Diagnostic of the Metal-Dielectric Interface in a Collective Oscillation of Electrons

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Light reflected from a dielectric- metal interface describe the existence of resonant modes of the collective oscillation in electron density. The experimental configuration proposed by Otto and Kretschmann- Raether can be used to characterizes the optical properties of thin metallic films in contact with a dielectric medium. In far-field detection, the angular dependence of the reflectivity on Ag/ ambient air shows a sharp minimum beyond attenuated total reflection. At a wavelength, λ the geometric parameters influence strongly the angular resonance θ_{SP}. In the case of Ag, $\lambda = 633.0$ nm, at the optimal thickness, d = 50.8nm, a resonant coupling is reaches between incident photons and free electrons in the angular range $45° < \theta_{SP} < 46°$. The angular resonance is associated with the optical phenomenon of an energetic transfer predicted theoretically.

Key Words: Evanescent wave, Resonant modes, Far-field Detection, Diagnostic of the metal/dielectric Interface.

1. INTRODUCTION

Plasma oscillations in metals (surface plasmon modes [1]) are excited at the attenuated total reflection of an incident electromagnetic wave on the structure interface. The study of the electromagnetic eigenmodes is applied to investigate the complex dielectric function ε_m and the thickness δ of alkali metals. In practice, a thin metal film is deposited onto a prism base and a plane monochromatic light wave illuminate the above structure. In the condition, $\varepsilon_p > \varepsilon_d$, of the dielectric constants of the prism and the medium in contact with the metal, surface plasmon modes (SP) are identified by the angular resonance on the reflectivity measurement in far-field detection. Several configurations exist to excite SP [2-4] for practical applications and extended for the investigation of surfaces or interface properties [5-7]. The important point in using SP for spectroscopic measurements is the possibility to examine interfaces as electromagnetic modes. We demonstrate this for experimental model configuration, focusing on angular-dependent reflectivity measurements.

2. ANALYTICAL EXPRESSION FIELDS NEAR INTERFACES

In the order to generate SP modes near metal-dielectric interface, we firstly adopted Kretschmann- Raether geometry (Cf. Fig. 1). An interface in the x, y– plane between two media is characterized optically by dielectric permittivities ε_m and ε_d. When an incident beam of light irradiate the structure, it follows Fresnel's law. From this optical concept the electric-field components associated to the electromagnetic wave in structure vacuum (Cf. Fig. 2) can be described by:

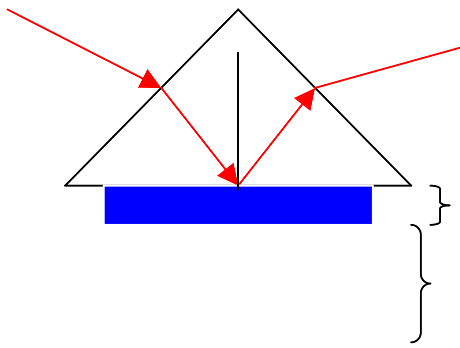

FIG.1 : Schematic view of the experimental setup for SP modes excitation in attenuated total reflection.

$$\left.\begin{aligned} &\vec{E}_{pi}=E_{px}(1,0,\frac{k_x}{k_{pz}}) \\ (1)\ &\vec{E}_{pr}=r_p E_{px}(-1,0,\frac{k_x}{k_{zp}}) \end{aligned}\right\}$$

$$\left.\begin{aligned} &\vec{E}_{mi}=E_{mx}\left(1,0,\frac{k_x}{k_{zm}}\right) \\ (2)\ & \\ &\vec{E}_{mi}=E_{mx}\left(1,0,\frac{k_x}{k_{zm}}\right) \end{aligned}\right\}$$

$$\vec{E}_{dt}=E_{dx}(1,0,\frac{k_x}{k_{zd}})\ (3)$$

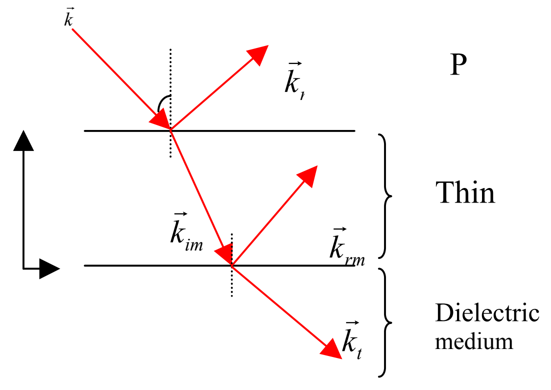

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FIG. 2: Electric fields propagation near interfaces in Kretschmann geometry.

The reason for the above forms in Eqs. 1 – 3, for electric field components is justified by the fact that incident electromagnetic wave is transverse magnetic polarized (TM). A coupling frequency ω_{SP} can be reached which is defined as the dispersion relationship:

$$k_x = \frac{\omega}{c}\left(\frac{\varepsilon_m \varepsilon_d}{\varepsilon_m + \varepsilon_d}\right)^{1/2} \quad (4)$$

As a consequence, SP modes exhibit typical mean free path, L_x along the interface in the x-direction:

$$L_x = \frac{1}{2k_i} \quad (5)$$

where the wave vector k_i of the plasmon is the imaginary part of the eqn. (4).

