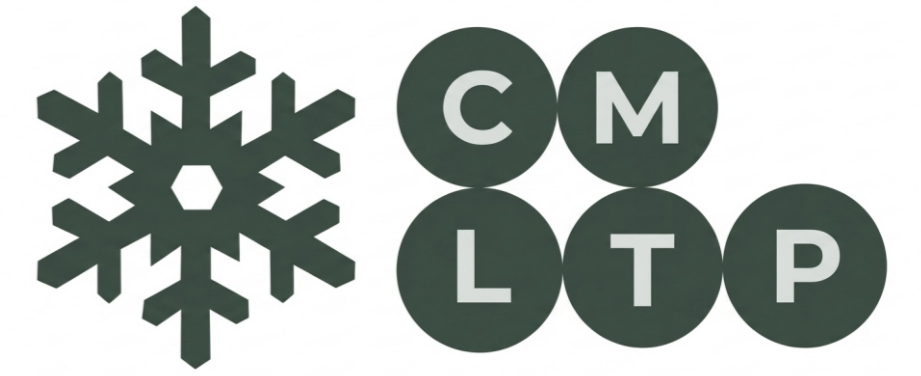




PLASMONIC ENHANCEMENT OF PHOTOEMISSION IN NEW-GENERATION SOLAR CELLS



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Abstract

Increasing the efficiency of the solar cells is a fundamental problem in modern photovoltaics. One promising approach to solving this problem is to modify the absorbing semiconductor layer of the solar cells with the metallic nanoparticles. The main idea of this approach is that the excitation of the plasmon resonances on the surfaces of the nanoparticles results in the enhancement of the local electric fields and the generation of the hot charge carriers. In this case, the hot carriers are injected into the semiconductor absorbing layer, amplifying the photocurrent. It should be pointed out that in works [1, 2], the amplification of the current in the photocell due to the excitation of the surface plasmon resonance and the change in the photoemission cross-section when changing the size of the metallic nanoparticles embedded into the semiconductor layer were investigated. However, the influence of the optical phenomena in the semiconductor layer itself on the physical and technical characteristics of the solar cells has not been studied, and therefore these issues remain relevant.

Statement of the problem

The paper shows that the photoemission cross-section is proportional to the enhancement factor of the local electric fields, which, in turn, depends on the dielectric functions of the nanoparticle and absorbing layer materials. In order to determine these functions, the Drude and Lorentz–Tauc models are used [3]:

$$\epsilon(\omega) = \epsilon^\infty - \frac{\omega_p^2}{\omega(\omega + i\gamma_{\text{eff}})} \quad (1)$$

$$\epsilon_m(\Omega) = \epsilon_m^\infty + \sum_{i=1}^3 C_i \left[1 - \left(\frac{\Omega}{E_i} \right)^2 - i \frac{\Omega}{E_i} \gamma_i \right]^{-1} - F_1 \frac{\ln(1 - \chi_1^2(\Omega))}{\chi_1^2(\Omega)} - \frac{F_2}{\chi_2^2(\Omega)} \ln \frac{1 - \chi_1^2(\Omega)}{1 - \chi_2^2(\Omega)}, \quad (2)$$

where

$$\chi_i(\Omega) = \frac{\Omega + i\Gamma_i}{E_i} \quad (3)$$

For Si: $\epsilon_m^\infty = 0.2$; $\Omega = \omega/\omega_p$; $C_1 = 0.77$, $C_2 = 2.96$, $C_3 = 0.3$; $F_1 = 5.52$, $F_2 = 4$; $\gamma_1 = 0.05$, $\gamma_2 = \gamma_3 = 0.10$; $E_1 = 3.38$, $E_2 = 4.27$, $E_3 = 5.3$; $\Gamma_1 = 0.08$, $G_2 = 0.1$.

In addition, the work takes into account the relaxation processes in the metallic nanoparticles.

$$\gamma_{\text{eff}} = \gamma_{\text{bulk}} + \gamma_s + \gamma_{\text{rad}} \quad (4)$$

In formula (4), $\gamma_{\text{bulk}} = \text{const}$ is the bulk relaxation rate, and the surface relaxation rate and the radiation damping rate have the form

$$\gamma_s = \mathcal{N}(\omega, R) \frac{v_F}{R} \quad (5)$$

$$\gamma_{\text{rad}} = \frac{V}{6\pi} \sqrt{\frac{\epsilon^\infty + 2\epsilon_m}{\epsilon_m}} \left(\frac{\omega_p}{c} \right)^3 \mathcal{N}(\omega, R) \frac{v_F}{R} \quad (6)$$

where v_F is Fermi electron velocity, and the relation for the coherence loss parameter has the form

$$\mathcal{N}(\omega, R) = \frac{3}{4} \frac{1}{\epsilon^\infty + 2\epsilon_m} \left(\frac{\omega_p}{\omega} \right)^2 \left[1 - \frac{2v_s}{\omega} \sin \frac{\omega}{v_s} + 2 \left(\frac{v_s}{\omega} \right)^2 \left(1 - \cos \frac{2\omega}{v_s} \right) \right] \quad (7)$$

$v_s = v_F/2R$ is the frequency of the individual oscillations of electrons.

Results of calculations and conclusions.

The results of the numerical experiments indicate the advisability of using small-radius gold nanoparticles to modify absorbing semiconductor layers in order to obtain the maximum photoemission cross-section.

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3. S. Adachi, H. Mori, and S. Ozaki, Phys. Rev. B. 66, 153201 (2002).