PLASMONIC CAPACITANCE OF THE GAP BETWEEN TWO CLOSELY SPACED SPHERICAL METAL NANOPARTICLES

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Abstract

The production of high-energy capacitors based on nanoparticles of various geometries is important for storing electrical energy due to their high pulse power and insignificant charge leakage. The collection and storage of electromagnetic energy has practical application in such important areas of human activity as photovoltaics, communications, fiber optics, data storage and integrated optoelectronics. Nanoparticles of noble metals are of considerable interest from this point of view due to strong localization and large magnitude of electric field upon excitation of plasmon resonance [1].

Statement of the problem and results of calculations

When two spherical metal nanoparticles are located at a small distance from each other, the capacitance of the gap between them increases due to strong electromagnetic interaction, which leads to a change in the plasmon modes and the energy of the plasmon resonance. The capacitance of the gap between the nanoparticles, taking into account electron tunneling, is determined by the relation

$$C=\left(\frac{1}{C_c}+\frac{2}{C_Q}\right)^{-1}, \qquad (1)$$

where the mutual capacitance of the metal spheres up to terms of the order of is

$$C_c=\pi\epsilon_0\left|\epsilon(\omega)\right|\frac{R^2}{D}\left(1+\frac{1}{2}\frac{R}{D}+\frac{1}{4}\left(\frac{R}{D}\right)^2+\ldots\right), \qquad (2)$$

and the quantum capacitance is

$$C_Q=\frac{4\pi R^2\epsilon_0}{\ell_{\mathrm{TF}}}. \qquad (3)$$

In formulas (2) and (3), ϵ_0 is the electric constant; R is the radius of the nanoparticle; D is the distance between centers of the particles; ℓ_{TF} is the screening length in a two-dimensional electron gas; $\epsilon(\omega)$ is the dielectric function determined by the Drude model.

Substituting the expression for the Thomas-Fermi screening length, we obtain

$$C_Q=\frac{4eR^2}{\hbar\sqrt{d}}\sqrt{\pi m^*\epsilon_0\left|\epsilon(\omega)\right|}, \qquad (4)$$

where e and m^* are the charge and effective mass of the electron; $d=D-2R$ is the size of the interparticle gap.

Statement of the problem and results of calculations

In the problem under consideration, the Drude model requires the so-called quantum correction, after which the dielectric function takes the form:

$$\epsilon(\omega)=\epsilon^{\infty}-\frac{\omega_p^2}{\omega\left(\omega+i\,\gamma_g(d)\right)}, \qquad (5)$$

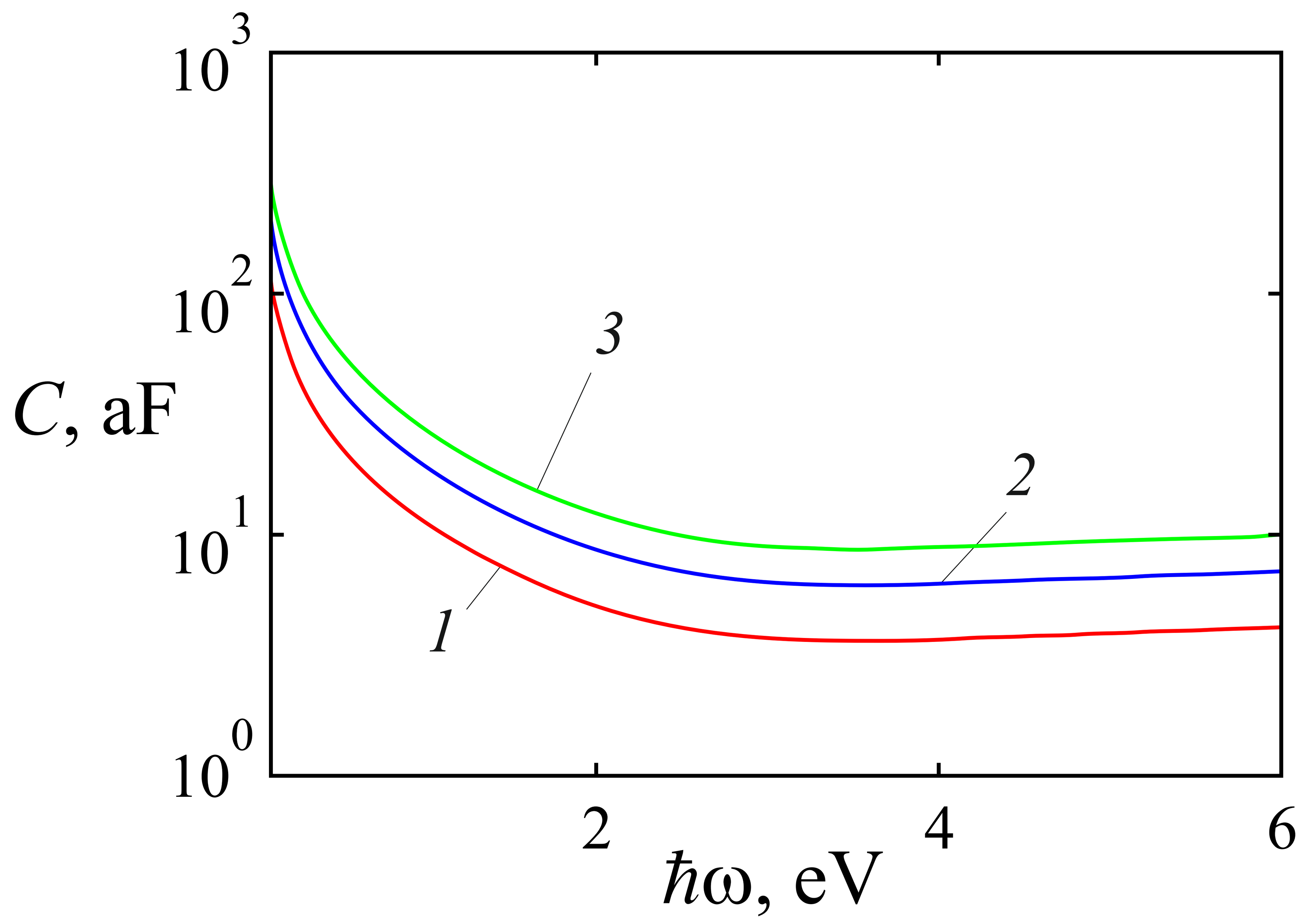
where is the relaxation rate of electrons in the gap

$$\gamma_g(d)=\gamma_{\mathrm{bulk}}\,e^{\frac{d}{l_c}}, \qquad (6)$$

$\gamma_{\mathrm{bulk}}=\mathrm{const}$ – rate of volume relaxation of electrons; $l_c\cong 0.1$ nm – correlation length.

Calculations of the frequency dependence of the plasmonic photocapacitance of the gap were carried out for closely spaced spherical Au nanoparticles of different radii (fig. 1).

Figure 1



Frequency dependences of the plasmonic photocapacitance of the gap between two Au nanoparticles of different radii:
1 – $R=30$ nm;
2 – $R=50$ nm;
3 – $R=70$ nm.

Conclusions

It is shown that for any frequency the capacitance is always greater for a gap between particles of a larger radius. In addition, the photocapacitance in all cases decreases with increasing frequency and reaches a minimum in the optical region of the spectrum.

1. A. Korotun, G. Moroz, R. Korolkov, I. Titov, 2023 IEEE XIIIth International Conference on Electronics and Information Technologies (ELIT) (Lviv, September 26-28, 2023), 320.