From these analytical expressions, with the application of the rule of the usual boundary conditions for the electric fields propagating near interfaces at the coordinates z = d and z = 0, respectively the reflectivities are deduced as follows:

$$\left.\begin{aligned} r_p &= \frac{\varepsilon_m k_{zp}(1+A) - \varepsilon_p k_{zm}(1-A)}{\varepsilon_m k_{zp}(1+A) + \varepsilon_p k_{zm}(1-A)} \\ r_m &= \frac{\varepsilon_d k_{zm} - \varepsilon_m k_{zd}}{\varepsilon_d k_{zm} + \varepsilon_d k_{zd}} \end{aligned}\right\} \quad (6)$$

with

$$A = r_m e^{2 i k_{zm} d}$$

The reflectance $R(\theta) = |r_p|^2$, treated numerically as a function of the incident light shows a pronounced dip indicating the confinement of the SP modes excited near Ag-air interface (Cf. Fig. 3), for d=50.8nm at λ=633.0nm. The thickness d≤30nm, has an influence on the rate of light intensity which is evaluated to more than 50%, with a large dip and a noticeable angular shift. At this limit value the metallic layer supported Ohmic losses along its interface.

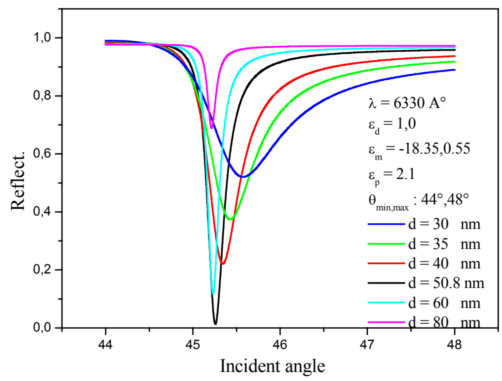

FIG. 3: Reflectance curve versus incident angle on Ag- air interface, taken at $\lambda = 633.0$nm, 30nm $\leq d \leq$ 80nm, $\varepsilon_{Ag} = -18.35 + i\,0.55$, $\varepsilon_p = 2.1$ and $\varepsilon_d = 1, 0$.

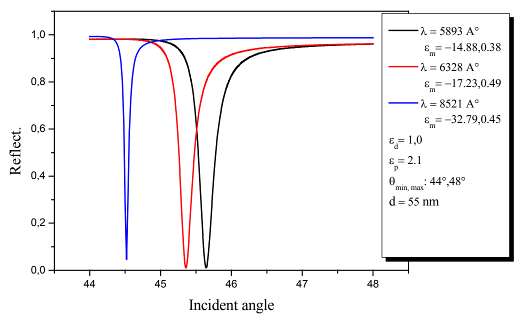

FIG. 4. : Wavelength effect of the incident light on reflectance curve versus incident angle on Ag- air interface, for an optimal SP modes, taken at the conditions indicate in Table. 1.

Let us recall that for each alkali metal, the angular resonance of SP is shifted by the dispersive effect when either the parameter ε_p or λ is increased or decreased(Cf.Figs.45).

The same properties of the SP modes have been observed with Copper and Chromium by Wang, Yu and Simon HJ et al [8,9].

A similar technique to observe plasmon coupling of nanoparticles in near-field detection is described in ref [10]. The use of the SP modes is an appropriate method to probe surfaces and interfaces. It gives rise to a measurement of optical properties.

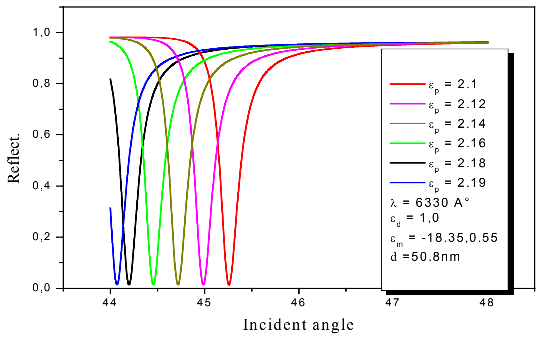

FIG. 5: Reflectance curve versus incident angle on Ag- air interface, with a significant value on the refractive index of glass prism

Wavelenght of incident light λ, nm	589.3	632.8	852.1
Dielectric function of the metal ε_{Ag}	- 14.88 + i 0.38	- 32.79 + i 0.49	- 32.79 + i 0.45

Table. 1. : Dielectric function for Silver (Ag), relative to the incident wavelength λ, measured by Johnson et Christy [8].

3. CONCLUSION

The above example demonstrates the potential of the SP modes for the characterization of metallic thin layers. The fitting procedure by a comparison between the theoretical model and the experimental measurements determines the optical constants for the used metal.

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