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Exact surface plasmon dispersion incorporating nonlinear effects due to ponderomotive potential in metal/dielectric structure

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Abstract

The dispersion relation of surface plasmon (SP), i.e. surface wave propagating along a metal/dielectric interface, incorporating nonlinear effects due to the ponderomotive force in metal is studied *exactly*. The decaying electric field of the surface wave away from the interface leads to a large gradient of the field intensity, which in turn drives electrons in the metal away from the high field region due to the ponderomotive force. The net effect is a field-dependent electron number density and thus a spatially varying plasma frequency in the metal as a function of the distance from the interface [1]. Considering the effect of the ponderomotive potential on the electron number density within the Drude model gives the dielectric constant ε_m of the metal as

$$\varepsilon_m = 1 - \frac{e^2}{3\pi^2 \varepsilon_0 m\omega^2}\left(\frac{2m}{\hbar^2}\right)^{3/2}\left(E_f - \frac{e^2E^2}{2m\omega^2}\right)^{3/2}, \qquad (1)$$

where the second term in the parentheses is the ponderomotive potential, E is the spatially dependent magnitude of electric field, and E_f is the Fermi energy. Ginzburg *et al*. [1] pointed out the importance of the effect and studied the SP dispersion relation by expanding Eq.(1) into

$$\varepsilon_m = 1 - \left(\frac{\omega_p}{\omega}\right)^2 + \frac{3}{2}\left(\frac{\omega_p}{3\pi^2\varepsilon_0\hbar m e}\right)^{2/3}\frac{e^2}{\hbar^2\omega^4}E^2, \qquad (2)$$

where ω_p is the plasma frequency without the ponderomotive effect. In this approximated form, the nonlinear term in Eq.(2) is of the Kerr form χE^2 and the SP dispersion can be studied by the first integral method [2-4]. In this paper, we show that the *complete form* of ε_m in Eq.(1) can be treated *exactly* and derive the SP dispersion relation. Under a strong electric field, the SP dispersion shows a cutoff frequency below which SP cannot be supported. The physics behind the key features in the SP dispersion relation will be discussed. Significant differences are found between results obtained by the exact form of Eq.(1) and the approximated form of Eq.(2). The ponderomotive effect in metals thus provides an alternative way to modify the SP dispersion relation, in addition to incorporating nonlinear effects through the dielectric medium.

References

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