MASKING OF NANOPARTICLES WITH THE HELP OF MULTILAYER CYLINDRICAL COATINGS

R. Yu. Korolkov[1], **A. V. Korotun**[1,2], **V. M. Matiushyn**[1], **R. V. Fliahin**[1]

[1]*National University Zaporizhzhia Politechnic, 64 University Str., Zaporizhzhia 69011, Ukraine*

[2]*G.V. Kurdyumov Institute for Metal Physics of the NAS of Ukraine,36 Academician Vernadsky Blvd., Kyiv 03142, Ukraine*

Abstract

The study of the possibility of creating invisible coatings of different geometries has been significantly developed after the publication of pioneering works [1, 2], in which it was proposed to use spatial transformation to realize the invisibility of material objects (the concept of "wave flotation"). One approach to achieving near-perfect invisibility is based on transformational optics and requires the use of materials with inhomogeneous and anisotropic dielectric and magnetic permittivities. This is impossible without the use of metamaterials, which, as a rule, have narrow bandwidths, high losses and other practical difficulties when used in the optical frequency range, and are therefore used in the microwave range. In this regard, an alternative approach, which consists in the reduction of scattering by plasmonic or dielectric layered structures, is actual.

Statement of the problem and results of calculations

It is known that the nanostructure does not contribute to the scattered field and does not absorb the energy of light wave if its absorption and scattering cross-sections are equal to zero, which is equivalent to the fact that the polarizability of the nanostructure is equal to zero. In turn, the polarizability can be found by solving the electrostatics boundary value problem, which for the three-layer cylindrical nanoparticle consists of Laplace equations for each layer and the space outside the nanostructure

$$\Delta\varphi_i = 0, \qquad (i = 1, 2, 3, 4) \tag{1}$$

where φ_i is the electrostatic potential in the i-th region of space, and boundary values

$$\varphi_1\big|_{r=a} = \varphi_2\big|_{r=a}, \quad \varphi_2\big|_{r=b} = \varphi_3\big|_{r=b}, \quad \varphi_3\big|_{r=R} = \varphi_4\big|_{r=R},$$
$$\epsilon_1 \frac{\partial\varphi_1}{\partial r}\bigg|_{r=a} = \epsilon_2 \frac{\partial\varphi_2}{\partial r}\bigg|_{r=a}, \quad \epsilon_2 \frac{\partial\varphi_2}{\partial r}\bigg|_{r=b} = \epsilon_3 \frac{\partial\varphi_3}{\partial r}\bigg|_{r=b}, \quad \epsilon_3 \frac{\partial\varphi_3}{\partial r}\bigg|_{r=R} = \epsilon_4 \frac{\partial\varphi_4}{\partial r}\bigg|_{r=R}, \tag{2}$$

the internal (masked) shell (region $0 < r \le a$) has permittivity ϵ_1, the shielding shell (region $a < r \le b$) and the shell, which compensates the scattering (region $b < r \le R$) – permittivities ϵ_2 and ϵ_3, and the entire nanostructure is placed in medium (region $R > r$) with permittivity ϵ_4. Here a, b and R are the radii of the first, second and third cylindrical regions, r is the current radial coordinate.

Statement of the problem and results of calculations

The results of the calculations show that the masking (electric field shielding) in the axis region of the cylindrical nanostructure is possible in two cases. The first case is shielding by the layer with quasi-zero permittivity ($\epsilon_2 \to 0$), which cannot be obtained from transformational optics because it corresponds to the excitation of resonant plasmon in the shielding layer (plasmonic masking). The second case – $|\epsilon_2| \to \infty$, which is predicted by transformational optics and corresponds to the presence of the dielectric permittivity singularity, can be realized with the help natural materials.

For cases $\epsilon_2 \to 0$ and $|\epsilon_2| \to \infty$ the optimal thicknesses of compensating layers (shells) are determined, when maximum masking takes place

$$b = R\sqrt{\frac{\epsilon_3 - \epsilon_4}{\epsilon_3 + \epsilon_4}}; \qquad b = R\sqrt{\frac{\epsilon_4 - \epsilon_3}{\epsilon_4 + \epsilon_3}}. \tag{3}$$

It should be noted that for the case of plasmonic cloaking $\epsilon_3 > \epsilon_4$, and for the case corresponding to the singularity of the permittivity, $\epsilon_3 < \epsilon_4$. For some values of ϵ_3 and ϵ_4, the values b_{opt} (in units of R) are given in Table 1.

Conclusions

Thus, the polarizability of a three-layer cylindrical shell is found in the work, the relationships between the parameters corresponding to the condition of equality of polarizability to zero are determined. For two cases of cloaking (plasmonic cloaking and cloaking by a singular layer), the thicknesses of the compensating layers are determined.

Table 1. Calculated values b_{opt} (in units R) for the cases of plasmonic cloaking and permittivity singularity

Parameter	$\epsilon_2 \to 0$				$\lvert\epsilon_2\rvert \to \infty$			
ϵ_3	3.10	4.67	6.15	6.50	3.10	3.10	3.10	3.10
ϵ_4	2.10	2.10	2.10	2.10	3.35	4.67	6.15	6.50
b_{opt}	0.439	0.616	0.701	0.715	0.197	0.450	0.574	0.595

References

1. J. B. Pendry, D. Schurig, D. R. Smith, Science. 312, 1780 (2006).

2. U. Leonhardt, Science. 312, 1777 (2006).