Plasmon-Polaritons And Their Use In Optical Sub-Wavelength. Event Of Copper And Silver

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ABSTRACT

The work undertaken in this article concerns the description of the propagation modes of an incident electromagnetic wave of wavelength λ (the visible spectrum) to its interaction with a structure typical metal / dielectric. The study of this interaction process is the measurement of features that are four parameters associated with longitudinal modes propagating interface. A comparative study between two structures silver and copper has been established. The characteristic parameters whose behavior is studied in the visible spectrum are the propagation length, and the length of penetration in rural and dielectric material. The typical structure of Kretschmann-Raether being used for the diagnosis of structure, analytical study shows that copper can be used as a guide for photonic transmission. The direction of propagation, the electromagnetic field associated with the interface modes present evanescent spatial coherence with which the behavior is justified by a study of the near field. For this, we have given some results on the density of states of plasmonic modes on a copper-air interface.

KEYWORDS

plasmon polariton surface, near field, wave resonant surface, thermal radiation,

1. Introduction

In 1902, Wood, observing the spectrum of a continuous source of white light using a diffraction grating reflection, observation of fine dark bands in the spectrum diffracted. Theoretical analyzes undertaken by Fano in 1941, led to the conclusion that these anomalies were associated with surface waves (surface plasmons) supported by the network. [1] In 1965, A. A. Hessel and A. Oliner propose a more general theory of Wood anomalies in networks métalliques.ils interpret these anomalies by resonance effects from the coupling between the incident wave and the modes of the network [2]. In 1968 Otto shows that these surface waves can be excited using attenuated total reflection. In the same year, Kretschmann and Raether get the same results from a different configuration of the attenuated total reflection method . Today, interest in surface plasmons is demonstrated. Along with the high success of the surface plasmon resonance (SPR) to measure changes in refractive index and thickness of the organic layers with high accuracy, or the design of biological sensors capable of detecting the interactions between enzymes and substrate, antigen / antibody. [3] We will begin this article with a few ideas on surface plasmons. We then discuss the results, the behavior of surface waves on a plane interface properties and then a comparison between two metal circles, silver and copper before finishing with a result on the density of electromagnetic state.

2. Surface plasmon

The surface polaritons appear at the interface between two media (for our part, we have considered only the case of the planar interface). They represent particular solutions of Maxwells equations which correspond to waves propagating parallel the interface and whose amplitude decreases exponentially as you move away perpendicularly thereto. This is why these waves are often called "surface waves" they remain confined near the interface.

3. Description of the system considered

Consider the system of Figure 1

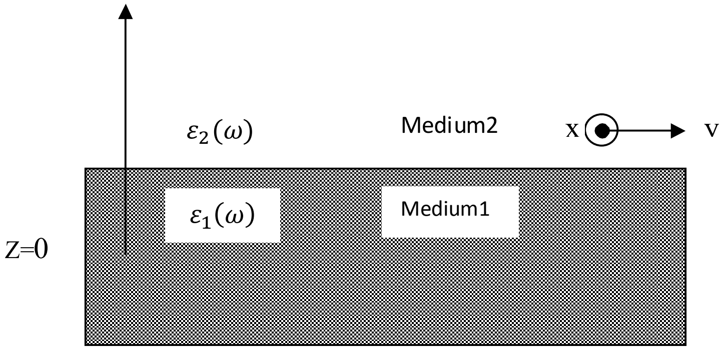

Fig.1: Geometry of the studied system

The space is divided into two semi-infinite (medium 1 and medium 2, linear, homogeneous, isotropic and non-magnetic. They are separated by a planar interface such that: for$z < 0$, ε(ω)=ε_1(ω) and for $z > 0$, ε(ω) $=\varepsilon_2$(ω). The z axis is perpendicular to the interface and the x-y plane parallel thereto. The unit vectors associated with the three axes are noted X, Y and Z. To a point $r = (x, y, z) = xX + yY + zZ$ space, we note r =(R, z), R being the vector component parallel to the x-y plane.

