MULTILAYER CYLINDRICAL INVISIBLE CLOAKS WITH ELLIPTICAL CROSS-SECTION

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Abstract

Over the past two decades, the intensive research has been conducted into the possibility of creating invisibility cloaks of various geometries. The basis for this research is the concept of "wave flow" proposed in [1] – the use of the spatial transformation to achieve the invisibility of material objects. There are two known approaches to achieving near-perfect invisibility. The first of these approaches is based on transformational optics and uses materials with the heterogeneous and anisotropic permittivity and permeability. These materials have high losses and narrow bandwidths in the optical frequency range, which significantly limits their use in the visible spectrum. Therefore, the second approach, which consists of minimizing scattering by the plasmonic or dielectric layers, is more relevant.

Statement of the problem

$$\Delta\varphi_i = 0 \qquad i=\overline{1,4} \qquad \Delta = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\right)$$

$$\left.\left(\varphi_1 + e_p r\frac{\partial\varphi_1}{\partial r}\right)\right|_{r=a} = \left.\left(\varphi_2 + e_p r\frac{\partial\varphi_2}{\partial r}\right)\right|_{r=a},$$

$$\left.\left(\varphi_2 + e_p r\frac{\partial\varphi_2}{\partial r}\right)\right|_{r=b} = \left.\left(\varphi_3 + e_p r\frac{\partial\varphi_3}{\partial r}\right)\right|_{r=b},$$

$$\left.\left(\varphi_3 + e_p r\frac{\partial\varphi_3}{\partial r}\right)\right|_{r=R} = \left.\left(\varphi_4 + e_p r\frac{\partial\varphi_4}{\partial r}\right)\right|_{r=R},$$

$$\epsilon_1\left.\left(\frac{\partial\varphi_1}{\partial r} + e_p r\frac{\partial^2\varphi_1}{\partial r^2}\right)\right|_{r=a} = \epsilon_2\left.\left(\frac{\partial\varphi_2}{\partial r} + e_p r\frac{\partial^2\varphi_2}{\partial r^2}\right)\right|_{r=a},$$

$$\epsilon_2\left.\left(\frac{\partial\varphi_2}{\partial r} + e_p r\frac{\partial^2\varphi_2}{\partial r^2}\right)\right|_{r=b} = \epsilon_3\left.\left(\frac{\partial\varphi_3}{\partial r} + e_p r\frac{\partial^2\varphi_3}{\partial r^2}\right)\right|_{r=b},$$

