Influence of quantum-dimensional effects on field localization in a planar DLC structure with embedded plasmon nanoparticle

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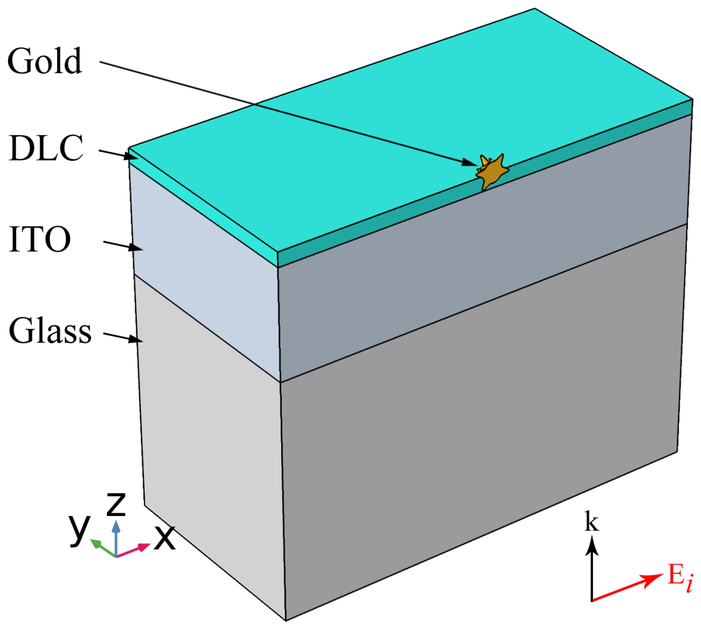
ABSTRACT

Aspects of stimulating the formation of field localization zones in DLC film structures by introducing plasmonic gold nanoparticles are discussed. This increases the sensitivity of structures to optical radiation. It is theoretically shown that taking into account the size factors leads to a noticeable change in the parameters of the quantum transport of electrons. The features of field localization on complex interfaces "gold nanoparticle-DLC-vacuum" under irradiation with a laser beam are investigated.

Formulation of the problem



Helmholtz equation:

$$\nabla \times \mu_r^{-1} (\nabla \times \mathbf{E}) - k_0^2 \varepsilon \mathbf{E} = 0.$$

$\mathbf{E}_i = E_0 e^{-ik_0 n_m z}$ - incident plane monochromatic wave

Dielectric function ε of bulk gold corrected by Δε for size-dependent electron scattering:

$$\varepsilon_{NSt}(\omega, r) = \begin{cases} \varepsilon(\omega, r), & r \in V_{core}, \\ \varepsilon(\omega, r) + \Delta\varepsilon\left(\omega, L_{eff}\right), & r \in V_{spike}, \end{cases}$$

$$\Delta\varepsilon\left(\omega, L_{eff}\right) = \frac{\omega_p^2}{\omega^2 + i\omega\gamma_b} - \frac{\omega_p^2}{\omega^2 + i\omega(\gamma_b + A_s v_f / L_{eff})},$$

ω_p - the plasma frequency; γ_b- the damping constant of bulk gold; A_s- parameter, takes into account the surface-electron scattering and CID contributions; v_f - the Fermi velocity; L_{eff}– effective path length.

[NG Khlebtsov, SV Zarkov, V Khanadeev, YA Avetisyan, Nanoscale, 2020, DOI: 10.1039/D0NR02531C]

Simulation results and discussion

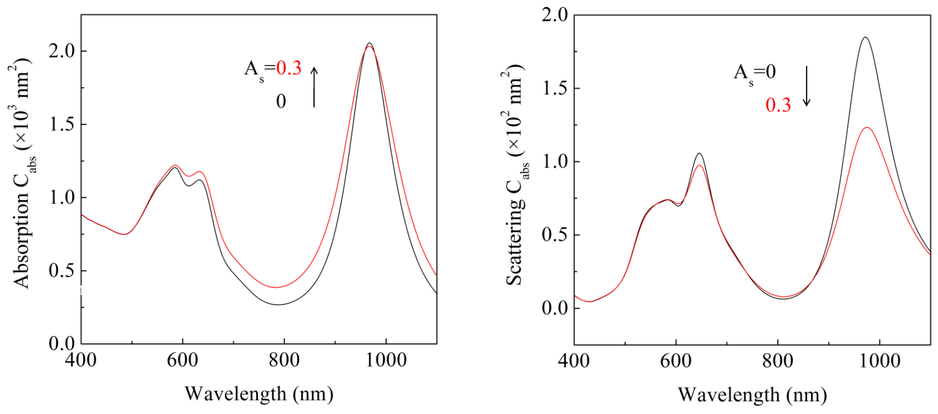


Figure 1. Spectral depedences of the absorption and scattering cross-section of gold nanostar (the core diameter is 28 nm, the spike length and spike base width is 10 nm, the tip curvative radius is 1.5 nm, the total number of spikes is 12), effective path length calculated according by Coronado-Schatz model and taken equal 6 nm.

