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SURFASE PLASMONS OF TWO PARTICLES WITH MULTIPOLE INTERACTION BETWEEN IN EXTERNAL ELECTRIC FIELD

The spectrum of superficial fashions of two metallic particles considered in external electric field ***E*** *and has been calculated. The effect of the external (time-dependent) electric field with a wave-length l_0 on the pair of different bullet nanoparticles at the distance d one from another considerably anymore for the size of particles and d has been calculated.*

The electrodynamics response of a small particles system on an external electric field was investigated. The resulting electric field was calculated for a system of small spherical particles of different radii R_i and permittivity $\varepsilon_i(\omega)$ placed near a substrate. Analytical expressions for the polarizability of a system of two small particles were received taking into account multipole substrate-particle interactions as well as interactions between the particles themselves. In a case of two different spherical particles, frequencies of surface plasmon modes were obtained. All the calculations are performing in the electrostatic approximation.

Key Words: surface plasmon, electrodynamics response, multipole interaction.

1. Introduction.

A study on the processes of interaction of electromagnetic radiation (EMR) with the band of small particles (SP) is presented with enormous interest, both from the point of view of non-destructive control of surface and due to creation of composite materials with the in advance set electrodynamics' properties [1-6].

In general, a few factors have an influence on descriptions of spectra of absorption, such as: height, width and position of peaks of SP. These factors are examined in the classic theory, comfortably to unite in groups which answer the types of interaction in the system of small particles. We will transfer these interactions in order of their diminishing intensity and, accordingly, their influence on light-spectra of absorption [5, 6] of such systems.

First, we look at interaction of SP with the external electromagnetic field. It is conditioned only descriptions of SP — their form, measuring, structure (by the presence of shells, additional layers etc.) and properties of material which they are made from.

Second, we look at interaction between particles in the system of SP. This interaction is a conditioned character of the spatial distributing of SP (dense distributing; for SP of non-spherical form matters also character of their spatial orientation: whether it is well-organized or chaotic), and also distributing character of them on sizes (mono- or polidisperse distributing).

The purpose of work is to study the character of electrodynamic response in the system of spherical SP, being in the external electric field; to define polarizability of SP, frequencies of superficial fashions, and also to analyze the frequency spectrum of superficial excitations of dipole interaction of particles between them.

2. Results and discussion.

The spectrum of superficial fashions of two metallic particles considered in the external electric field ***E*** was calculated. A study on the external (time-dependent) electric field of two particles at the distance *d* one from other with a wave-length λ_0 considerably anymore for the size of particles and *d* was found [7, 8].

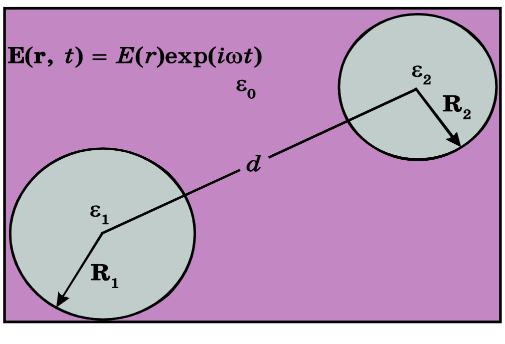

Fig. 1. Two small spherical particles on solid surface in the external electric field of $\vec{E}(r,t)$.

The tensor of polarization of *i*-particle can be presented if we take only dipole interactions between particles:

$$\alpha^{m}_{im_1} = 4\pi a_{i1}\frac{1+(-1)^m \eta_m a_{\bar{i}1}}{1-\eta_m^2 \frac{a_{11}a_{21}}{d^6}}\delta^{m'}_{m}. \qquad (1)$$

where $\bar{i}$ = 1, if i = 2; $\bar{i}$ = 2, if i = 1, $\varepsilon_0 \equiv \varepsilon_a$; R_i - the radius of *i*-particle.

$$a_i = \frac{\varepsilon_i - \varepsilon_0}{\varepsilon_i + 2\varepsilon_0}R_i^3, \quad i = 1,2 \qquad (2)$$

Other denotations those.

A condition for finding frequencies of surface plasmons (equality the zero of denominator in (1)) should be in this case:

$$\eta_m^2 \frac{R_1^3 R_2^3}{d^6}\left(\frac{\varepsilon_{1\infty}-\varepsilon_0}{\varepsilon_{1\infty}+2\varepsilon_0}\right)\left(\frac{\varepsilon_{2\infty}-\varepsilon_0}{\varepsilon_{2\infty}+2\varepsilon_0}\right) \cdot \left(\frac{\omega^2-\omega_{e1}^2}{\omega^2-\omega_{f1}^2}\right)\left(\frac{\omega^2-\omega_{e2}^2}{\omega^2-\omega_{f2}^2}\right) = 1 \qquad (3)$$

