FREQUENCY SPLITTING OF SURFACE PLASMON RESONANCE IN A CYLINDRICAL SHELL OF VARIABLE THICKNESS

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Abstract

The spectral position of surface plasmon resonances (SPR) depends on the size, shape of nanoparticles, their composition, and the dielectric constant of the environment. Therefore, the number and position of surface plasmon resonance peaks can be easily adjusted by manipulating the size and shape of nanoparticles, as well as their composition. The use of layered structures of the "core-shell" (A@B) type, in which the core of material A is covered with a shell of material B, where both material B can act as a dielectric and another metal, is more promising. Among the various forms of nanoparticles, cylindrical nanoshells attract great attention [1] due to their high spectral rearrangement in the windows of biological transparency, as well as the existence of a large number of new synthesis methods that allow controlling the size, morphology, and surface area of such structures. Note that it is technologically very difficult to obtain shells of constant thickness during the synthesis of such structures. In this regard, the study of the optical properties of metallic cylindrical shells of variable thickness is of great practical interest and is an urgent task.

Statement of the problem and results of calculations

In the case when dissipation can be neglected, we have four branches of SPR frequencies

$$\omega_{sp}^{(1,2)(\pm)} = \frac{\omega_p}{\sqrt{\epsilon^{\infty} - \epsilon_s^{(1,2)(\pm)}}} \qquad (1)$$

where ω_p is the plasma frequency; ϵ^{∞} is the contribution of the crystal lattice to the dielectric constant.

Since $\epsilon_s^{(1,2)(\pm)}$ is a size-dependent functions (depends on the radii of the cylinders and the distance between their axes), the corresponding SPR frequencies will also be dimension-dependent.

Expressions for $\epsilon_s^{(1,2)(\pm)}$ have the form

$$\epsilon_s^{(1,2)(\pm)} = -\frac{(\epsilon_c+\epsilon_m)(1+x_{1,2})}{2(1-x_{1,2})} \pm \frac{\sqrt{(\epsilon_c^2+\epsilon_m^2)(1+x_{1,2})^2 - 2\epsilon_c\epsilon_m(1-6x_{1,2}+x_{1,2}^2)}}{2(1-x_{1,2})} \qquad (2)$$

where ϵ_c and ϵ_m – dielectric permittivity of the material of the core and the surrounding medium;

$$x_{1,2} = \frac{1}{2}(\vartheta^4+\vartheta^2) + \vartheta^2\delta^2 \pm \frac{1}{2}\vartheta^2\sqrt{(1-\vartheta^2)^2 + 4\delta^2(1+\vartheta^2+\delta^2)} \qquad (3)$$

$$\vartheta = \frac{a}{b} < 1 \qquad \delta = \frac{d}{b} < 1 \qquad (4)$$

a and b – radii of the inner and outer cylinders; d – distance between cylinder axes.

