Interaction of Light with metal: A Brief Overview

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Abstract: In order to understand plasmonics, the study of important properties of certain novel materials is very essential. In this article, basic of electromagnetic theory and its physical significance has been discussed. Finally, the detail theory of interaction of electromagnetic wave with metal surface has been discussed.

Introduction

In this planet electromagnetic (em) radiation is a part of everybody life. This em waves are classified into different categories such as radio wave, IR wave, UV wave and so on. The high frequency em-waves shows the properties such as high energetic and it has more penetrate power than low frequency waves. Earlier, scientists have initiated to investigate the metal nanostructures optical properties, they found that gold nanoparticles of different size creates a multitude of colours. The examples are the Lycurgus cup shows a green colour when it shines with red light. The properties of em radiation at metal-dielectric interfaces undergo a steadily increasing interest in science. To understand the behaviour of this interaction, first a study is required for the interaction of em-radiation with metal. This article discusses a detail background for the interaction of em-radiation or light wave with metal surface.

Interaction of Light with metal

Based on the classical Maxwell equations, a complete description can be possible to observe the interaction of metals with electromagnetic (em) field. The differential form of

FOUR Maxwell equations in the presence of magnetic or polarizable media have the following form [1]-[2]:

$$D \qquad (1)$$

$$B \quad 0 \qquad (2)$$

$$E \qquad \frac{B}{t} \qquad (3)$$

$$H \quad J \qquad \frac{D}{t} \qquad (4)$$

Where the four macroscopic vector functions E, B, D and H are usually called:

E: Electric field (volt/meter), B: Magnetic induction (tesla), D: Electric displacement field (c/mt^2), H: Magnetic field intensity (amp/mt).

and J: Electric current density(amp/mt^2), : Electric charge density(c/mt^3)

The equations in this thesis are given in SI units. The four fields are related through the polarization P (coulomb/meter^2) and magnetization M (ampere/meter) by [1]-[2]:

$$D \; _0EP \qquad (5)$$

$$H \quad \frac{1}{_0}B \quad M \qquad (6)$$

Where $_0$ is the electric permittivity and $_0$ is the magnetic permeability, both measured in vacuum. Throughout this thesis we have limited ourselves to isotropic and nonmagnetic media. Equations (5) and (6) can, therefore, be simplified to [1]-[2]

$$D_0 \; E \qquad (7)$$

$$B_0 \, H \qquad (8)$$

Where and $_0$ are the relative permittivity and permittivity of free space respectively.

and $_0$ are relative permeability or magnetic permeability and magnetic permeability of free space respectively. For nonmagnetic medium the relative permeability is set to one i.e.

1 . The relation between J and E can be written [1]-[2].

$$J E \tag{9}$$

Optical properties of metal

When metal nanostructures dimension reduces to a few nanometre size, the basic optical properties of metal can be described with the help of the classical plasma concept, where an electron gas of density N is assumed that freely propagates behind a background of core nucleus[3]-[4]. These electrons start to vibrate in the presence of an external applied electric field $E(t)\ E_0\ e^{i\ t}$. Then it will be damped after the collision with core nuclei at a collision frequency 1/ , where is average collision time. At room temperature, Hz. A complex dielectric function of the free electron gas can be calculated ^{10} by using kinetic theory and can be written as [3]-[4]:

$$(\ )\ 1 \quad \frac{{}_{p}^{2}}{{}^{2}\quad i} \tag{10}$$

Where $_p$ $\sqrt{\frac{Ne^2}{m\ _0}}$ is called plasma frequency. The above equation is called as the Drude model, This equation provides all dispersive properties of metal. This ( ) is a complex function and can be written as $\underset{\sim}{(\ )}\ _1(\ )\ i\ _2(\ )$ [2],[3],[5]. The complex form of refractive index can be expressed $_{n(\ )}$ $_{n(\ )}$ $_{i\ (\ )}$ $\sqrt{\ (\ )}$. Also, we can write as the following expressions:

$$_1(\ )\quad n^2\quad ^2 \tag{11}$$

and

$$_2(\ )\quad 2n \tag{12}$$

Again,

$$n^2\quad \frac{1}{2}\quad \frac{1}{2}\sqrt{_1\ ^2\ _2^{\ 2}\qquad ^2} \tag{13}$$

and

$$\frac{^2}{2n} \tag{14}$$

The real part of the RI $n(\ )$ shows information of the dispersion in the medium, the imaginary part $(\ )$ shows the absorption. Now from the dielectric function Eq^n. (10), it can be concluded that:

(i) For low frequencies regime, 1, leading to $_2 \quad 1$ and hence metal are absorbing with co-efficient $\sqrt{2\ ^2_p \ / c^2}$.

(ii) For high frequencies, the product1, leading to insignificant damping. Thus $(\ )$ is predominantly real i.e [3]-[4]

$$(\quad)\quad 1\quad \frac{^2_{\ p}}{^2} \tag{15}$$

From Eqn. (15), gives the dielectric function of the undamped free electron plasma. However, the noble metals behaviour in this frequency region is completely altered by interband transitions, leading to an increase in $_2(\ )$ [4]-[6]. Fig. 1 and Fig. 2 shows the behaviour of the real and the imaginary part of the dielectric function for Au and Ag respectively. From this figure, at high frequencies this model is not adequate, and in the case of Au, its breaks validity at the boundary between the near-IR and the visible region. It is to be pointed out that at optical frequency the real part of the dielectric function of noble metals are negative and has much larger values than the imaginary part at the same energy (or frequency).

