Electromagnetic fields near metal surfaces

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Abstract. Electromagnetic field variation at the surface region of nearly free electron metal (Al), noble metal (Ag) and transition metals (Cr, Rh, Pd and Mo) are studied with respect to the incident photon energy. The electromagnetic field used is the one calculated by Bagchi and Kar using the local frequency dependent dielectric response function. The results so obtained may be of significance in the photoemission scattering cross-section calculations in understanding electronic structure and properties of these metals.

Keywords. Photoemission; plasmon energy; electromagnetic fields; dielectric; photocurrent.

1. Introduction

Photoemission from solids has long been a source of interest in physics but only recently has its potential as a probe of electronic structure been recognized. It is of fundamental importance since it is connected with the basic interaction of electromagnetic field and solid.

The calculation of electromagnetic fields has been a topic of study and has been given due attention by many scientists earlier. To cite a few examples, Kleiwer (1976) considered the semi-classical infinite barrier model, Forstman and Stenschke (1977) used a hydrodynamical approach while Feibelman (1975a, b) has given the most complete results for jellium. However, all these calculations are applicable only in the case of free electron metal. These fields in the surface region can then form the basis for photoemission calculations.

Here, we have been concerned only with the photon energy dependence of the electromagnetic field. The solids taken for the case study are nearly free electron metal (Al), noble metal (Ag) and transition metals (Cr, Rh, Pd and Mo). We provide here a very simple way of understanding the spatial variation of the electromagnetic field for the surface region defined by 
\[ -\frac{a}{2} \leq z \leq \frac{a}{2} \]
by considering a local frequency dependent dielectric function \( \varepsilon(\omega, z) \) described elsewhere (Bagchi and Kar 1978). We shall focus our attention mainly on the calculation of the electromagnetic field variation in the surface region for both below and above the plasmon energy since this is responsible for the enhancement of photoyield compared to the value calculated from the classical Fresnel fields.

2. Theory

The model used (Bagchi and Kar 1978) is a fairly simple one. The z-direction is assumed to be perpendicular to the nominal surface plane which is chosen to be \( z = 0 \)
plane. The metal is assumed to occupy all the space to the left of $z = 0$ plane. The response of the electromagnetic field is assumed to be bulk-like everywhere except in a surface region which extends over $-a/2 \leq z \leq a/2$. In this region, the model dielectric function is chosen to be a local function which interpolates linearly between the bulk value inside the metal and the vacuum value (unity) outside. The model frequency dependent dielectric function is therefore given by

$$
\varepsilon(\omega, z) = \begin{cases} 
\varepsilon(\omega) = \varepsilon_1(\omega) + i\varepsilon_2(\omega) & z \leq -a/2 \\
\frac{1}{2}[1 + \varepsilon(z)] + [1 - \varepsilon(\omega)](z/a), & -a/2 \leq z \leq a/2 \\
1 & z \geq a/2
\end{cases}
$$

For complex dielectric function, we have used the experimental values given by Weaver (1987–88). We consider a $p$-polarized light to be incident on the surface plane making angle $\theta_i$ with the $z$-axis. For $p$-polarized light, the magnetic field $B(z) = B(\vec{Q}, \omega, z)$ (where $\vec{Q} = \omega/c \sin \theta_i$ is small) is in the $y$-direction and it obeys the following equation (Landau et al 1984) with $\varepsilon = \varepsilon(\omega, z)$

$$
\frac{d}{dz} \left( \frac{1}{\varepsilon} \frac{d B}{dz} \right) + \left( \frac{\omega^2}{c^2} - \frac{Q^2}{\varepsilon} \right) B = 0
$$

The electric field components can be obtained from the magnetic field by using the relation

$$
E^z(\vec{Q}, \omega, z) = \frac{c}{i\omega \varepsilon} \frac{d B}{d z} \\
E^y(\vec{Q}, \omega, z) = -\frac{\sin \theta_i}{\varepsilon} B
$$

Then we get the long wavelength limit ($\omega a/c \to 0$) and following result (Bagchi and Kar 1978)

$$
E^z(Q \to 0, \omega, z) = \frac{E_0}{\varepsilon} = \begin{cases} 
-\frac{\sin 2\theta_i}{[\varepsilon(\omega) - \sin^2 \theta_i]^{1/2} + \varepsilon(\omega) \cos \theta_i}, & z \leq -a/2 \\
-\frac{\sin 2\theta_i}{z/a + a/2[1 + \varepsilon(\omega)]/[1 - \varepsilon(\omega)]} \cdot \frac{\varepsilon(\omega)/[1 - \varepsilon(\omega)]}{[\varepsilon(\omega) - \sin^2 \theta_i]^{1/2} + \varepsilon(\omega) \cos \theta_i}, & -a/2 \leq z \leq a/2 \\
-\frac{\sin 2\theta_i}{[\varepsilon(\omega) - \sin^2 \theta_i]^{1/2} + \varepsilon(\omega) \cos \theta_i}, & z \geq a/2
\end{cases}
$$

We are mainly interested in the $z$-component of the electric field because for normal photoemission if the initial and final states are symmetric then $E^z$ is the component which will give a non-vanishing matrix element.