ELECTROMAGNETIC LATTICE "INVISIBILITY" OF THE RESONANCE CUBIC CRYSTAL MADE OF MAGNETODIELECTRIC SPHERES

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Abstract

A solution and analysis of a problem on phenomenon of electromagnetic lattice "invisibility" of the limited resonance cubic crystal made of spheres are presented. The obtained results may be used when developing the devices wherein stealth technologies are employed.

Keywords: magnetiodielectric sphere, resonance cubic crystal, electromagnetic invisibility, stealth technology.

1. INTRODUCTION

A problem of modeling a phenomenon of physical bodies "invisibility" at optic and roentgen wave bands is a serious direction of the investigations in the applied electromagnetics. In this paper, properties of a limited crystal with a cubic lattice, when the structural (lattice) resonance excited in it entails a phenomenon of electromagnetic lattice "invisibility", are analyzed.

Considered here is the case equivalent to a roentgen optics of crystals when $a/\lambda' << 1$; $a/\lambda_g \sim 1$; $d,h,l/\lambda' \sim 1$ where a is the radius of the spheres; λ', λ_g the lengths of the scattered wave outside and inside the spheres; d,h,l constants of the lattice. The solution of the problem is obtained on the basis of the second kind Fredholm integral equations of electromagnetics [1, 2, 3, 4].

2. MAIN PART

Let us determine the scattered field from the known internal field of scatterers through electric $\vec{\Pi}^e$ and magnetic $\vec{\Pi}^M$ Hertz's potentials of the spatial lattice [1, 2, 3]

$$\begin{aligned} \vec{A}_{scat} &= \left(\nabla\nabla + k^2\varepsilon_0\mu_0\right)\vec{\Pi}^e - ik\mu_0\left[\nabla,\vec{\Pi}^{м}\right], \\ \vec{H}_{scat} &= \left(\nabla\nabla + k^2\varepsilon_0\mu_0\right)\vec{\Pi}^M + ik\varepsilon_0\left[\nabla,\vec{\Pi}^{э}\right]. \end{aligned}, \quad (1)$$

Having known internal fields of the individual scatterers, present Hertz's potential $\vec{\Pi}^e$ of the field scattered by a system of the lattices as a superposition of Hertz's potentials of individual spheres of the lattices in the form

$$\vec{\Pi}^e\left(\vec{r},t\right) = \sum_{c=1}^{C}\left[\sum_p\sum_s\sum_t \frac{1}{k_1^3}\left(\sin k_1a_c - k_1a_c\cos k_1a_c\right)\times\right.$$

$$\left.\times\left(\frac{\varepsilon_{cef}}{\varepsilon_0}-1\right)\vec{E}^0_{c(p,s,t)}(\vec{r},t)\frac{e^{-ik_1r_{c(p,s,t)}}}{r_{c(p,s,t)}},\right]_c \quad (2)$$

$$r_{c(p,s,t)} = \sqrt{\left(x-x_{c,s}\right)^2+\left(y-y_{c,t}\right)^2+\left(z-z_{c,p}\right)^2} \quad (3)$$

where coordinates (x, y, z) specify points of observation of the field outside the spheres; whereas ($x_{c,s}, y_{c,t}, z_{c,p}$) are coordinates of the points whereat centers of the scattering spheres of the lattice are located; $\vec{E}^0_{c(p,s,t)}(\vec{r},t)$ is the internal field of the spheres to be found from the algebraic system of inhomogeneous equations of the quasi-stationary approximation [1]. Let us present one of the equations of this system for a simple lattice as

$$\vec{E}_{0c'(p',s',t')}\left(\vec{r},t\right) = \frac{\left(\varepsilon_{c'ef}+2\varepsilon_0\right)+\theta^2_{1c'}\varepsilon_{c'ef}+i\theta_{1c'}\left(\varepsilon_{c'ef}+2\varepsilon_0\right)}{3\varepsilon_0 e^{i\theta_{1c'}}}\times$$

$$\times\vec{E}^0_{c'(p',s',t')}\left(\vec{r},t\right) - \sum_{\substack{p\\c'(p,s,t)\neq c'(p',s',t,)}}\sum_s\sum_t\left\{\left(\nabla\nabla+k^2\varepsilon_0\mu_0\right)\frac{1}{4\pi}\left(\frac{\varepsilon_{c'ef}}{\varepsilon_0}-1\right)\times\right.$$

$$\times W^e_{c'(p,s,t)}\left(\vec{r}\right)E^0_{c'(p,s,t)}\left(\vec{r},t\right) - ik\mu_0\times$$

$$\left.\times\left[\nabla,\frac{1}{4\pi}\left(\frac{\mu_{c'ef}}{\mu_0}-1\right)W^{м}_{c'(p,s,t)}\left(\vec{r}\right)H^0_{c'(p,s,t)}\left(\vec{r},t\right)\right]\right\}$$

