite complicated functions of frequency. Some possible low Z support materials such as diamond have values of $|\epsilon_1|>2$ for values of $\hbar\omega$ in the range between 12 eV and 20 eV (Daniels *et al* 1970) where many molecular excitations might occur. $|\epsilon_1|$ can however be smaller than 1 or even zero at other frequencies so that an enhancement of the fields at these frequencies could be expected. In these situations the damping of the excitation mode, described by ϵ_2, will clearly be important. In the case of diamond, for instance, where ϵ_1 is zero near 10 eV, ϵ_2 is very large at that frequency. Detailed calculations are in progress to investigate the situation near such resonances either of the bulk $\epsilon_1=0$ or of the surface $\epsilon_1=-1$.

The calculation just described is approximate in that it neglects any perturbation of the molecule itself on the excitation properties of the support film. In actuality the two entities should be treated as a single system. This would be equivalent to allowing for local field corrections depending on the polarisability of the molecule and the shape of the cavity it occupies in the support film.

Despite the evident shortcomings of the calculations so far made, it seems clear that some kind of potentially useful screening action of the support film exists for direct ionisation processes. A considerable degree of ionisation damage probably also occurs indirectly as a result of cascade processes initiated by the generation of higher energy excitations such as plasmons and fast secondary electrons by the primary beam. The screening effect just considered, however, could reduce the damage caused by these excitations also. It is clear that the dielectric properties of the support film should be taken into account when different measurements of ionisation damage in the electron microscope are compared. Even if the values of f obtained are no smaller than 0·5, this would allow an increase in the image exposure by a factor of 4 with a corresponding improvement in the theoretically achievable resolution of structure by a factor of 2 (Glaeser 1975). It should be recalled that it is commonly regarded as worthwhile to expend considerable effort in improving the basic instrumental resolution by factors of this magnitude.

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