4.Conditions for the existence of a surface polariton on a planar interface in the absence of losses

Assume now that medium 2 is an environment where there is no propagation attenuation. That is to say, ε_2 (ω) is a positive real number and must ε_2 (ω) <0. It is said that the middle is the middle one "active":

- It only appears polariton polarization p (TM).
- The dispersion relation of the surface polariton is:

$$k = k_0\sqrt{\frac{\varepsilon_1(\omega)\varepsilon_2(\omega)}{\varepsilon_2(\omega)+\varepsilon_1(\omega)}} \tag{1}$$

5. Results and discussions

We wish to clarify that we are working in conditions to excite the plasmon-polariton wave surface (PPS) propagating at a frequency $\omega_{SPP} \leq \omega$ (in the visible spectrum) recording in particular the negative sign the dielectric function of the metal ($\varepsilon_r < 0$). The data for this complex dielectric function is obtained from the Drude model. Plots of this function are obtained using the Fortran language.

5.1. Optical characteristics of the material

A response to an electromagnetic field of a wave with a given material, two optical inputs involved: - the effect of dispersion and absorption. These optical effects are described by the term real and imaginary parts of the complex function of the material. Allowing himself to recall the model of the dielectric permittivity of the material. According to the Drude model, we have:

$$\varepsilon_m(\omega) = 1 - \frac{\omega_p^2}{\omega^2 + i\omega\gamma} \qquad (2)$$

Where ω_p is the plasma frequency (typical value of the metal) and γ is the attenuation term absorption [2], which characterizes the friction of the electron with the metal. . We explain the equation (2) complex as $\varepsilon_m = \varepsilon_m' + i\varepsilon_m''$

$$\varepsilon_m' = 1 - \frac{\omega_p^2}{\omega^2 + \gamma^2} \qquad (3)$$

and

$$\varepsilon_m'' = \frac{\omega_p^2 \gamma}{(\omega^2 + \gamma^2)\omega} \qquad (4)$$

For copper and silver, the profiles of these terms are plotted as a function of the wavelength in the visible spectrum.

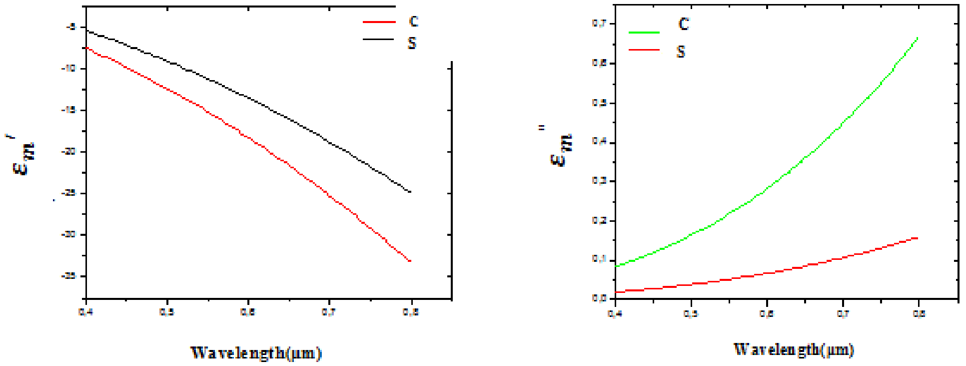

Fig.2 - Parts of the real and imaginary complex dielectric function of copper and silver haves characteristic parameters $\omega_{pcopper} = 1{,}38 \times 10^{16}\ rad/s,\ \ \omega_{\gamma copper} = 4{,}61 \times 10^{13} rad/s\ \ et\ \omega_{p\ silver} = 1{,}2 \times 10^{16}\ rad/s,\ \ \omega_{\gamma Argent} = 1{,}45 \times 10^{13} rad/s$) in the visible spectrum.

Strong contribution of energy loss by absorption is clearly visible between the Cu and Ag, which is to say that the modes excited at wavelengths associated with low frequencies are affected by greater losses. If we make a choice on a material functioning as a guide photonics, silver is the best candidate.

