Optical properties of *PT*-symmetric periodic stacks of the layers.

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Abstract- The scattering properties of *PT*-symmetric periodic stack of binary dielectric layers characterised by balances loss and gain are explored. It is shown that resonant phenomena are connected with surface mode excitation at internal boundaries of the stack. The effects of the structure parameters and direction of incidence on the resonant phenomena and spontaneous symmetry breaking transition are determined. It is shown that structure periodicity significantly increase the number of resonant phenomena, especially in stacks with high dielectric permittivity of the layers.

Parity-time (*PT*)-symmetric systems attract increasing interest fuelled by their applications for optical range. It has been shown that these materials can exhibit several exotic features. To date, most of the studies in optical realizations of *PT*-symmetric media have connected with investigation of stacked layers and films [1-3]. The planar structures are of particular interest because on one hand they are compatible with the existing fabrication technologies and, on the other hand, their basic models provide deep insight in the main features and mechanisms of the scattering. The aim of this work is to analyse the influence of the periodicity and individual layer parameters onto the scattering properties of *PT*-symmetric stacks of periodically sequenced binary dielectric layers stack of binary dielectric layers with balanced loss and gain under oblique incident plane-wave illumination.

It is assumed that the periodic stack of binary dielectric layers of the total thickness $L=2Nd$ (N is the number of structure periods, d is the thickness of the layers) is illuminated by obliquely incident TM-wave (see Fig.1). The slabs are characterized by complex-conjugate relative permittivities $\varepsilon = \varepsilon' - i\varepsilon''$ and $\varepsilon^* = \varepsilon' + i\varepsilon''$ corresponding to balanced gain and loss regions. The structure is surrounded by homogeneous medium.

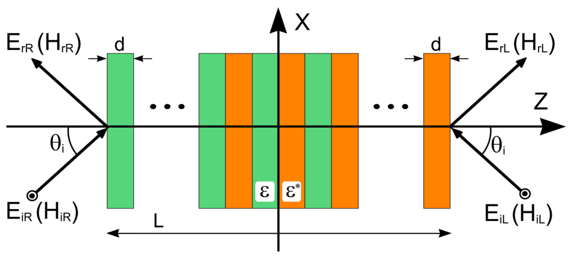

Fig.1. Geometry of the problem.

To evaluate scattering properties and symmetry breaking transitions in *PT*- symmetric periodic structure, we use the scattering matrix formalism. In the approximation of non-depleting waves, this is accomplished with the aid of the transfer matrix of whole stack composed by the transfer matrices of individual layers. As the result of analytical and numerical investigation we demonstrate that tunneling phenomenon in periodic structures is connected with excitation of surface waves at the boundaries separating gain and loss regions within each unit cell and tunneling conditions for periodic stack can be reduced to the conditions for one period. Alternatively, it is shown that coherent perfect absorber (CPA) laser states are mediated by excitation of surface modes localised at all internal boundaries of the structure.

The detailed parametric study has been carried out to explore the influence of the periodicity and constitutive parameters of the layers on the resonant scattering properties and symmetry breaking transitions in *PT*-symmetric periodic structure. The numerical examination of dependences for eigenvalues of scattering matrices shows that with increase of *N* (increase of total thickness of the stack) symmetry breaking occurs at lower frequency. But in the cases of thick structures with high dielectric permittivities, the phase transition at lower frequencies can be suppressed by Bragg resonances. At the same time, for increased number of unit cells in the stack and constant total thickness of the stack the transition tends to occur at higher frequencies. The examination of frequency dependencies for eigenvalues of scattering matrices shows that existence of singular points in the broken-symmetry phase is primarily determined by the ratio between real and imaginary parts of dielectric permittivities and level of gain/loss. It is noteworthy that number of singular points rises with number of unit cells. The reflectance of TM waves incident at slant angle on the stack of layers with $\varepsilon' = 0.2$, $\varepsilon'' = 0.1$ is displayed in Fig. 2. It can be seen that the phenomenon of anisotropic transmission resonance (ATR) is essentially dependent on the material and thickness of the constituent binary layers and do not depend on the number of the periods. Peaks of reflectivity and transmittivity at $\omega = 2.988\times10^{13}\,s^{-1}$ for bilayer structure and multiple peaks for *N*=5 are the CPA laser resonant points corresponding to singular points of scattering matrix.

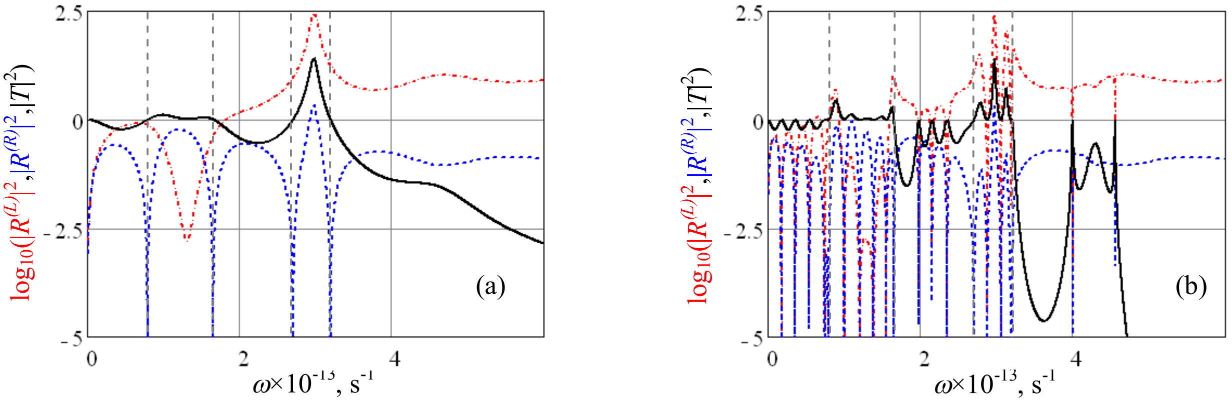

Fig.2. TM wave reflectance for right ($\left|R^{(L)}\right|^2$) and left incidence ($\left|R^{(R)}\right|^2$) and transmittance ($\left|T\right|^2$), for *PT*-symmetric stack with *d*=125 μm, (a) - *N*=1, (b) - *N*=5, illuminated at the angle $\theta_i = 10°$. ATRs are marked by vertical dotted lines.

Acknowledgements - The research work was partially supported by the European Union Seventh Framework Program (FP7-REGPOT-2012-2013-1) under grant agreement No. 316165.

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