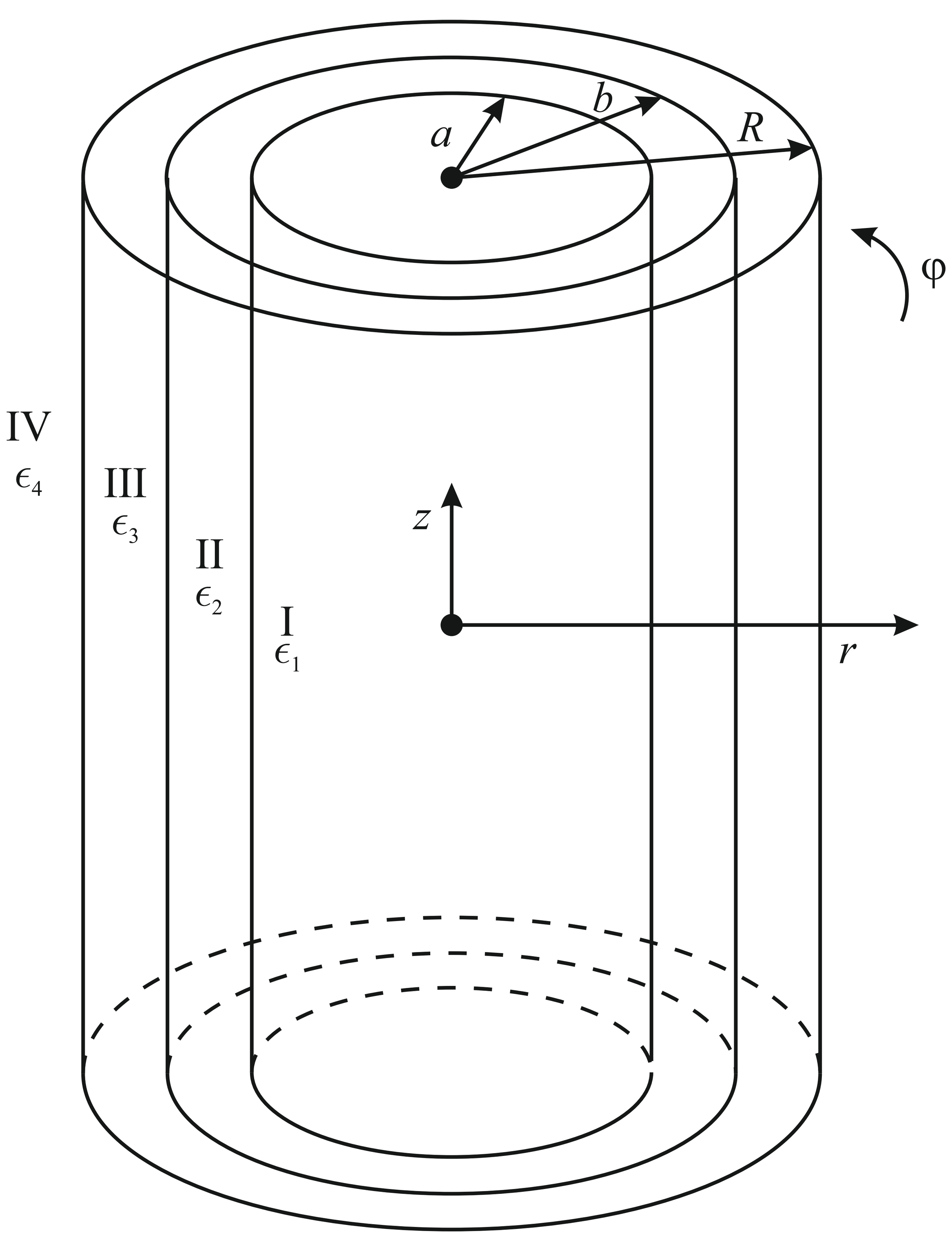
$$\epsilon_3\left.\left(\frac{\partial\varphi_3}{\partial r} + e_p r\frac{\partial^2\varphi_3}{\partial r^2}\right)\right|_{r=R} = \epsilon_4\left.\left(\frac{\partial\varphi_4}{\partial r} + e_p r\frac{\partial^2\varphi_4}{\partial r^2}\right)\right|_{r=R},$$

where a, b, R – represents the "effective" radii of the first, second, and third layers; $e_p = \sqrt{1 - R_\perp^2 / R_\parallel^2} \to 0$ is the eccentricity, $a = \sqrt{a_\perp a_\parallel}$, $b = \sqrt{b_\perp b_\parallel}$, $R = \sqrt{R_\perp R_\parallel}$.

Statement of the problem

Any nanoparticle does not contribute to the scattered field if its scattering cross-section, and therefore its polarizability, is equal to zero. In order to find the polarizability, it is necessary to solve the boundary problem of electrostatics for an infinitely long multilayer cylindrical structure with the elliptical cross-section. Let us limit ourselves to considering three-layer structure, the transverse cross-section of which differs slightly from the circular one. In this case, according to the boundary shape variation method [2], the task is to solve Laplace equation for each layer and the surrounding environment in a polar coordinate system with "deformed" boundary conditions (Fig. 1)

Figure 1



Geometry of the problem

Results of calculations and conclusions.

The numerical experiments show that the shielding of the electric field in the inner region of the cylindrical structure is possible due to the layer with quasi-zero permittivity ($\epsilon_2 \to 0$) when the resonant plasmon is excited in the shielding layer. In addition, the masking is possible in the presence of the singularity of the permittivity ($|\epsilon_2| \to \infty$). Both of these cases can be realized using natural materials. The approach proposed in this work also allows the optimal thicknesses of the compensating shell to be determined for these cases.

1. J. B. Pendry, D. Schurig, D. R. Smith, Science. 312, 1780 (2006).
2. A. V. Korotun, Phys. Sol. St. 56, 1245 (2014).