MAGNETOPHOTONIC CRYSTAL ON BASE OF GYROTROPIC SEMICONDUCTOR AND METAMATERIAL

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Metamaterials [1, 2] and magnetophotonic crystals (MPC) [3] are widely used in various applications of optoelectronics, spectroscopy, antenna technology and acoustics. The features of wave propagation in such photonic-crystal structures and left-handed media are completely determined by the geometric dimensions of the layers and by the dependences of their material parameters on frequency. The properties of wave propagation in such composite materials that are composed of isotropic media have been thoroughly studied [4]. Among the most promising applications are magnetophotonic crystals with a controlled gyrotropic layer. The presence of a gyrotropic layer in such structure makes it possible to change the values of the material parameters of the medium by means of the applied magnetic field and, ultimately, to control the dispersion properties of the crystal and the wave propagation characteristics electrically. In the presence of gyrotropy the material parameters are tensor quantities. The properties of such structures have been little studied. There are only separate publications using the matrix approach and numerical methods for solving such problems. The simultaneous presence of metamaterial layers and gyrotropic semiconductor ones in a photonic crystal can lead to new features of wave propagation in such media. In this report, based on a rigorous mathematical approach, the eigenvalues and eigenfunctions problem and describing the waves in a multicomponent metamaterial are solved. A characteristic equation is obtained and its solution found in analytical form suitable for different frequency ranges. The main features of waves propagation for arbitrary relations between the geometric sizes of layers and material parameters are elucidated.

Let us consider one-dimensional MPC with an external transverse magnetic field (Fig. 1). One layer of the MPC is a gyrotropic semiconductor layer whose permittivity is a standard type tensor [5], the other layer is a metamaterial for which the refractive index is a negative value. Following [3, 6] we obtain a solution of the characteristic equation for the Floquet-Bloch wave number of transversely electric waves in a crystal:

$$K_{TE}(\beta)=\frac{1}{L}\arccos\left\{\cos\xi_2 b\cos\xi_1 a-\frac{1}{2}\left[\frac{\xi_1}{\xi_2}\frac{\varepsilon_{\perp 2}}{\varepsilon_1}+\frac{\xi_2}{\xi_1}\frac{\varepsilon_1}{\varepsilon_{\perp 2}}\left(1+\frac{\beta^2}{\xi_2^2}\frac{\varepsilon_{a2}^2}{\varepsilon_2^2}\right)\right]\sin\xi_2 b\sin\xi_1 a\right\},$$

here $\xi_1=\sqrt{k^2\varepsilon_1\mu_{zz1}-\beta^2}$, $\xi_2=\sqrt{k^2\varepsilon_{\perp 2}\mu_{zz2}-\beta^2}$, a and b are the thicknesses of the layers, L – period of the structure, β – the wave number along the layers. For transversely magnetic waves of a scalarized field the solution is relatively simple using the principle of permutation duality of fields and material parameters [3, 5].

Analysis of the solutions of the characteristic equation shows the existence of forbidden and transmission bands in the MPC as well as two modes of wave propagation: the regime of fast bulk waves (ξ_1, ξ_2 are real quantities) and the surface waves regime (ξ_1, ξ_2 are purely imaginary quantities). In the regime of surface waves there are several varieties of surface waves associated with the fulfillment of certain conditions for various material parameters of a

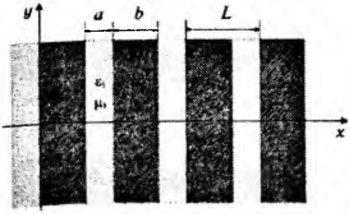

Fig. 1. Schematic of magnetophotonic crystal

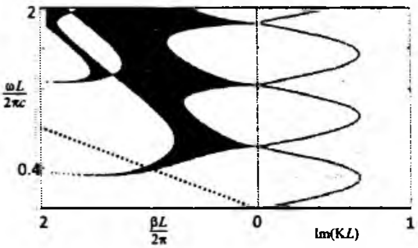

Fig. 2. Dispersion diagram

metamaterial and semiconductor. Moreover in the case of the absence of gyrotropy in a semiconductor $\left(\varepsilon_{a2} = 0\right)$ the main contribution to the formation of the surface wave is determined by the metamaterial layer.

A surface wave can exist only with a negative refractive index of the metamaterial. This is a modified surface wave of Zennek-Sommerfeld. If the semiconductor layer is gyrotropic then several cases of the existence of a surface waves which different from the Zennek-Sommerfeld wave are possible. A gyrotropic surface wave is observed for a negative refractive index and a condition: $1 + \left(\beta^2/\xi_2^2\right)\left(\varepsilon_{a2}^2/\varepsilon_2^2\right) > 0$. Such wave exists for permittivity values with different signs: $\varepsilon_{\perp 2} < 0$ and $\varepsilon_1 > 0$. In addition, the surface wave is realized under other conditions: $1 + \left(\beta^2/\xi_2^2\right)\left(\varepsilon_{a2}^2/\varepsilon_2^2\right) < 0$; $\left(\xi_1/\xi_2\right)\left(\varepsilon_{\perp 2}/\varepsilon_1\right) + \left(\xi_2/\xi_1\right)\left(\varepsilon_1/\varepsilon_{\perp 2}\right)\left(1 + \left(\beta^2/\xi_2^2\right)\left(\varepsilon_{a2}^2/\varepsilon_2^2\right)\right) < 0$.

Fig. 2 shows dispersion diagrams and imaginary values of the Floquet-Bloch wave number K for the value $\beta = 0$. The parameters of MPC are $\varepsilon_1 = -6.1$, $\mu_1 = -1.2$, $\varepsilon_2 = 3.5$, $\varepsilon_{a2} = 2.75$, $a = 0.7L$. The area of surface waves lies below the dotted line. It can be seen that another regime is being implemented for $\beta = 0$ that is important for practical application. The transmission bands exist only at several points. This fact allows creating narrow-band high-Q filters based on such MPC [7, 8]. The presence of a gyrotropic layer makes it possible to control not only the frequency characteristics of the MPC with the help of a magnetic field, but also the modes of wave propagation, which is essential for the development of various functional devices for optoelectronics. By combining the parameters of the metamaterial layer and gyrotropic semiconductor layer, it is possible to realize a regime of frequency sensitive surface plasmon-polariton waves propagating along the boundaries of structure layers.

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