Parity-time-symmetric photonic hypercrystals

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Abstract-In this work we investigate the electromagnetic wave propagation in a *PT*-symmetric hypercrystal composed of hyperbolic metamaterial layers separated by dielectric media with balanced loss and gain. The effect of the loss/gain level on the evolution of dispersion curves is considered. It is shown that the scattering properties of the stack and spontaneous symmetry breaking are strongly influenced by the constitutive and geometrical parameters of the layers and wave angles of incidence.

The dispersion properties of multilayered structures formed by hyperbolic media have been investigated mainly for the photonic crystal regime avoiding the hypercrystal limit [1]. Such materials exhibit unusual properties that can find many applications in nanophotonics. The discovery of parity-time (*PT*)-symmetric media [2] has shown significant potential for advancing toward the goal of new metamaterial design. In this work we explore the optical properties of the *PT*-symmetric hyperbolic semiconductor metamaterial formed by periodic variation of uniaxial metamaterial layer placed between two dielectric slabs of identical thickness, with complex-conjugate dielectric permittivities $\varepsilon_d = \varepsilon' - i\varepsilon''$ and $\varepsilon_d^* = \varepsilon' + i\varepsilon''$ (Fig.1a). We assume that the metamaterial medium is a periodic multilayer stack of alternating layers of two lossless semiconductors.

The dispersion relation and characteristic frequencies for dispersion dependencies of the eigenwaves of *PT*-symmetric hypercrystal were determined. Using the exact transfer-matrix approach and an effective medium theory, we have analysed the scattering properties of *PT*-symmetric hypercrystal stack of total thickness *L*. It was obtained that the effective medium approach does not adequately describe the propagating waves in the *PT*-symmetric stacks. We have shown that the unidirectional

invisibility can be observed at frequencies corresponding to hyperbolic regimes. The amplification of reflected waves was obtained for a case of left incidence. The spontaneous symmetry breaking phenomenon is observed at frequencies corresponding to first hyperbolic regime (blue shaded area, $\varepsilon_{xx} < 0, \varepsilon_{zz} > 0$, where $\varepsilon_{xx,zz}$ are the components of an effective permittivity tensor), where $|\lambda_1| = 1/|\lambda_2| > 1$ (Fig.1b).

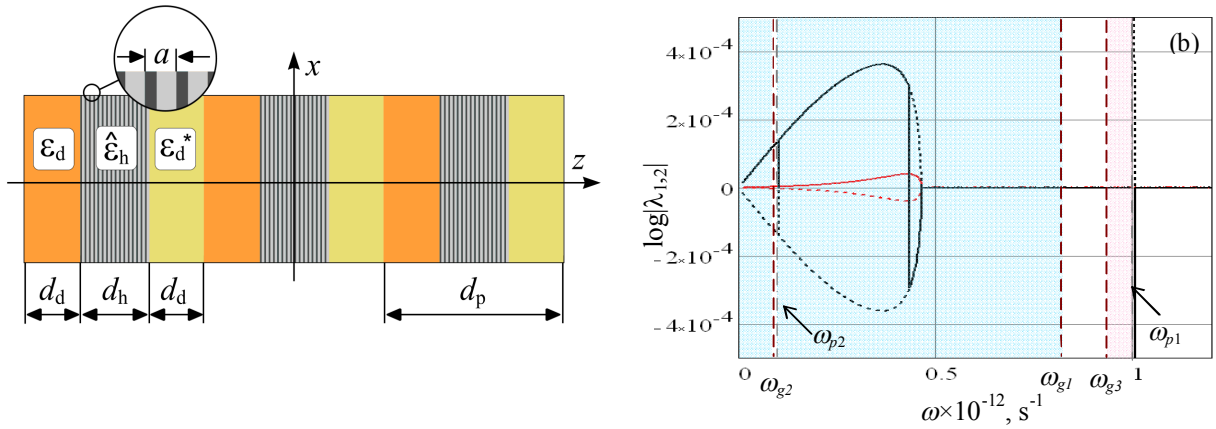

Fig.1. (a) – Geometry of the problem; (b) – log|$\lambda_{1,2}$| as a function of frequency at $\varepsilon' = 2.1$, $\varepsilon'' = 0.1$, *L*=1.2 mm; red lines - θ_i = 15°, black lines - θ_i = 75°; solid and dashed curves of the same colour correspond to the different eigenvalues of the same scattering matrix.

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