ABSORPTION CROSS-SECTION OF TOROIDAL METALLIC NANOPARTICLES

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Abstract

Toroidal-shaped nanostructures have recently found increasing applications in nanooptics [1] and for the creation of the composites with toroidal inclusions, which have the properties of “left-handed” media. Moreover, such particles are used as nanoscale sensors, transformers and resonators [2]. Hence, the task of the studying the optical properties of metallic nanoparticles, which have toroidal shape, is an actual task.

Statement of the problem and results of calculations

The absorption cross-section of the considered nanoparticle is determined by the following relation due to the presence of axial symmetry

$$C_{\text{abs}} = \frac{\omega}{c}\sqrt{\epsilon_{\text{m}}}\,\text{Im}\left(\frac{2}{3}\alpha_{\perp} + \frac{1}{3}\alpha_{\parallel}\right), \quad (1)$$

where ω and c are the frequency and velocity of light; ϵ_{m} is dielectric permittivity of the environment, and $\alpha_{\perp(\parallel)}$ are the diagonal components of the polarizability tensor of toroidal nanoparticle, which are given by the following formula in the frameworks of ϵ-method

$$\alpha_{\perp(\parallel)} = \frac{\epsilon^{\perp(\parallel)}(\omega) - \epsilon_{\text{m}}}{4\pi\epsilon_{\text{m}}}\sum_{l} C^{l}_{\perp(\parallel)} \frac{\epsilon_{l}^{\perp(\parallel)} - \epsilon_{\text{m}}}{\epsilon_{l}^{\perp(\parallel)} - \epsilon^{\perp(\parallel)}(\omega)}. \quad (2)$$

In formula (2) $\epsilon_{l}^{\perp(\parallel)}$ – the values of the components of the dielectric tensor at the frequencies of the transverse and longitudinal plasmon resonances of multipoles l, summation is carried out over all multipoles; $\epsilon^{\perp(\parallel)}(\omega)$ – the diagonal components of the dielectric tensor of the nanoparticle material, determined by the Drude formula

$$\epsilon_{l}^{\perp(\parallel)}(\omega) = \epsilon^{\infty} - \frac{\omega_p^2}{\omega\left(\omega + i\gamma_{\text{eff}}^{\perp(\parallel)}\right)}, \quad (3)$$

