IMPROVEMENT OF QUANTUM EFFICIENCY OF PHOTODETECTORS BY INTRODUCING PLASMONIC NANOPARTICLES

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Abstract

In recent years plasmonic nanoparticles have found wide application to improve the efficiency of photodetectors by increasing light extraction by amplifying local electric fields or directly converting absorbed photons into electrical energy by transferring hot charge carriers from plasmonic metals to semiconductor receptors. Hence, the problem connected with the influence of plasmonic effects in metallic nanoparticles on the physical and technical characteristics of photodetectors is actual.

Statement of the problem and results of calculations

The most important characteristic of photodetectors, in which the thickness of the semiconductor layer is significantly greater than the radius of the nanoparticle, is their quantum efficiency, defined by the relation

$$\eta = \frac{\mathcal{A}}{8\varepsilon_F}\frac{(h\omega - e\varphi_B)^2}{h\omega}, \qquad (1)$$

where ε_F is Fermi energy; φ_B is the height of Schottky barrier at the interface "metal – semiconductor"; ω is the frequency of light, and the absorption coefficient at $\gamma_{eff} \ll \omega \ll \omega_p$ (in the working area of photodetectors – near infrared and visible regions) is determined by the formula

$$\mathcal{A} = \frac{2\gamma_{eff}}{\omega_p}. \qquad (2)$$

In formula (2) ω_p is plasma frequency, and the effective relaxation rate of electrons in spherical nanoparticle γ_{eff} is determined by the additive contribution of bulk relaxation, surface relaxation and radiation damping [1]

$$\gamma_{eff} = \gamma_{bulk} + \frac{\mathcal{K}}{\omega^2}, \qquad (3)$$

where γ_{bulk} = const for specific metal;

$$\mathcal{K} = \frac{1}{4}\omega_p^2\frac{v_F}{R}\left[1 + \frac{V}{6\pi\sqrt{\epsilon_m}\left(\epsilon^\infty + 2\epsilon_m\right)}\left(\frac{\omega_p}{c}\right)^3\right], \qquad (4)$$

c is light velocity; v_F is Fermi electron velocity; R and V are the radius and volume of nanoparticle; ϵ_m is dielectric permittivity of semiconductor medium; ϵ^∞ is the contribution of the crystal lattice into the dielectric function of metal.

Calculations of frequency and size dependences of quantum efficiency were carried out for spherical Pt and Ag nanoparticles embedded in Si matrices (Fig. 1). The calculation results indicate that in the considered range of frequencies and radii of plasmonic nanoparticles, the maximum quantum efficiency will be for silicon photodetectors modified with Pt nanoparticles.

