• **Нанооптика та фотоніка**

The multimode island kind photonic crystal resonator: states classification

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The existing terminology distinguishes photonic crystals, photonic membranes and photonic crystal resonators (PCR). The infinite 2D structures ordered in XY plane which has also infinite size in Z direction are usually called photonic crystals. A photonic crystal resonator is a finite 2D system with perfectly smooth side walls. The latter circumstance leads to a clearly expressed angular area of total internal reflection (Fig. 1a, light lines) for a field closed inside the resonator.

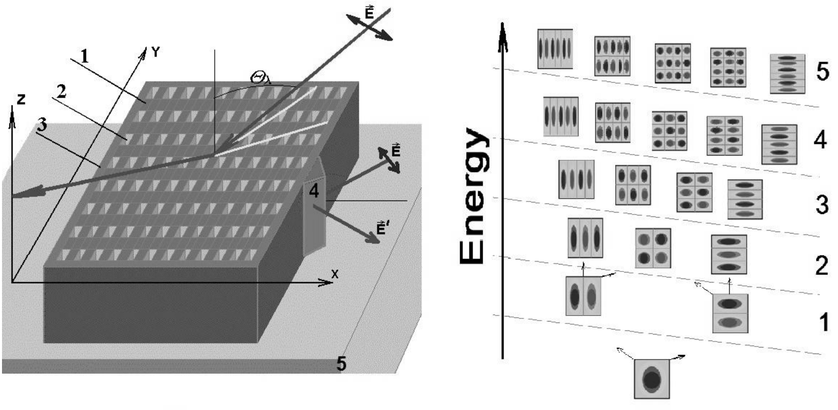

Fig. 1. A multimode photonic crystal resonators. (a) A finite 8x12 2D photonic crystal resonator. **Out-of-plane incidence:** s-polarisation, Θ_l, external polar angle of incidence, azimuth angle $\Phi_l=\pi/4$; light lines, sector of total internal reflection. **In-plane incidence:** p-polarisation. The is not shown. 1, system matrix; 2, rectangular bar/air wells in matrix; 3, covering layer, 4, input prism, 5, substrate. **(b)** The states classification in an island kind 2D photonic crystal resonator, field density distribution, lowest 20 modes. Two systems of nodal lines, oriented along Z and Y axis; it is taken that Y direction has softer spectrum, 1, 2… 5 shells of states;

In this work, we consider some important aspects of electromagnetic field behavior in photonic crystals of island kind. The finite $N_x \times N_y$ period finite structures are investigated analytically and numerically in the framework of standing wave expansion method (SWE). The 2D basis formation procedure was implemented with the use of analytically obtained two 1D basis sets for the two probe 1D structures and Courant's nodal line theorem in the process of basis generation. Though the rectangular lattice was considered, the proposed SWE method for finite resonators may be adapted for any symmetry of the lattice as well as for any shape of bars in matrix. In the ideal case, the system should have infinite size in Z direction. It worth to note that an only way to excite intrinsic standing waves exists through the input prisms which allow the external beam to enter the total internal reflection area. The classification of the trapped inside the resonator modes is ruled by the Courant nodal line theorem claiming that for the system defined in the space R^m, the nodal set of eigenfunctions (modes) of electromagnetic field trapped inside the resonator is locally composed of hypersurfaces of dimensions *m-1*. The Courant nodal line theorem gives a base to test the results of calculation both the set of mode branches (eigenvalues) and mode coordinate dependencies (eigenfunctions). In Fig.1b, the classification of lowest eigenstates in the IPCR is presented. Two factors influence to classification: number of node lines and correlation between them. The first circumstance leads to the shell structure of states when a shell unites modes with the same number of node lines. It is obviously that two types of node lines produce three kinds of modes: with node lines along Z axis, along Y axis, and containing both transverse and longitudinal node lines. In Fig 3a, the ground state is represented by a mode without nodal lines, first shell consists of two modes with one node line, second shell contains 3 two-node line states and so on. In accordance with the Courant theorem, every added node line, even of another type, increases energy of state. Nevertheless in a binary structure with rectangular (non-square) lattice, the modes containing node lines of one kind may form more or less densely the ladder of energy levels. In particular, if period $d_y > d_z$ then modes with transverse node lines have softer spectrum. Mixed modes occupy intermediate positions. Therefore the shells have a tilt that makes energy hierarchy of states more complicate like it is shown in Fig. 1b. We discusses a method of smooth transformation of an island PCR to a structure with extremely large magnitudes d_y which expresses here in an essential reconstruction of the modal structure: the left column remains the same, soft modes containing transverse node lines become practically indistinguishable from the left column modes with the same number of longitudinal nodal lines and vanish. As the result, the 2D energy angular diagram coincides with the spectrum angular diagram of a layered photonic structure.

The proposed island kind PCRs and their discrete modes may serve for various all-optical logic devices and applications.