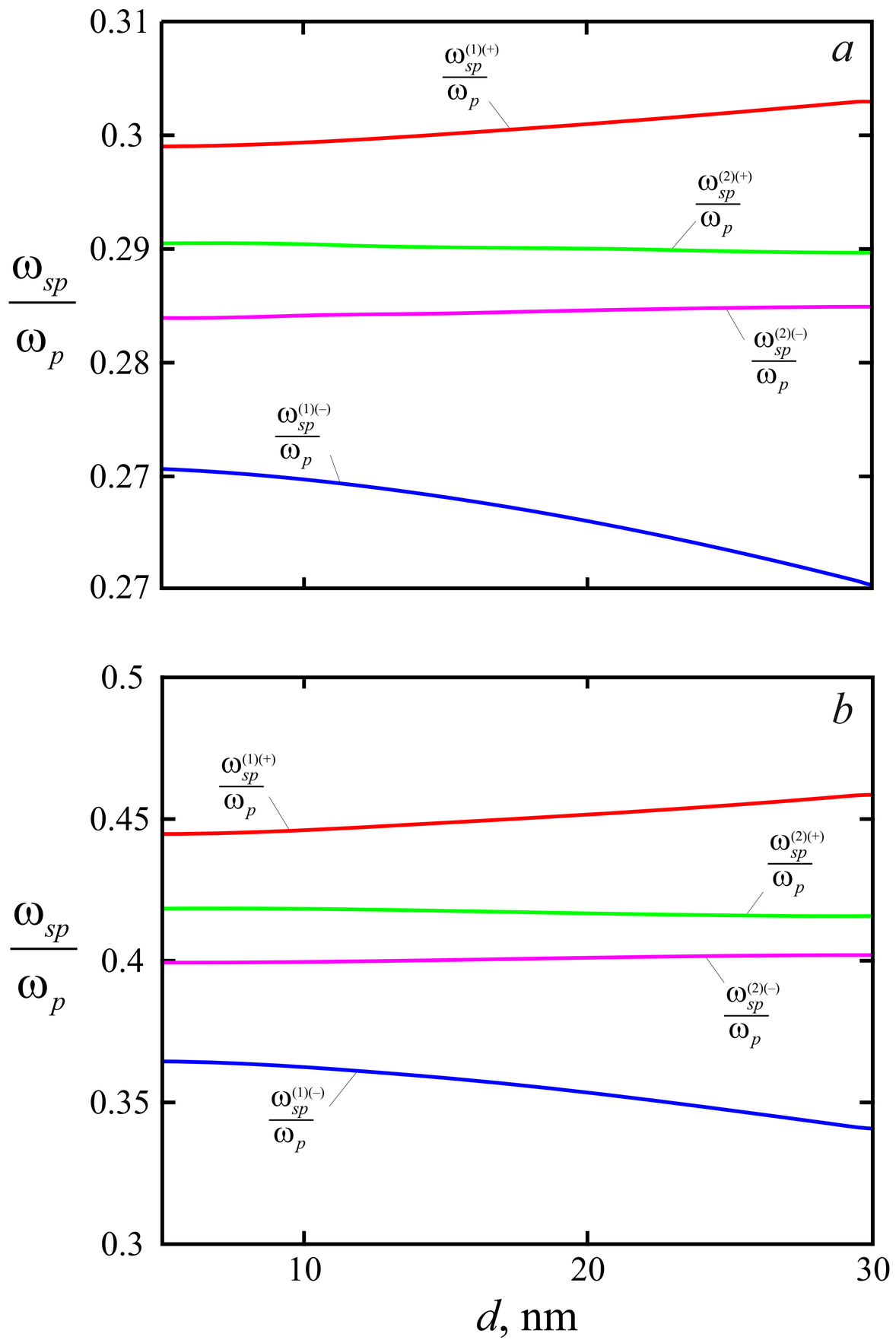
Splitting of SPR frequencies, when the materials of the core and surrounding medium are air (ϵ_c=ϵ_m=1) with accuracy up to the fourth power according to ϑ and δ are determined by the expressions

$$\omega_{sp}^{(1)} = \omega_{sp}^{(1)(+)} - \omega_{sp}^{(1)(-)} = \frac{2\omega_p\vartheta(1+\delta^2)}{(\epsilon^{\infty}+1)^{3/2}} \qquad (5)$$

$$\omega_{sp}^{(2)} = \omega_{sp}^{(2)(+)} - \omega_{sp}^{(2)(-)} = \frac{2\omega_p\vartheta^2}{(\epsilon^{\infty}+1)^{3/2}} \qquad (6)$$

Calculations of the dimensional dependence of the SPR frequencies were carried out for structures SiO_2@Au and SiO_2@Ag (Fig. 1). Qualitatively, the nature of the dependencies of $\omega_{sp}^{(1,2)(\pm)}(d)$ with different shells is similar. Cleavage of $\Delta\omega_{sp}^{(1)}$ is noticeable, while $\Delta\omega_{sp}^{(2)}$ is constant and very small. This is confirmed by the approximate formulas (5) and (6), according to which $\Delta\omega_{sp}^{(1)}$ increases with an increase in δ, and accordingly d, and $\Delta\omega_{sp}^{(2)}$ in the first non-zero approximation does not depend on the distance between the axes of the cylinders.

Figure 1



Frequency dependences of surface plasmons in nanocylinders SiO_2@Au (*a*) and SiO_2@Ag (*b*) with a = 10nm, b = 40nm in Teflon (ϵ_m = 2.3).

Conclusions

It was established that, unlike the case of a shell of constant thickness, where there are two branches of SPR frequencies, in the case of a shell of variable thickness there are four branches of these frequencies due to the additional splitting of SPR frequencies due to the mismatch of the cylinders.

It is shown that for one pair of SPR frequencies there is an increase in the splitting with increasing distance between the cylinder axes, while for the second pair this splitting is a very small constant value. In addition, the nature of the dimensional dependence of the SPR frequencies for shells of different metals is qualitatively similar, and the differences are quantitative.

References

[1] S.A. Scherbak, A.A. Lipovskii, J. Phys. Chem. C, 122, 15635 (2018).