RADIATION EFFICIENCY OF AN ENSEMBLE OF DISK-SHAPED PLASMONIC NANOPARTICLES

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Abstract

Ensembles of metal nanoparticles of various shapes are widely used nowadays, in particular, to increase the efficiency of light absorption by thin film solar cells due to the excitation of localized surface plasmon resonance. Therefore, the study of the optical properties of ensembles of metal nanoparticles of different shapes, compositions, and morphologies is an urgent task.

Statement of the problem and results of calculations

An important characteristic of ensembles of nanoparticles is the radiation efficiency, i.e., a value that indicates how much absorption capacity of the ensemble is.

The radiation efficiency is determined by the expression

$$\xi_{\mathrm{rad}} = \frac{\langle Q_{\mathrm{abs}} \rangle}{\langle Q_{\mathrm{abs}} \rangle + \langle Q_{\mathrm{sca}} \rangle} \qquad (1)$$

where $\langle Q_{\mathrm{abs}} \rangle$ and $\langle Q_{\mathrm{sca}} \rangle$ are averaged efficiencies of absorption and scattering of an ensemble, directly proportional to the averaged absorption and scattering cross sections $\langle C_{\mathrm{abs}} \rangle$ and $\langle C_{\mathrm{sca}} \rangle$, so

$$\langle Q_{\mathrm{abs}} \rangle = \frac{\langle C_{\mathrm{abs}} \rangle}{S} \qquad \langle Q_{\mathrm{sca}} \rangle = \frac{\langle C_{\mathrm{sca}} \rangle}{S} \qquad (2)$$

where S is the equivalent cross-sectional area, which in the case of disk nanoparticles is determined by the expression

$$S = \pi R_{\mathrm{eq}}^2 \qquad (3)$$

and the equivalent radius is found from the condition of equality of the volumes of the sphere and the disk and is equal

$$R_{\mathrm{eq}} = \frac{1}{2}\sqrt[3]{D^2 H} \qquad (4)$$

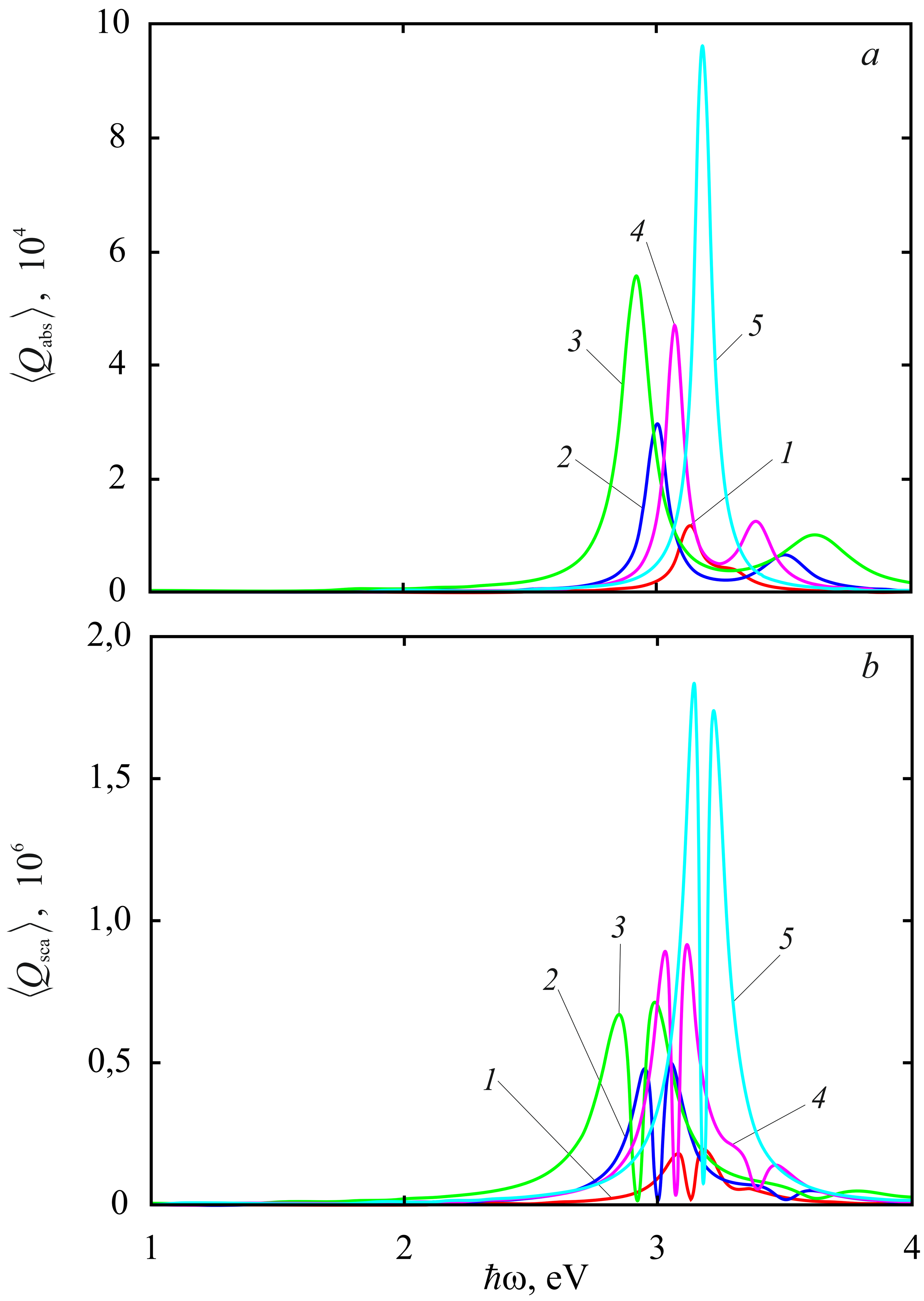
where D and H – diameter and height of the disc.

