Slow-Wave Regimes of the Photonic Crystal Waveguides

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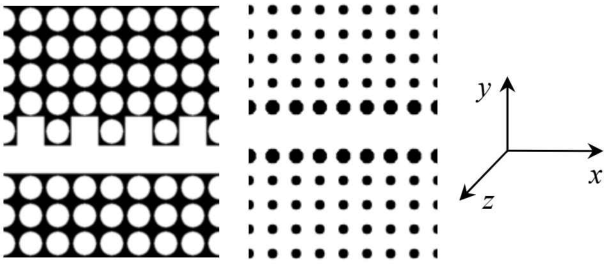
Abstract – **Modified photonic crystal waveguides that support slow waves are considered. MIT Photonic-Band package is used for calculation of dispersion characteristics and electric field spatial distributions. Symmetrical and antisymmetrical guided modes with different phase velocities are obtained within and outside the photonic band gaps.**

Photonic crystal waveguides are usually formed by introducing a line defect in the periodic dielectric structure [1, 2]. These structures have numerous potential applications because of its unique capability to control the propagation of electromagnetic waves by utilizing the photonic band gap effect.

For example, the laser-driven charged particle acceleration structures can be developed on basis of photonic crystals [3]. Interaction of the synchronous speed-of-light mode with particle beam results in high accelerating gradient without using of any metal structures. It is clear that the beam-wave interaction may be realized for smaller particles velocities if the slow-wave modes exist in the photonic crystal waveguide. This phenomenon is perspective for development of the THz electron devices.

In this report the different configurations of the photonic crystal structures that guide slow-wave modes in one direction are considered. Fig.1 shows schemes of the photonic crystal lattices consisting of vacuum holes in dielectric (Fig. 1a) and dielectric cylinders in vacuum (Fig. 1b). Lattice spacing is a. The coordinate system is shown too. Obviously the hexagonal arrays of vacuum and dielectric cylinders with vacuum waveguides introduced are considered. Perfect photonic crystals of these types possess band gaps for different polarizations (see Fig. 2). Guided modes should lie within the band gaps in order to prevent radiation losses in the bulk crystal.



(a) (b)

Fig. 1. Schemes of the photonic crystal waveguides, formed by different linear defects in bulk crystals.
(a) the square lattice of vacuum holes in dielectric.
(b) the square lattice of dielectric cylinders in vacuum.

Fig.1a shows waveguide which has a comb structure on the upper edge. Also double comb waveguide can be investigated. It is well known that grating placed on the one or two walls of the conventional waveguides forms impedance surfaces and sets conditions for spatial harmonics existence.

Photonic crystal waveguide with increased radii of dielectric cylinders in two rows of the structure next to the line defect is shown in Fig. 1b. Similar structure with vacuum holes instead of dielectric cylinder has been proposed earlier for designing single mode waveguide [4].

For the simulation of the photonic crystal waveguides the MIT Photonic-Bands (MPB) package is used [5]. It is the freely available software. For a given geometries MPB computes dispersion characteristics and field spatial distribution of supported waveguide modes.

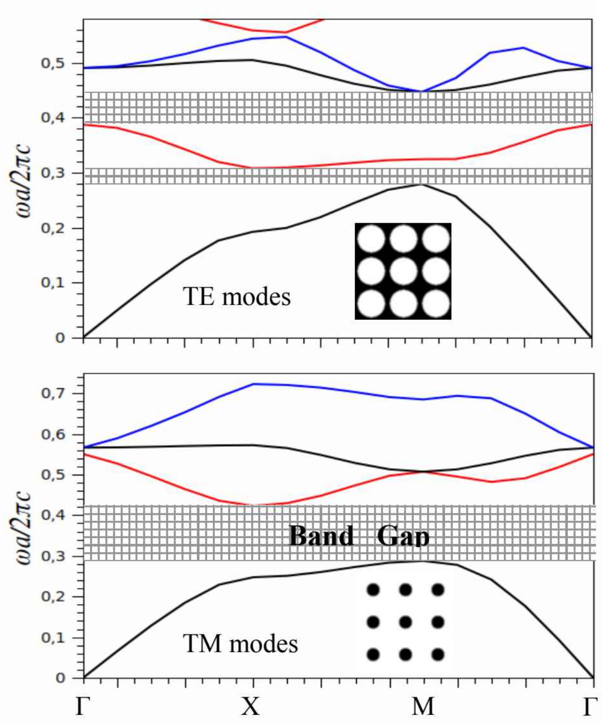


Fig. 2. Photonic band structures for square arrays of vacuum holes (top) and dielectric cylinders (bottom).