where

$$W^e_{c(p,s,t)}\left(\vec{r}'\right) = \frac{4\pi}{k_1^3}\left(\sin k_1a_c - k_1a_c\cos k_1a_c\right)\frac{e^{-ik_1r_{c'(p',s',t'),c(p,s,t)}}}{r_{c'(p',s',t'),c(p,s,t)}},$$

$$\varepsilon_{cef} = \varepsilon_c F\left(\theta\right), \quad \mu_{cef} = \mu_c F\left(\theta\right),$$

$$F\left(\theta\right) = 2\left(\sin\theta - \theta\cos\theta\right)/\left(\theta^2-1\right)\sin\theta + \theta\cos\theta;$$

$$\theta = ka_c\sqrt{\varepsilon_c\mu_c}.$$

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The field scattered by the system of orthogonal lattices can be found from (1) taking into account (2) as

$$\vec{E}_{scat}\left(\vec{r},t\right)=\sum_{c=1}^{C}\Bigg[\sum_{p}\sum_{s}\sum_{t}\frac{1}{k_1^3}\left(\sin k_1 a_c - k_1 a_c \cos k_1 a_c\right)\text{x}$$
$$\text{x}\left\{\left(\frac{\varepsilon_{cef}}{\varepsilon_0}-1\right)\widehat{L}_c\vec{E}^0_{c(pst)}\left(\vec{r}'\right) - ik\mu_0\left(\frac{\mu_{cef}}{\mu_0}-1\right)\right. \qquad (4)$$
$$\left.\text{x}\,\widehat{P}_c\vec{H}^0_{c(pst)}\left(\vec{r}'\right)\right\}e^{i\left(\omega t-k_1 r_{c(pst)}\right)}\Bigg]_c$$

where $\widehat{L}_c$ and $\widehat{P}_c$ are the functional scattering matrices. Expression (4) describes propagating and damped constituents of the scattered field inside and outside the crystal in the Fresnel and Fraunhofer regions.

The full field at an arbitrary, located outside the spheres, point of medium is defined as

$$\begin{aligned}\vec{E}\left(\vec{r},t\right)&=\vec{E}_0\left(\vec{r},t\right)+\vec{E}_{scat}\left(\vec{r},t\right),\\ \vec{H}\left(\vec{r},t\right)&=\vec{H}_0\left(\vec{r},t\right)+\vec{H}_{scat}\left(\vec{r},t\right)\end{aligned} \qquad (5)$$

where $\vec{E}_0\left(\vec{r},t\right),\vec{H}_0\left(\vec{r},t\right)$ are the undisturbed fields of the scattered wave.

Power densities of the scattered (1) and full (5) electromagnetic fields can be found from the relation

$$\omega=\frac{1}{8\pi}\left(\vec{E}^2+\vec{H}^2\right). \qquad (6)$$

The numerical analysis of expressions (1) and (6) has been carried out for the resonance cube-shaped crystal. Its results are given in Figs 1,2. The relationship between the resonance length of the scattered plane wave λ_r^t and constant d of the cubic lattice of the crystal is chosen in the form [3]

$$\lambda_r^t = 0{,}8d\ . \qquad (7)$$

Under this condition, there occur the structural (lattice) resonance with index n = 3 (Fig.1a) and the associated with it phenomenon of electromagnetic lattice “invisibility” when the scattered wave does not experience reflection and mainly passes through the crystal (Fig. 2c,d). Shapes of the resonance curves here depend on the algebraic sum of the fields with corresponding phase multipliers (4).

The occurrence of regions with resonance propagation of the scattered wave is connected with this effect (Fig. 1b).

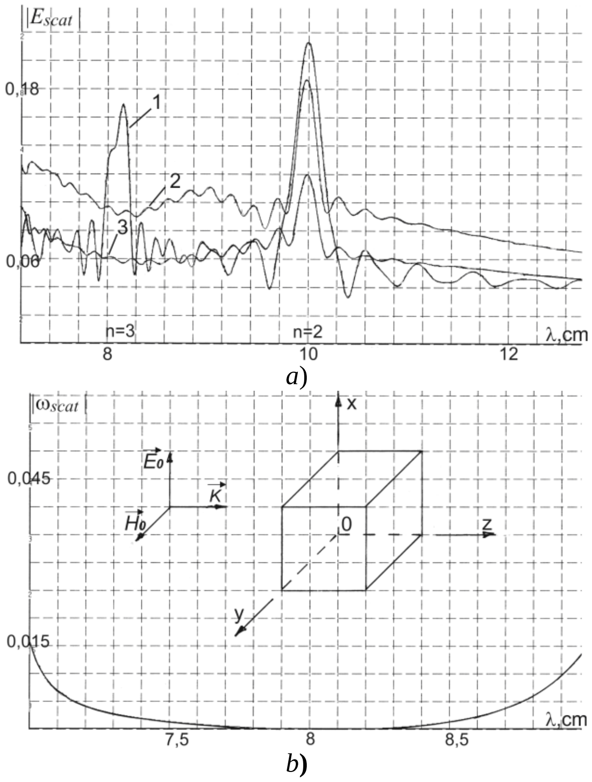

Fig.1. Dispersive dependences for $|E_{scat}|$ and $|\omega_{scat}|$ of the resonance cubic crystal.

