

## The multimode island kind photonic crystal resonator: states classification

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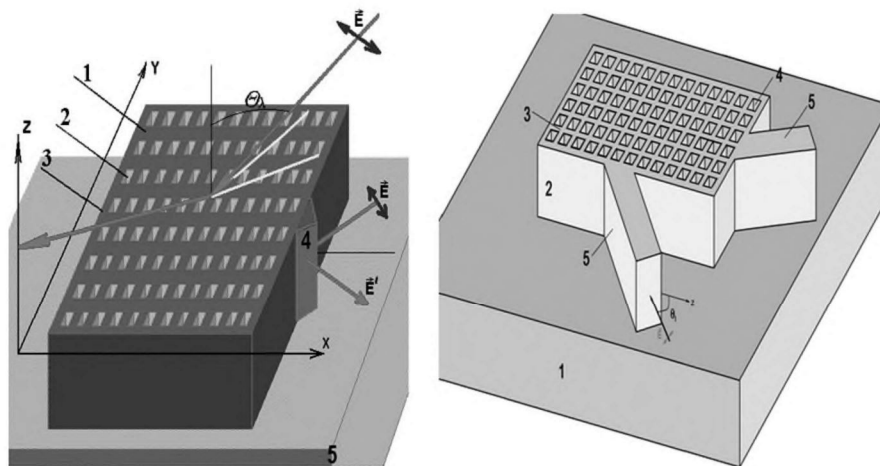
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A finite 2D system of alternating optical materials and perfectly smooth side walls is called island photonic crystal resonator (IPCR). The perfect walls determine the resonator Q-factor and it also leads to a clearly expressed angular area of total internal reflection (Fig. 1a, yellow lines) for a field closed inside.



**Fig. 1.** A multimode island kind photonic crystal resonator (IPCR). (a) Out-of-plane incidence: s-polarisation,  $8 \times 12$  2D IPCR,  $\Theta_p$ , external polar angle of incidence, azimuth angle  $\Phi_i = \pi/4$ ; yellow lines, sector of total internal reflection. In-plane incidence: p-polarisation, 1, system matrix; 2, rectangular bar/air wells in matrix; 3, covering layer, 4, input prism, 5, substrate. (b) A binary  $13 \times 6$  period 2D IPCR as an element of integrating optical circuit. 1, substrate; 2, covering layer, 3, matrix material, 4, accompanying material (shown air wells), 5, input-output waveguides,  $\theta_i$ , angle of incidence, p-polarized plane wave.

At the present time the photonic crystals (PhC) have been widely investigated as perspective objects of optical technologies in computing, signal processing, telecommunication, sensing and a wide area of other applications in optoelectronic and all-optical devices. In the main, the

2D PhC is considering only as a perfect reflecting medium surrounding an optical waveguide. Therefore the conditions of omnidirectional gaps in photonic spectrum are of interest for determination the optimal wavelength range of optical devices based on optical properties of finite photonic crystals. Meanwhile, further development of this area may be related to more detailed consideration of a resonator's finite sizes influence on the modal structure and features of field modal distribution inside a finite photonic crystal. It worth noting that a number of FDTD investigations is devoted to wave transmission through infinite photonic structures of various symmetries whereas resonators of finite sizes need a more adequate mathematical model. Therefore the proposed island kind 2D resonator being a generalisation of the 2D photonic crystal is of interest due to various useful properties of captured electromagnetic field.

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 structures of various optical contrastivity (porous Si, Si-SiO<sub>2</sub>, SiO<sub>2</sub>-SiO<sub>2</sub>, Si-air-SiO<sub>2</sub>) are investigated analytically and numerically in the framework of modified standing wave expansion method (MSWE). The 2D basis formation procedure was implemented with the use of analytically obtained two 1D  $\Psi$ -basis sets of functions for two probe 1D structures and Courant's nodal line theorem in the process of basis generation. Though the rectangular lattice was considered, the proposed MSWE 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, when the system has infinite size along a direction, the 2D case transforms into the 1D one. The classification of the trapped inside the resonator modes which is ruled by the Courant nodal line theorem was considered. It was shown that the Courant nodal line theorem gives a ground to test the results of calculation both the set of mode branches (eigenvalues) and mode coordinate dependencies (eigenfunctions). A binary island kind photonic crystal resonator is investigated analytically and numerically in the framework of standing wave expansion method. The correlation between  $\Psi$ -basis sets of functions and electromagnetic modal functions was taken into account to increase the accuracy. The photonic bandgap structure for the finite SiO<sub>2</sub>/SiO<sub>2</sub> resonator with rectangular elementary cell of micron sizes is first calculated. The classification concept of resonator's modes is proposed. It is concluded that depending on the structure three types of local states of electromagnetic field exist inside the resonator besides the transmitted standing waves: intrinsic, surface and edge states. The field distribution inside the resonator is calculated and ways of use the island resonators and their lowest modes as integrated elements of optical devices are discussed.