5.2 The parameters associated with the modes of PPS

The excitation of modes of a given material PPS offers the advantage of this structure in a size scale smaller than the wavelength of the incident electromagnetic wave [4]. For the realization of photonic circuit, it is important to miniaturize the component. In this scale, Barnes gives the idea of using the Silver for which it is defined parameters associated with four modes of PPS : The normalized wavelength λ_{PPS}/λ_0 , The propagation length of the SPP δ_{PPS} , The penetration depth in the metalδ_m, and in the dielectric δ_d

5.2.1. Wavelength of plasmon surface polariton

We begin by examining the wavelength of PPS can be expressed from the real part of the dispersion relation which is described as:

$$k'_{PPS} = k_0\sqrt{\frac{\varepsilon_d \varepsilon'_m}{\varepsilon_d + \varepsilon'_m}} \tag{5}$$

with $k_0 = \frac{\omega}{c}$,

On the other hand we can deduce the expression of the normalized wavelength of PPS (λ_{spp}/λ_0) which is written:

$$\frac{\lambda_{spp}}{\lambda_0} = \sqrt{\frac{\varepsilon_d + \varepsilon'_m}{\varepsilon_d \varepsilon'_m}} \tag{6}$$

Where λ0 is the wavelength in free space propagation is given by: $\lambda_0 = 2\pi/k_0$

On the other hand, the penetration depth of which the electric field is expressed from the imaginary part of the dispersion relation (wave vector of PPS), which is expressed [5]:

$$k''_{PPS} = k_0 \ \frac{\varepsilon''_m}{2(\varepsilon'_m)^2} \ \left(\frac{\varepsilon'_m \varepsilon_d}{\varepsilon'_m + \varepsilon_d}\right)^{\frac{3}{2}} \tag{7}$$

And the penetration length of the PPS is given by the following formula: $\delta_{PPS} = \frac{1}{2k''_{PPS}}$

So then we can approximate the penetration length δ PPS as when a metal without loss:

$$\delta_{PPS} = \lambda_0 \frac{(\varepsilon'_m)^2}{2\pi \varepsilon''_m} \tag{8}$$

The behavior of the standard wavelength and the length of penetration of the surface plasmons for the case of silver and copper are plotted against the wavelength in the visible spectrum in the figure (3) and Figure (4) respectively.

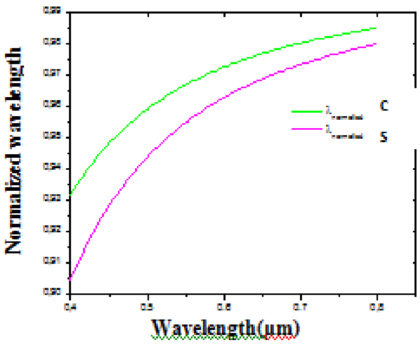

Fig.3- Evolution of the normalized wavelength plasmon surface polaritons depending on the wavelength in the visible spectral range.

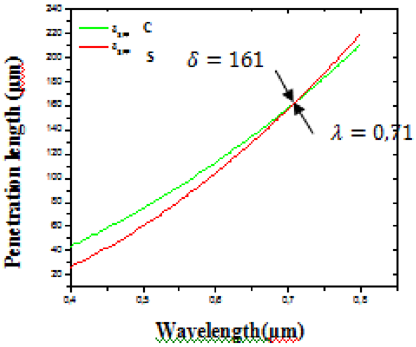

Fig.4-Penetration length plasmon surface polariton (SPP) as a function of the wavelength in the visible spectral range for copper and silver

We can see from Figure 3 that the wavelength of PPS (PPS λ) increases with the wavelength λ_0 swept in the visible spectrum. This behavior changes slightly in the case of silver compared to copper. From Figure 4, we see that the penetration length augment when the wavelength tends to augment and when to high frequencies we see a high propagation length. Second, we note that the propagation length of PPS is greater than the wavelength of PPS.

5.2.2. Penetration depth of the field of plasmon surface polariton

In a material with a relative permittivity ε_i the total wave vector of the light wave vector k_0 give by $\varepsilon_i k_0^2$, with the z direction perpendicular to the plane in which the PPS thus propagates the relationship between the wave vector and the z-component total give by:

$$\varepsilon_i k_0^2 = k_{Spp}^2 + k_{z,i}^2 \tag{9}$$

As we have already noted, the wave vector of plasmon surface polariton is always higher than that of photon propagating freely in the medium, that is to say $k_{Spp}^2 > \varepsilon_i k_0^2$ then the wave vector component z in both environments is imaginary, which is the exponential decrease of the field in the two environments. We used the equations (1) and (9) to write the depth of penetration into the dielectric δ_d,, and the metal δ_m as follow:

$$\delta_d = \frac{1}{k_0}\left|\frac{\varepsilon_m' + \varepsilon_d}{\varepsilon_d^2}\right|^{\frac{3}{2}} \tag{10}$$

$$\delta_m = \frac{1}{k_0}\left|\frac{\varepsilon_m' + \varepsilon_d}{\varepsilon_m^2}\right|^{\frac{3}{2}} \tag{11}$$