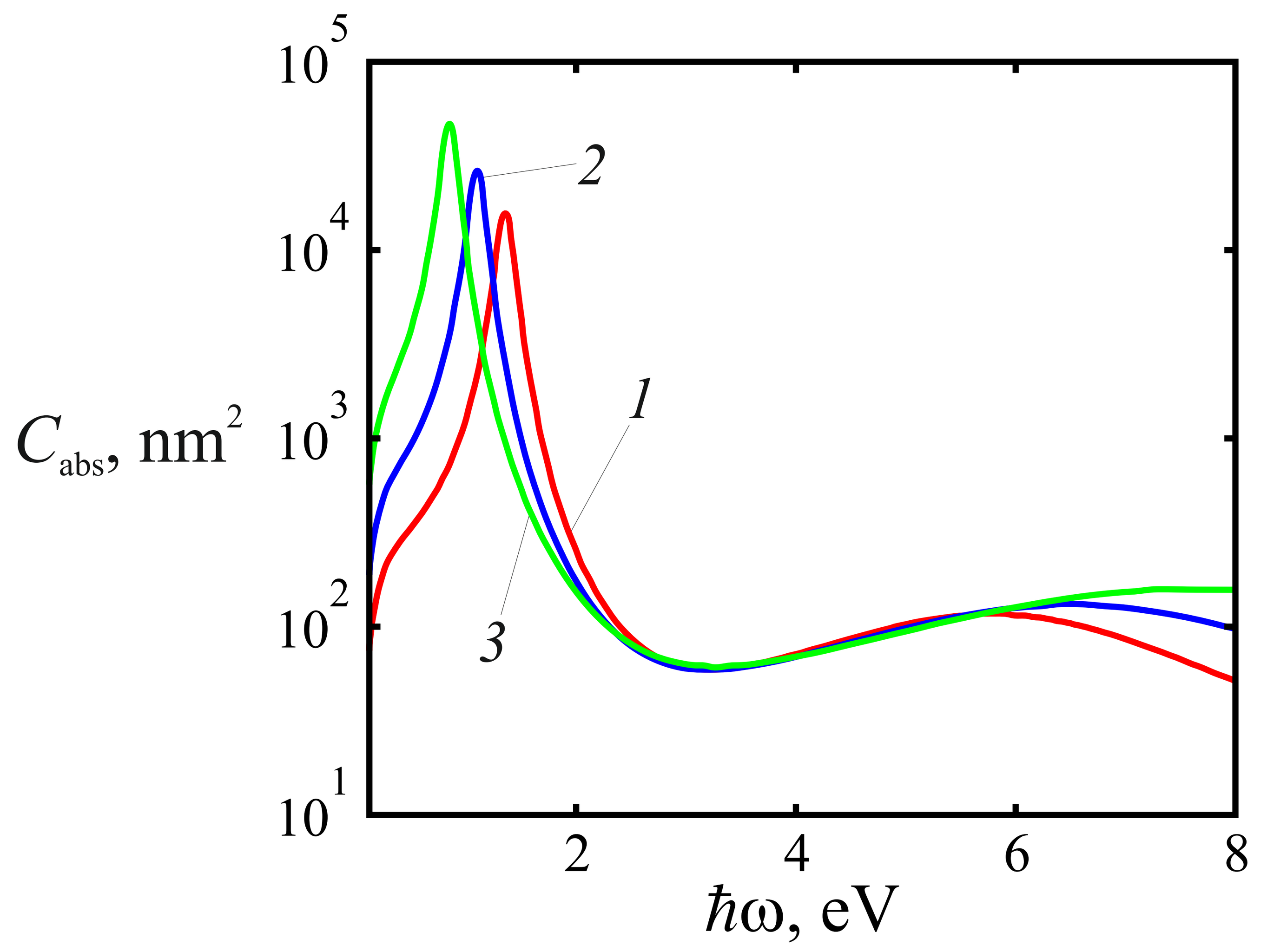
where ϵ^{∞} is the contribution of interband transitions to the dielectric permittivity, ω_p is the plasma frequency, $\gamma_{\text{eff}}^{\perp(\parallel)}$ – the diagonal components of the effective relaxation rate tensor; $C^{l}_{\perp(\parallel)}$ – geometric factors determined by volume integrals of the intensity of electric fields

$$C^{l}_{\perp(\parallel)} = \frac{\int_V \mathscr{E}_{\perp}^{\,l}\,dV \int_V \mathscr{E}_{\parallel}^{\,l}\,dV}{\int_V \left(\mathscr{E}_{\perp}^{\,l} + \mathscr{E}_{\parallel}^{\,l}\right)dV}, \quad (4)$$

$\mathscr{E}_{\perp}^{l}$, $\mathscr{E}_{\parallel}^{l}$ – transverse and longitudinal components of electric field strengths of multipolarity.

Calculations of the frequency dependences of the absorption cross section were carried out in the dipole approximation for toroidal Ag nanoparticles with different values of the cross section radius (Fig. 1).

Figure 1



Frequency dependences of the absorption cross section of Ag nanotoroids with different values of the cross section radius (R = 60 nm): *1* – *r* = 10 nm; *2* – *r* = 20 nm; *3* – *r* = 30 nm.

Conclusions

The presence of two maxima corresponding to dipole transverse and longitudinal surface plasmon resonances is demonstrated. It is shown that the broadening of $C_{\text{abs}}^{\max}$, corresponding to the longitudinal resonance, is small and practically does not change when the cross-sectional radius of the torus changes, while the broadening of the maximum corresponding to the transverse resonance decreases with an increase in the cross-sectional radius.

References

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