Excitation by Light of $\omega_+$ and $\omega_-$ Surface Plasma Waves in Thin Metal Layers

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Calculations with the extended Fresnel formulae show, that $\omega_+$ and $\omega_-$ surface plasma waves can be excited by light, using the following optical arrangement: The metal foil is embedded between two dielectric layers of low index of refraction and equal thickness. Both sides of this 3-layer packet are in optical contact with a high index prism. Total reflection is broken by $\omega_+$ and $\omega_-$ resonances in reflectivity, transmission and absorption. The $\omega_+$ resonance is mainly transmissive, (transmission through a 800 Å thick silver foil greater than 50% at a wavelength of 5,461 Å) the $\omega_-$ resonance is mainly absorptive. The polarization of the transmitted light exceeds 99% — the $\omega_+$ resonance is proposed as a principle for a new optical polarizer.

I. Introduction

In a previous paper it has been shown experimentally, that non-radiative surface plasma waves at the boundary of bulk silver and air can be excited by the method of frustrated total reflection. This effect was in agreement with theoretical calculations using the extended Fresnel formulae. These calculations were carried further in search of resonance structures due to $\omega_+$ and $\omega_-$ surface plasma waves in thin metal foils.

II. Surface Plasma Waves in Thin Metal Foils

In thin metal foils the nonradiative surface plasma waves on either side interact and split up into two branches. The mode with antisymmetric surface charge distribution with respect to the middle plane of the foil is called $\omega_+$, the symmetric mode $\omega_-$. The dispersion relations $\omega(k)$ (frequency $\omega$, wavenumber $k$) of $\omega_+$ and $\omega_-$ wave for a metal foil of thickness $t$ and dielectric constant $\epsilon(\omega)$, embedded between two non-absorbing dielectrics of dielectric constant $\eta=n^2(\omega)$ ($n(\omega)$: index of

Fig. 1. Dispersion $\omega(k)$ of $\omega_+$, $\omega_-$ and $\omega_1$ surface plasma waves, $\omega_+$, $\omega_-$ for a silver foil (optical constants\(^5\)) of 300 Å thickness embedded in LiF, $\omega_1$ for a boundary of bulk silver with LiF. $\omega$ in units of $\hbar \omega$. $n_z = 1.392$, $n_p = 1.9018$. Vertical line: $\hbar \omega$, corresponding to wavelength $\lambda = 5.461$ Å

refraction) are respectively (derived from \(^4\), formula (13))

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\varepsilon(\omega) = -\eta(\omega) \frac{\sqrt{k^2 - \varepsilon(\omega) \omega^2/c^2}}{\sqrt{k^2 - \eta(\omega) \omega^2/c^2}} \left\{ \frac{\tanh \left( \sqrt{k^2 - \varepsilon(\omega) \omega^2/c^2} \frac{t}{2} \right)}{\cosh \left( \sqrt{k^2 - \eta(\omega) \omega^2/c^2} \frac{t}{2} \right)} \right\}.
$$

In Fig. 1, $\omega_+$ and $\omega_-$ branch are plotted for a silver foil of 300 Å thickness (optical constants\(^5\)), embedded in LiF (index of refraction $n_z$, $n_z(5461$ Å$)=1.392$) and compared to the surface plasma wave $\omega_1$ at the boundary of bulk silver with LiF*.

If a prism of glass with index of refraction $n_p$ (for example IRG 2 (Schott), index of refraction $n_p$, $n_p(5461$ Å$)=1.9018$) is brought into optical contact to the LiF, then, following the arguments given in\(^1\), the evanescent wave present in total reflection may interact with surface waves at the metal boundary, which have $\omega$ and $k$ values within the area between lines I and II. The following calculations were performed to

* LiF can be replaced by polycrystalline MgF\(_2\) ($n \approx 1.38$\(^6\)). The differences in the results of the calculations will be negligible\(^1\).