5.2.2.1 Depth of penetration into the dielectric and the metal

We report the trace of δ_d and δ_m as a function of the wavelength in the visible spectral range

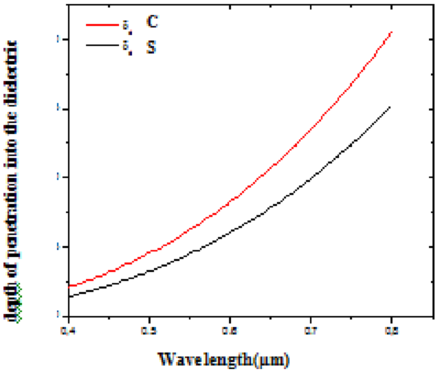

Fig.5. depth of penetration into the dielectric as a function of wavelength in the visible spectral range of the copper and silver.

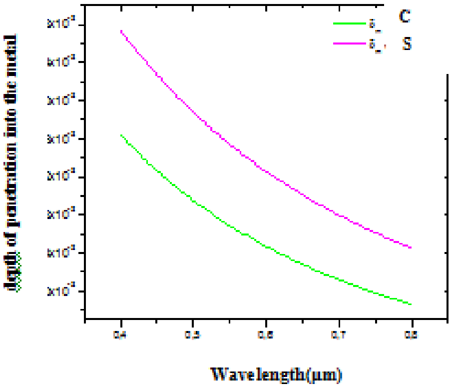

Fig.6. depth of penetration into the metal (copper and silver) as a function of the wavelength in the visible spectral range

We have seen from figure 5 that for large wavelengths, the penetration depth in the dielectric is deeper than shorter wavelengths. This behavior changes slightly in the case of silver compared to copper. This increase, in relation to the wavelength is seen because as one moves towards the larger wavelengths the metal is a better conductor and the user has a wave vector which is nearest of the wavevector. From Figure 6 we have seen that when the wavelength increases the depth of penetration into the metal decreases that is to say penetrating into the metal is inversely proportional to the wavelength.

6. Comparison between the characteristics of PPS modes for silver and copper

In this section we make a comparison between the characteristics of PPS modes for two metals: silver and copper

		$\boldsymbol{\delta_{pps}(\mu}$	$\boldsymbol{\delta_d(\mu m)}$	$\boldsymbol{\delta_m(\mu m)}$	$\boldsymbol{\omega_p}$	$\boldsymbol{E=\hbar\omega_p}$
silver	$\lambda = 0.4\mu m$	25	0,1	$4{,}8 \times 10^{-3}$	$1{,}2 \times 10^{16}$ rad/s	$7{,}95 \times 10^{-18} J$
	$\lambda = 0.8\mu m$	220	1,5	$2{,}4 \times 10^{-3}$		
copper	$\lambda = 0.4\mu m$	45	0,25	$3{,}7 \times 10^{-3}$	$1{,}38 \times 10^{16}$ rad/s	$9{,}14 \times 10^{-8} J$
	$\lambda = 0.8\mu m$	210	2,0	$1{,}9 \times 10^{-3}$		

Table 1 - Characteristics of PPS method for copper and silver in the visible range.

According to the table. We noticed in the first part, we examined whether the penetration length of PPS (δpp), we conclude that δpp in the case of copper is deeper than the silver which is this implies that the Copper has less loss than the silver, but when moved in the high frequency loss becomes less silver than copper. In the following, we consider the depth of penetration into the metal and the dielectric we conclude that copper is the best driver and it allows strong confinement of the field.

7. Conclusion

In this paper we have studied the surface plasmon modes and the interaction of the free electron metal. A response to an electromagnetic field of a wave with a given material, two optical inputs involved: - the effect of dispersion and absorption, we found that the modes excited at wavelengths associated with low frequencies are affected by higher losses and result parameters associated with the four modes of PPS handled at sub-wavelength are obtained from analytical calculations. We report these four parameters as a function of wavelength in the visible spectral range for copper and silver, we want to make a choice on the metal which is acting as a good conductor, copper is the best candidate.

Références

[1] résonance plasmon de surface : définition de résonance plasmon de surface et synonyme de resonance.
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