EXCITATIONS OF SURFACE GUIDED MODES BY ELECTRONS

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In 1966, Kliewer and Fuchs[1] showed that in a thin foil of material with the long-wavelength dielectric function $\varepsilon(\omega)$ larger than unity there exist a number of polariton modes with frequencies satisfying the dispersion relation

$$\varepsilon(\omega) = \pm \frac{\beta}{\alpha_o} (\mathrm{tg}\ \beta a)^{\pm 1} . \quad (1)$$

Here 2a is the thickness of the foil, $\beta=(\varepsilon(\omega)-\frac{\omega^2}{c^2})^{1/2}$, $\alpha_o=(k^2-\frac{\omega^2}{c^2})^{1/2}$ and $\vec{k}$ is the wave vector of the modes, parallel to the foil surfaces. These modes, sometimes called trapped modes, are associated with electric fields which damp exponentially outside the foil and exhibit oscillatory behaviour inside, differing, therefore, strongly from the behaviour of the field of surface polariton modes. Experimentally, surface guided modes have been observed very recently in electron-transmission experiments performed with very high angular resolution on Al_2O_3 [2] and Si[3]. In this communication we report the quantum-mechanical result for the electron energy loss due to the emission of surface guided modes. This result is needed for the interpretation of experimental results. We quantized the surface-guided mode field following exactly the method of quantization of the surface polariton field in thin foils[4]. For the electron energy loss function, i.e., the probability that electrons lose the energy $\hbar\omega$, exciting surface guided modes, which should be directly proportional to the observed electron spectra, we obtained the following result in the Born approximation and for the normal (to the foil surface) electron incidence:

$$P(\omega) = \sum_{m=1,3,...} P_{m+}(\omega) + \sum_{m=2,4,6} P_{m-}(\omega)$$

$$P_{\pm}(\omega) = 4 \frac{e^2}{\hbar v^2} \frac{k}{\alpha_o} \left|\frac{dk}{d\omega}\right| \omega \frac{(\varepsilon-1)^2}{\varepsilon} \frac{k^2}{\phi_o^4 \phi^4} \times \tag{2}$$

$$\times \frac{\left| \xi^2 \begin{Bmatrix} \sin \frac{\omega a}{v} \\ \cos \frac{\omega a}{v} \end{Bmatrix} + \alpha_o \varepsilon \frac{\omega}{v} \left(\frac{v}{c}\right)^2 \begin{Bmatrix} -\cos \frac{\omega a}{v} \\ \sin \frac{\omega a}{v} \end{Bmatrix} \right|^2}{\left[\varepsilon + \frac{\omega}{2} \frac{d\varepsilon}{d\omega}\right] \left[\frac{1}{\alpha_o^2} \left(\frac{\omega}{c}\right)^2 \alpha_o a \begin{Bmatrix} \cos^{-2} & \beta a \\ \sin^{-2} & \beta a \end{Bmatrix} + \frac{k^2}{\beta^2} - 1\right] + \varepsilon\left(1 + \frac{k^2}{\alpha_o^2}\right)} .$$

Here $\phi_o^2=\alpha_o^2+(\frac{\omega}{v})^2$, $\phi^2=\beta^2-(\frac{\omega}{v})^2$, $\xi^2=k^2+(\frac{\omega}{v})^2$ $(\frac{\omega}{c})^2(\varepsilon+1)$ and v is the electron velocity. The index m counts the modes, i.e., solutions of equations (1), in the sense that modes with higher frequencies have larger m. Quantities such as k,α and α_o are functions of ω through equation (1) and their definitions. Inspection shows that the shape of the spectrum given by (2) is mostly determined by the factor ϕ^{-4}, which is largest whenever the Cherenkov condition $\frac{c^2}{v^2} < \varepsilon(\omega)$ is fulfilled. A detailed comparison of the theoretical electron energy loss spectrum (2) with the observed spectra will be given elsewhere.

References

1) K.L. Kliewer and R. Fuchs, Phys. Rev. 144, 495 (1966).
2) C.H. Chen and I. Silcox, Solid State Commun. 17, 273 (1975).
3) C.H. Chen, I. Silox and R. Vincent, Phys. Rev. B12 64 (1975).
4) M.S. Tomaš, M. Šunjić and Z. Lenac, to be published.