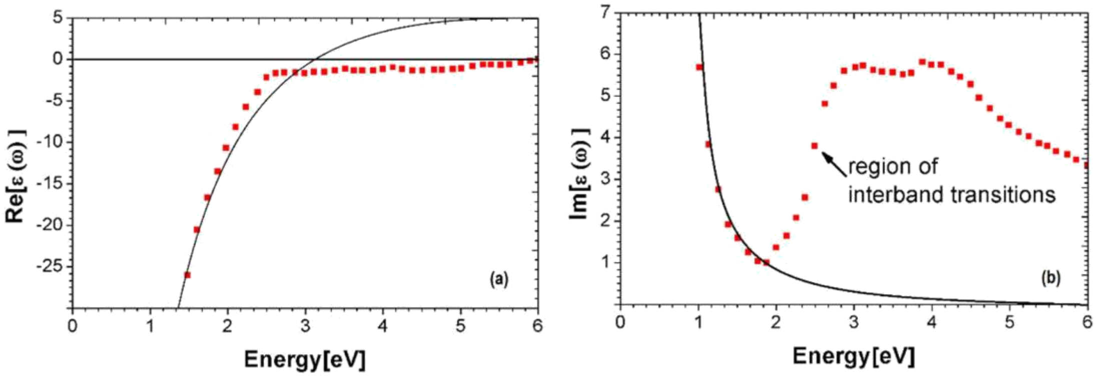

Fig 1: (a) The real of ε(ω) for Au and (b) imaginary part of ε(ω) for Au (Adapted from [3])

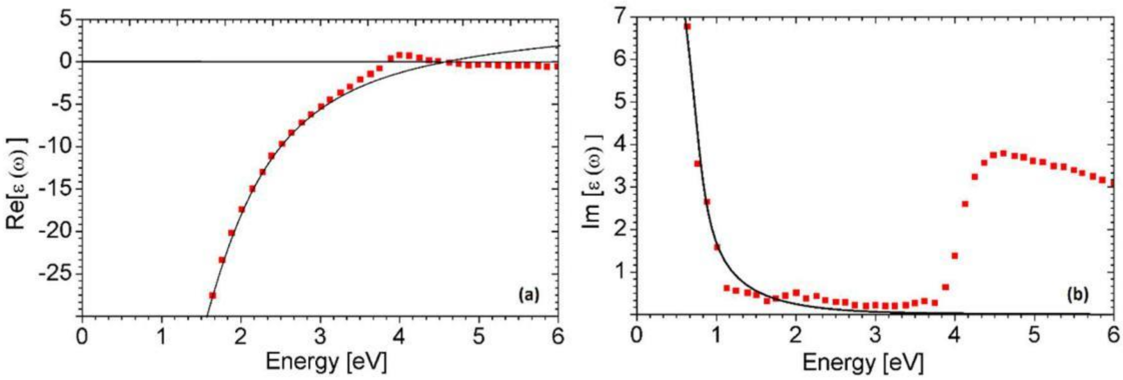

Fig 2: (a) The real of ε(ω) for Ag and (b) imaginary part of ε(ω) for Ag.(Adapted from [3]) Now the

dispersion relation of travelling electromagnetic field can be determined by

using expressions $k|^{2}|$ $k^{2}\,{}^{2}/c^{2}$ **and** Eq^{n}**. (2.15),**

$$ {}^{2}{}_{p}^{2} \quad k^{2} c^{2} \qquad (16)$$

Thus, Fig. 3 shows that propagation of em waves below the plasmon frequency $_p$ **not**

happened. For $_p$ **waves propagate with a group velocity** v_g $d\ \ / dk\ \ c$ **. In case of**

$_p$ **,** $(\ _p)\ 0$ **.**

Thus one can find that a collective longitudinal excitation mode (k || E) is formed. The importance of this is a collective oscillation of the conduction electron gas with respect to the fixed background of positive atom cores. The quantisation of charge oscillation is known as

plasmon. As these are longitudinal waves, bulk plasmons cannot couple to transversal electromagnetic fields and thus cannot be excited from or strayed to direct irradiation.

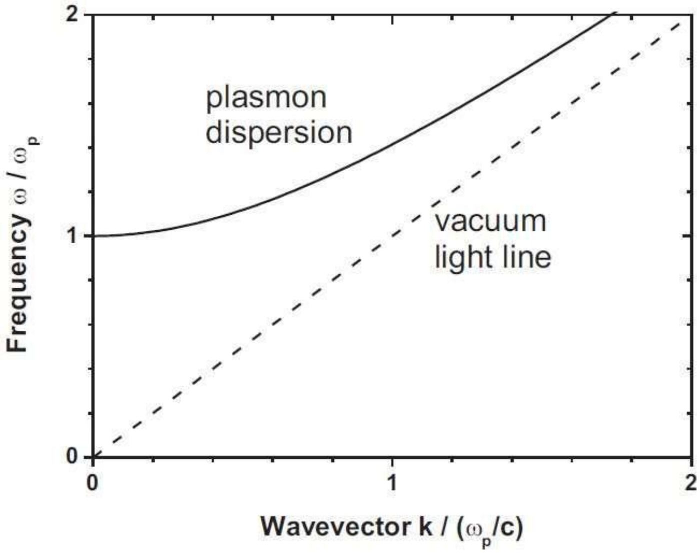

Fig. 3 Dispersion relation of the free electron plasma [3]

Conclusion

The concepts of interaction of electromagnetic wave and metal has been discussed. The optical properties of metal has been discussed. Also, this article discussed briefly about dispersion relation and frequency dependent dielectric function. This study suggest that study it will help for the understanding of surface plasmon resonance at the metal dielectric interface.

Reference

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