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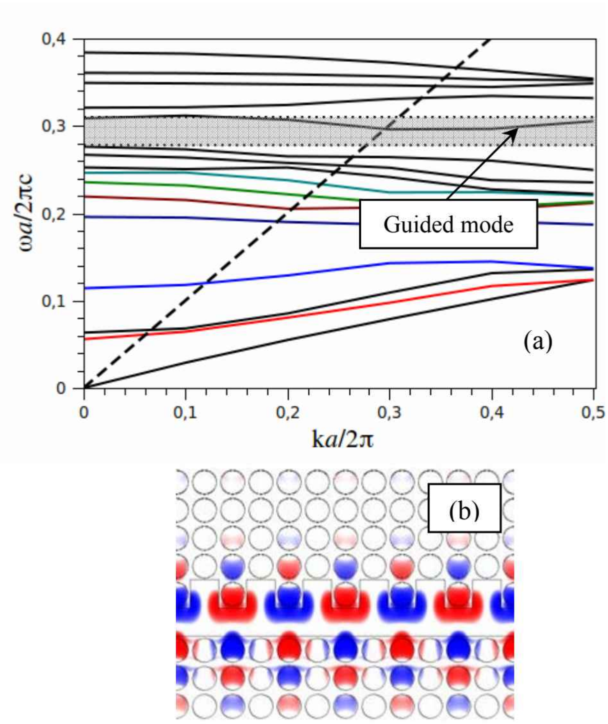


Fig. 3. Band structure and electric field distribution for waveguide from Fig. 1a.

Band diagram of the photonic crystal waveguide of Fig. 1a is represented in Fig. 3a. The shaded region indicates the band gap of the perfect photonic crystal. Dashed line is the speed-of-light line. Inside the band gap there is a single guided band that corresponding to TE mode. Electric field has components in the plane of the structure. Fig. 3b shows the E_x field spatial distribution in the waveguide. This mode likes the surface-localized wave because it decays both into the bulk crystal and waveguide channel. Phase velocity for wave number value $k_x = \pi/a$ is about $0.6c$.

Band diagram of the guiding structure of Fig. 1b is shown in Fig. 4. There are four guided bands inside band gap of the perfect photonic crystal. In this case electric field has single component E_z i.e. TM modes is realized. Spatial distributions of the electric field in plane xy are shown in Fig. 5. Patterns (a), (b) and (c) correspond respectively to points 1, 2 and 3 in dispersion diagram (Fig. 4) for $k_x = \pi/a$. It is clear that some guided bands are formed outside the band gap. For example points 1 and 2 in Fig. 4 correspond to different bands (band1 and band6 in MPB). First mode is symmetrical or even mode. In this case electric field amplitude in the waveguide center is not equal to zero. Mode in Fig. 5b is antisymmetrical (odd mode). Naturally the field amplitude equals to zero on the waveguide longitudinal axis.

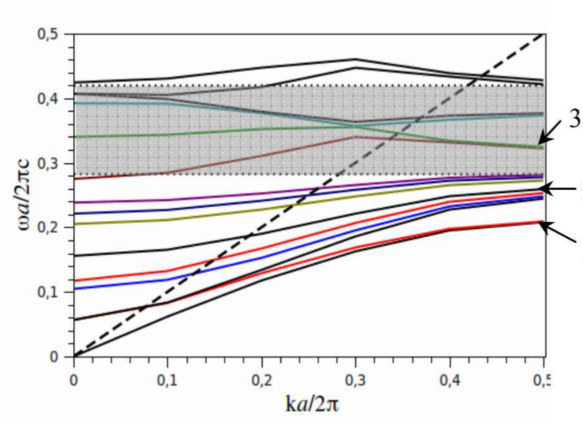
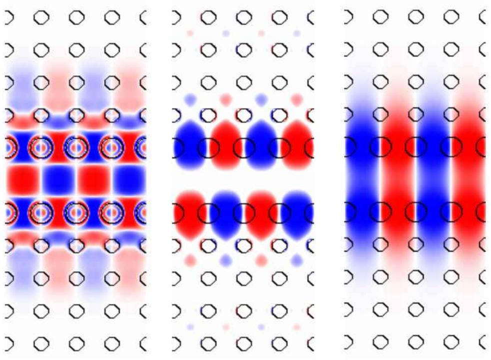


Fig. 4. Band diagram for photonic crystal waveguide from Fig. 1b.

Band gap guided mode is shown in Fig. 5c. It is even mode (band11 in MPB). It should be noted that odd modes also placed within the band gap (band10 and band12 in MPB). Phase velocity of the modes localized in the band gap of the perfect photonic crystal is higher than outside the band gap.



(a) (b) (c)

Fig. 5. Electric field patterns of the photonic crystal waveguide from Fig. 1b for three points on the band diagram.

It is known that double grating electrodynamic structures support two modes – symmetrical and antisymmetrical. Symmetrical modes are used in O-type electron devices. Thus photonic crystal waveguide modes can be synchronized with electron beams for developing of the novel beam-wave systems.

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