Figure 1, *a*

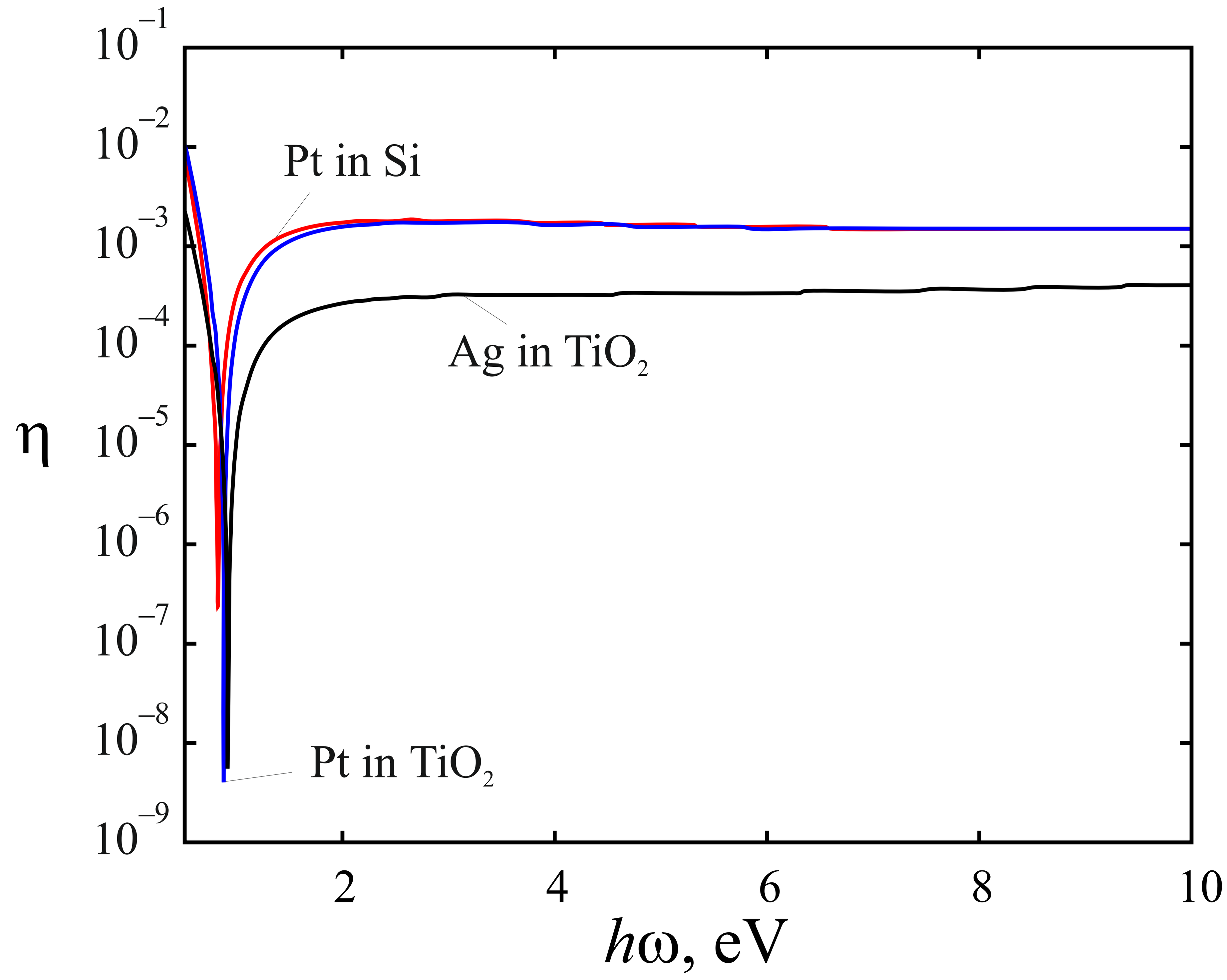
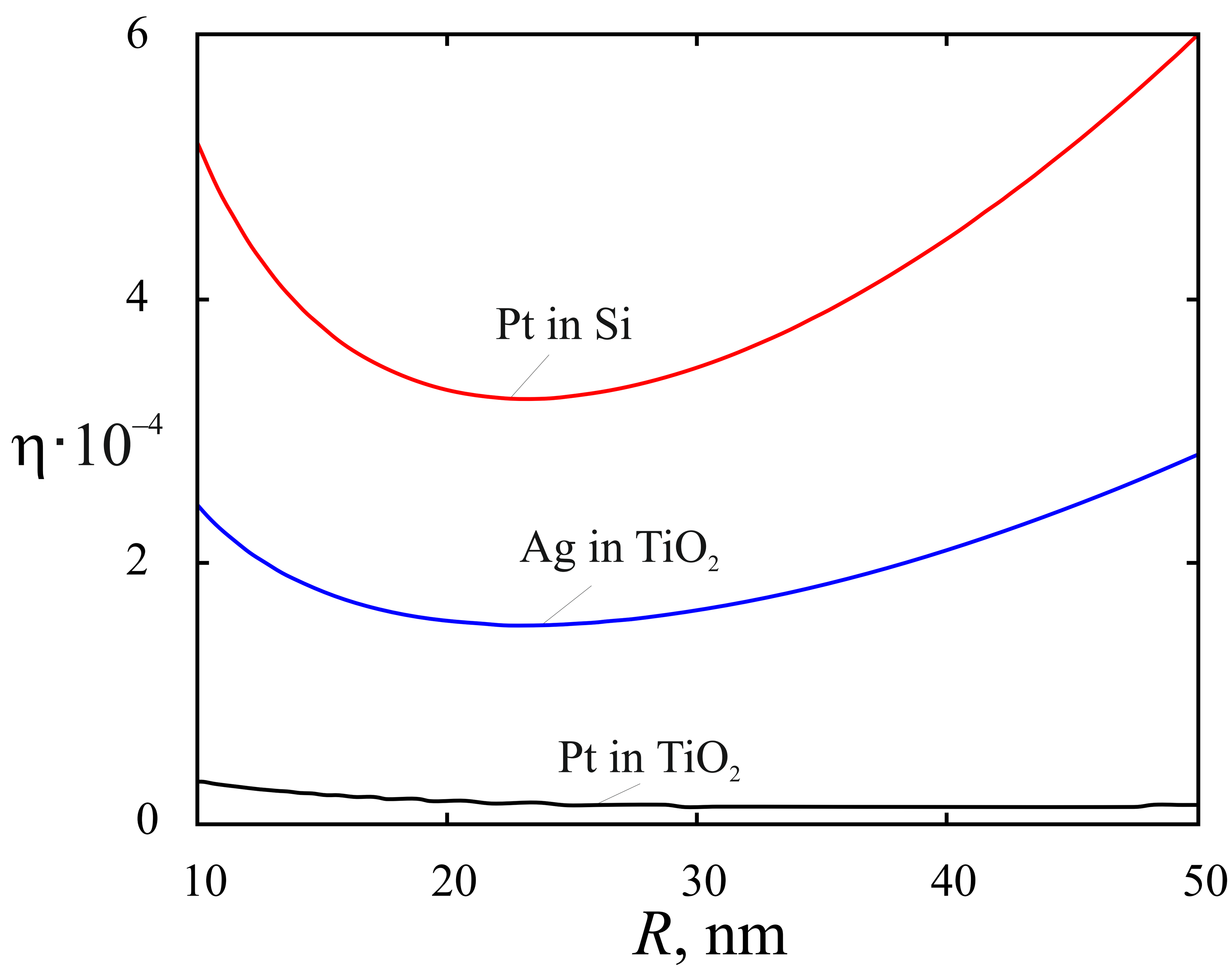


Figure 1, *b*



Frequency (*a*) and size (*b*) dependences of the quantum efficiency of spherical Pt and Ag nanoparticles embedded in different matrices:
1 – Pt in Si;
2 – Pt in TiO_2;
3 – Ag in TiO_2

Conclusions

The feasibility of using silicon as photodetector matrices and modifying such matrices with Pt nanoparticles has been established, since such photodetectors have high quantum efficiency.