The inductivities of metallic spheres were chosen in Drude formula [2]:

$$\varepsilon_1(\omega) = \varepsilon_{1\infty} - \frac{\omega_{p1}^2}{\omega(\omega + i\gamma_1)};$$
$$\varepsilon_2(\omega) = \varepsilon_{2\infty} - \frac{\omega_{p2}^2}{\omega(\omega + i\gamma_2)},$$

and at a receipt (3) γ_1, γ_2 directed to the zero. In addition, in (3) denotations are entered:

$$\omega_{fi}^2 = \frac{\omega_{pi}^2}{\varepsilon_{i\infty} + 2\varepsilon_0}; \qquad i = 1,2. \qquad (4)$$
$$\omega_{ei}^2 = \frac{\omega_{pi}^2}{\varepsilon_{i\infty} - \varepsilon_0},$$

With these remarks from equalization (3) frequencies of SP were expected:

$$2\left(\omega_m^{\pm}\right)^2 = \bar{\omega}_{f1}^2 + \bar{\omega}_{f2}^2 \pm \left[\left(\bar{\omega}_{f1}^2 - \bar{\omega}_{f2}^2\right)^2 + 4\bar{\omega}_{f1}^2 \cdot \bar{\omega}_{f2}^2 \frac{(1-\alpha_1)(1-\alpha_2)A_m^2}{\left(1-\alpha_1 A_m^2\right)\left(1-\alpha_2 A_m^2\right)}\right]^{\frac{1}{2}}, \qquad (5)$$

where

$$A_m^2 = \eta_m^2 \frac{R_1^3 R_2^3}{d^6},$$
$$\alpha_{12} = \alpha_1\alpha_2;\ \alpha_i = \frac{\varepsilon_{i\infty}-\varepsilon_0}{\varepsilon_{i\infty}+2\varepsilon_0}; \qquad (6)$$

$$\bar{\omega}_{f1}^2 = \omega_{f1}^2 \frac{1-\alpha_2 A_m^2}{1-\alpha_{12}A_m^2}; \qquad i = 1,2.$$
$$\bar{\omega}_{f2}^2 = \omega_{f2}^2 \frac{1-\alpha_1 A_m^2}{1-\alpha_{12}A_m^2},$$

The equation (5) is a basic formula for the calculation of frequencies of SP in the system of two metallic nanoparticles which are at a distance *d* one from another in the external electric field. Expressions (5) assumes the existence of four values of resonance frequencies of SP.

We will consider the special case, when particles consist of the same material $\varepsilon_1(\omega) = \varepsilon_2(\omega)$, but have different sizes $R_1 \neq R_2$. Then, from equalization (5) find frequencies of superficial plasmons in the system of two particles [3]:

$$\left(\omega_m^{\pm}\right)^2 = \frac{(1 \pm A_m)\omega_f^2}{1 \pm \alpha_0 A_m}, \omega_f = \frac{\omega_p^2}{\varepsilon_\infty + 2\varepsilon_0},$$
$$\varepsilon_1(\omega) = \varepsilon_2(\omega) \equiv \varepsilon(\omega),$$

were

$$\varepsilon(\omega) = \varepsilon_\infty - \frac{\omega_p^2}{\omega^2}, \qquad \Delta = R_2/R_1 \quad (R_2 \leq R_1),$$
$$\alpha_0 = \frac{\varepsilon_\infty - \varepsilon_0}{\varepsilon_\infty + 2\varepsilon_0}, \qquad A_m = \eta_m \Delta^{3/2}(R_1/d)^3,$$

$$\eta_m = \begin{cases} 2,\ m = (0;\ II) \\ 1,\ m = (\pm 1;\ \perp). \end{cases} \qquad (7)$$

Notation II and $\perp$ mean: $\perp$ - the external field of E_0 is directed as perpendicular to the line which connects the centers of particles; II - parallel to this line.

$$(\Delta\omega)^2 \equiv \left(\omega_0^+\right)^2 - \left(\omega_1^-\right)^2 = 3\omega_p^2\left[\frac{(R_1R_2)^{1/2}}{d}\right]^3. \qquad (8)$$

At $R_1 = R_2$ maximal value $\Delta\omega$ arrived at $d = 2R_1$. If $\varepsilon_\infty = \varepsilon_0 = 1$, than

$$\Delta\omega = (1/8)^{1/2}\ \omega_p \sim 0{,}35\,\omega_p. \qquad (9)$$

Note, $\Delta\omega$ makes the one-third part of plasma frequency ω_p of material of SP and is an evaluation. In real systems it is necessary to take into account the electronic fadings (γ_1 , γ_2) and experimental frequency dependences $\varepsilon_1(\omega)$ and $\varepsilon_2(\omega)$. It requires a lot of numeral calculations and it will be conducted in future.

3. Conclusion.

On the basis of our study and the results developed by us, the general theory of interaction of nanoparticles can assert with various surfaces (including biological), that multipole interaction arises up only in presence the external electric field of $\boldsymbol{E_0}$ and it causes the change in electrodynamical properties of both SP and to the surface – redistribution of charges, change in position of peaks and change in intensity of absorption of electromagnetic radiation of the system of nanoparticles, being on-the-spot.

Character of change of processes of absorption and dispersion, depends both nanoparticles and surface on the electrodynamics' parameters of surface and nanoparticles (effective inductivities, physical and chemical state of surface et cetera). It enables us to get information about the physical and chemical parameters of surface on the basis of analysis of light-spectra of absorption of the small particles and molecules adsorbed on them.

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