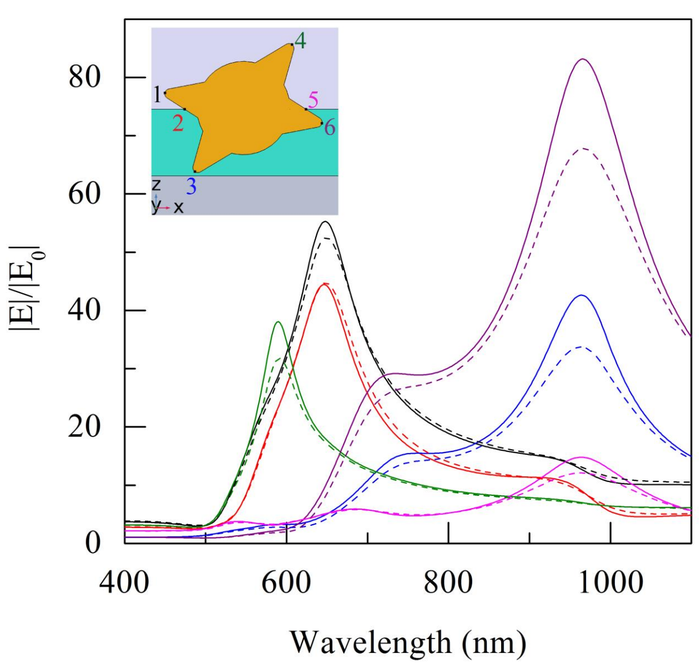


Figure 3. Spectral depedences of the normalized modulus of electric field in points showed on inset.

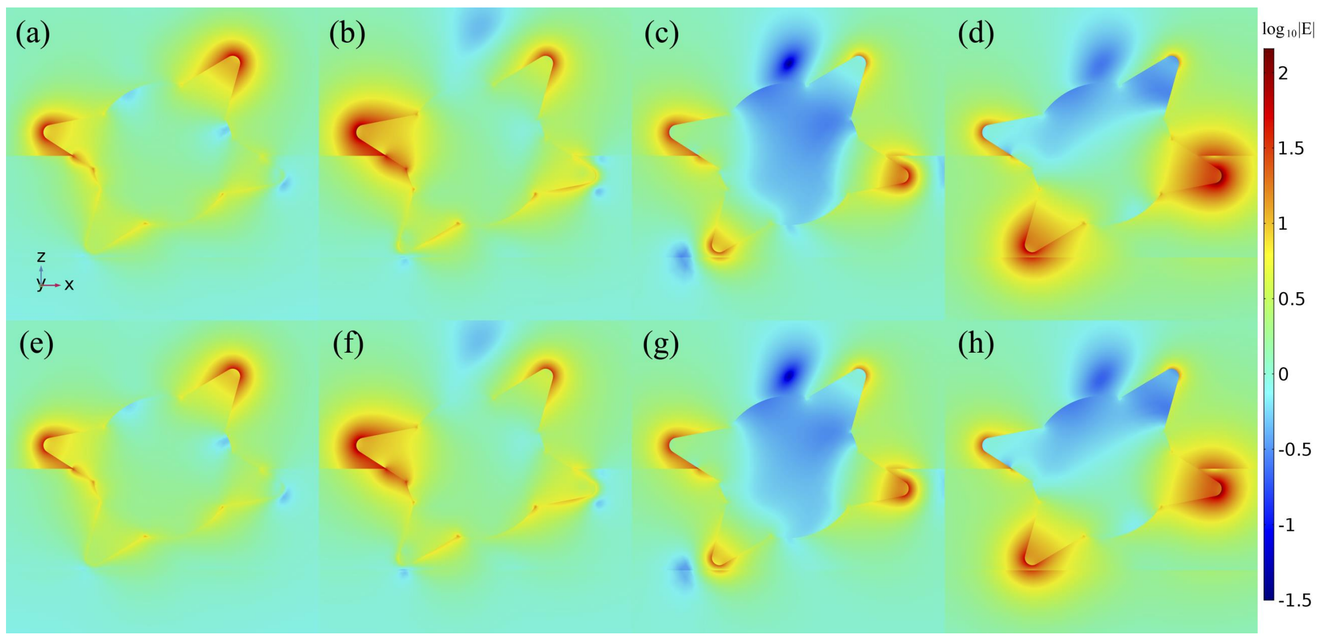


Figure 2. 2D slices of normalized electric field at 584 nm (a, e); 634 nm (d, f); 808 (c, g); 970 nm (d, h) calculated for bulk (a, b, c, d) and size-corrected (e, f, g, h) dielectric function of spikes.

The results in Fig. 1 allow one to identify three resonant wavelengths of the structure under study the functions of integral absorption and scattering at which have local maxima. These are λ = 584 nm, λ = 634 nm and λ = 970 nm. The splitting of the initially single peak is associated with the breaking of the symmetry of the structure upon immersion of the nanostar into the DLC film. It is seen that taking into account the size correction does not lead to a noticeable change in the spectral dependence in the absorption cross section. The scattering cross section decreases approximately 1.5 times only in the region of the long-wavelength extremum.

Slices in Fig. 2 demonstrate how the localization zones are redistributed along different spikes of the nanostar with a change in the wavelength of the laser irradiation. In addition to the sharpness, localization zones are also observed on the exit / entry lines of the spikes into the DLC film.

The localization zones of the field strength are indicated in Fig. 3 by dots numbered 1-6. From the data shown in Fig. 3, it follows that taking into account the size correction, as in the case with the scattering cross section, decreases noticeably (by a factor of 1.2-1.3) only at a wavelength of λ = 970 nm.

The absolute maximum of the field strength corresponds to the vicinity of the spike immersed in the DLC film, the tip of which is located near the surface (point 6).

CONCLUSIONS

A model is proposed and a numerical simulation of the spectral properties and localization of the field under irradiation of the DLC film system with embedded gold nanoparticles is performed. The appearance of additional maxima with a significant detuning from the main one, associated with the plasmon properties of the spikes of the nanostar and depending on the degree of their immersion in the film, is revealed. Taking into account the dimensional dependences leads to a noticeable change in the degree of field localization only for resonances in the IR range.

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