Electron Interferometry and EELS

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This theoretical work shows how models of decoherence in electron interferometry can be linked to models of electron energy-loss spectroscopy (EELS). It is motivated by biprism interferometry experiments in which decoherence arises from Coulomb coupling between an electron and a nearby dielectric surface. Sonnentag and Hasselbach demonstrated that the electron fringe visibility from recombined wave packets decreases for trajectories that pass closer to dielectric surfaces [1]; Kerker *et al.* showed that visibility also decreases for packets that are more widely separated [2].

Here, we clarify the physical logic of these experiments to connect them to well-established models in EELS. Howie [3] already suggested how such experiments might be linked to expressions for surface losses in EELS, but Kerker *et al.* found experimental disagreement with Howie's model, favoring instead the approach of Scheel and Buhmann [4], which was derived using macroscopic quantum electrodynamics (QED). In this work, we show how Howie's EELS-based approach can be modified to capture the same physical content as Scheel and Buhmann's QED-based approach. The essential modification involves multiplying the total loss probability in the integrand by $[1-\cos(k_x d)]$. While the standard EELS probability describes the interaction of a single packet, this geometric cross-term accounts for the phase correlation between the two paths.

Mode-specific EELS expressions for an aloof electron passing over a dielectric half-space have been expressed as a loss probability per unit length z, per frequency ω, per transverse wavevector k_x—that is, as $d^3P/(dz\, d\omega\, dk_x)$. (See Fig. 1.) The fringe visibility $0 \le V \le 1$ for wave packets that, during the interaction length L, pass the dielectric surface at a distance of b while separated by a transverse distance of d can be expressed as $V = \exp[-\gamma(b, d)\, L]$, with $\gamma(b, d)$ as the integral of $d^3P/dz\, d\omega\, dk_x$ over ω and k_x, with the integrand multiplied by the factor $[1 - \cos(k_x d)]$. This quantifies how separated wave packets will interact differently with the dielectric substrate, leading to decoherence.

This approach allows us to isolate how various physical assumptions change our predictions for fringe visibility. EELS models for $d^3P/(dz\, d\omega\, dk_x)$ can, variously, be carried out without [5] or with [6] signal retardation, and can also incorporate thermal effects [7,8]. The EELS-based model for fringe visibility that includes both signal retardation and thermal effects reproduces the prediction of Scheel and Buhmann that was found to be empirically successful by Kerker *et al.* While signal retardation and thermal statistics are standard to the EELS framework, the $[1 - \cos(k_x d)]$ spatial correlation term is what formally reconciles the EELS and QED results.

This reframing allows decoherence experiments to be interpreted directly in terms of measurable EELS surface-loss spectra, which provides a route for using standard EELS modeling tools to predict interferometric decoherence.

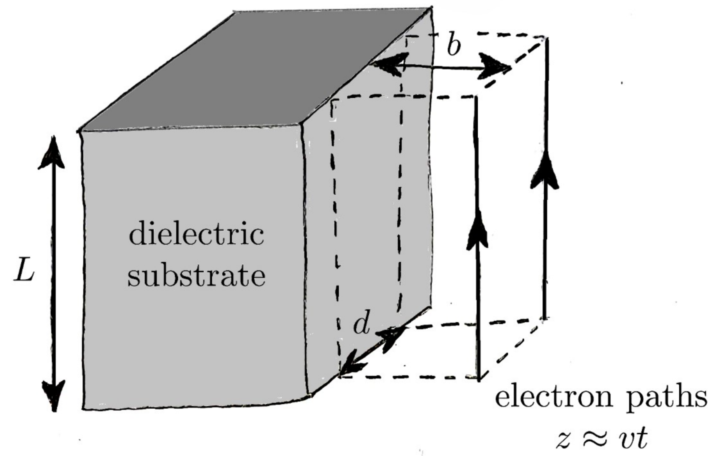

Fig. 1. Schematic of the interaction geometry. Two electron paths are separated by a distance *d*, propagate at a height *b* above the substrate with velocity *v*, and interact over a length *L*.

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