Position of $|\omega_{scat}|$ (6) at fixed distances on both crystal sides along a z-axis (Fig.1b) at the Fresnel and Fraunhofer regions in the direction the scattered wave propagates allows estimating widths of regions of resonance wave propagation.

The number of spheres in the crystal here is N = 64000; the radius of the spheres *a* = 0.5 см; the permittivity and permeability of the spheres are $\varepsilon = 95$ and $\mu = 1$, and those of their surroundings are $\varepsilon_0 = \mu_0 = 1$; a constant of the cubic crystal lattice is *d* = *h* = *l* =10 cm.

Fig.1a shows the dispersive dependences $|E_{scat}|$ (4) at the cube centre (curve 1) in the vicinity of the cube corner (curves 2, 3). Indices n = 2,3... specify the number of the structural resonance [3].

Shown in Fig. 1b are the dispersive dependences (6) outside the cube for distances of $\pm$10000 cm along a z-axis.

In Fig. 2a,b,c, and d, a structure of the internal field of the resonance cube in the directions of x,y,z-axes for $|\omega_{full}|$ and in the direction of z-axis for $|\omega_{scat}|$ (6) is considered.

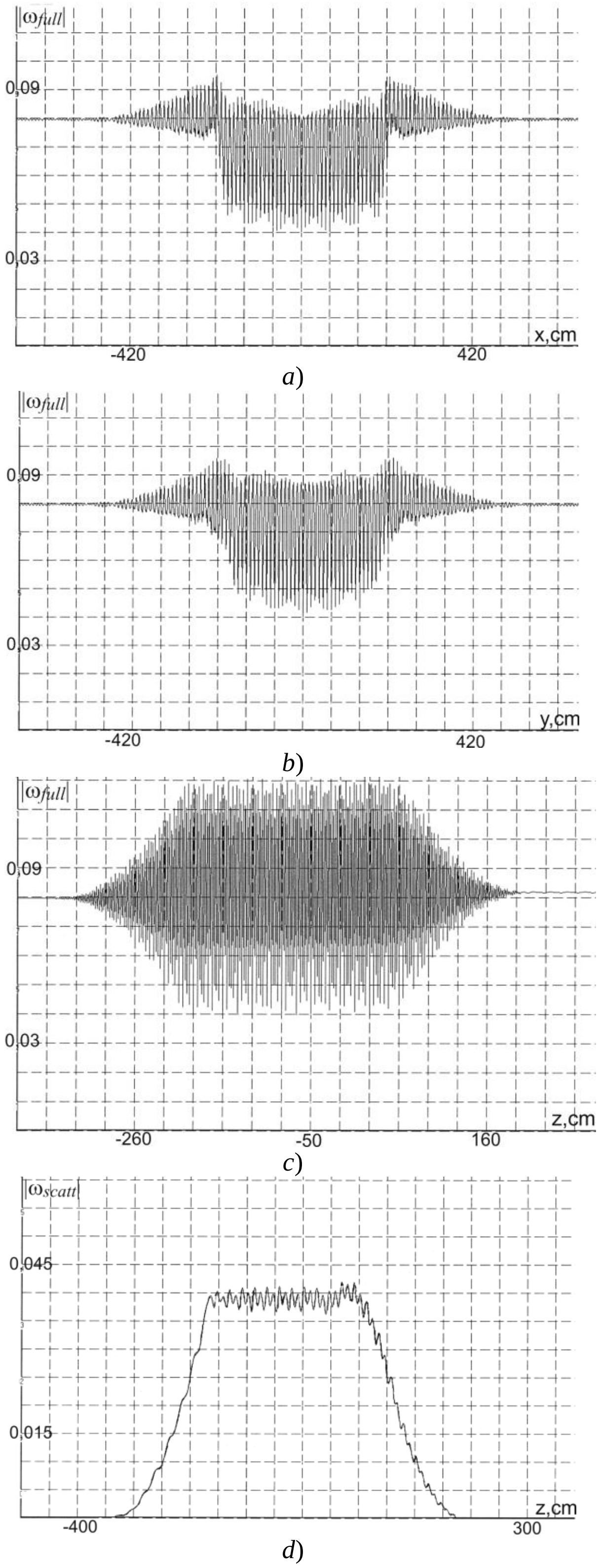

Fig.2. Dependences for $\left|\omega_{full}\right|$ and $\left|\omega_{scat}\right|$ of the internal field of the resonance cubic crystal.

3. CONCLUSION

Using structural (lattice) resonances of the crystals, whose occurrence is related to the presence of the certainly shaped external surface enveloping the crystal, it is possible to create conditions for occurrence of the resonance lattice "invisibility" for electromagnetic waves scattered by the crystals and to form a structure of the internal field of the crystal.

The presented in the paper results of our investigations may be used when creating devices in which stealth technologies are employed.

4. REFERENCES

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