Calculations were made for organic solar cells ($\epsilon_m = 2.3$) з Au nanoparticles in the form of disks of different sizes introduced into them.

In fig. 1 shows the frequency dependences of the ensemble-averaged absorption and scattering efficiency for solar cells with disk nanoparticles of different sizes. The curves of the frequency dependences of the averaged absorption efficiency in the case of the introduction of disk particles have two maxima corresponding to the longitudinal and transverse surface plasmon resonances. In the latter case, with a decrease in the aspect ratio (both due to a decrease in diameter and an increase in height), there are "blue" shifts in the maxima of the averaged absorption efficiency. In addition, as the aspect ratio increases, the magnitude of the first maximum will increase and the magnitude of the second maximum will decrease.

The behavior of $\langle Q_{\mathrm{sca}}(\omega) \rangle$ is similar to that of $\langle Q_{\mathrm{abs}}(\omega) \rangle$, with the differences being larger values of the magnitude of the maxima and smaller values of the distances between the maxima of $\langle Q_{\mathrm{sca}}(\omega) \rangle$.

Figure 1



Frequency dependences of the average absorption (*a*) and scattering (*b*) efficiency of ensembles of metal nanodisks of different sizes:
1 – D = 50 nm; H = 10 nm;
2 – D = 100 nm; H = 10 nm;
3 – D = 200 nm; H = 10 nm;
4 – D = 100 nm; H = 15 nm;
5 – D = 100 nm; H = 25 nm;

Conclusions

Expressions for the absorption and scattering efficiencies, the radiation efficiency, and the reflection coefficient in the Kubelka-Munk approximation were obtained.

It is shown that the dependence of the amplitudes of extrema and their positions on the aspect ratio is characteristic of the optical characteristics of batteries with introduced disk particles.

It was established that the ensemble-averaged scattering efficiency at any frequency outweighs the averaged absorption efficiency, which indicates the promising approach to improving the properties of modern solar cells due to the introduction of metal nanoparticles into the semiconductor medium.