Synthesis of Ultra-Wide Bandgaps for 2-D Photonic Crystals of Finite Thickness

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Abstract

The synthesis problem of 2-D photonic crystals of finite thickness providing the ultra-wide stopbands for the plane incident waves is solved on the base of EAC-method (method of exact absorbing conditions) [1–11].

1. Introduction

2-D photonic crystals of finite thickness having the same length of the period are able to produce clearly pronounced stopbands. Their position on the frequency axis can be effectively controlled by the variation of the geometric and material parameters of a unit cell of a periodic structure (see, for example, Fig. 1). This fact allowed proposing a simple, but quite effective scheme for the model synthesis of photonic crystals structures with ultra-wide stopbands.

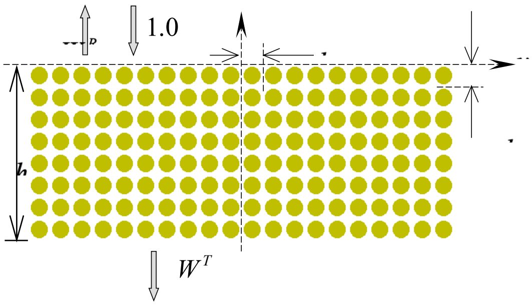

Figure 1: 2-D crystal of finite thickness.

The results presented for discussion have been obtained when working with models of the method of exact absorbing conditions (EAC) [1–11].

2. Formulation of the problem

The simple photonic crystal formed by circular dielectric cylindrical rods with various ε and $\sigma = 0$, oriented parallel to the axis x, had been considered. The intersection of the rods' axes with the planes $x = const$ defines the nodes of the infinite in the directions y and z rectangular grid; the cell size of such grid is $l \times l$. The radius of rods is r. Crystals of finite thickness h have been cut of from this crystal (Fig. 1).

The numerical results have been obtained within the framework of the approaches that had been implemented in [11]. Here we considered the case of H-polarization, that means that the vector $\mathbf{E}$ lies in the plane $y0z$.

The dimensions of all considered physical units are omitted: they correspond to the International System of Units, except the 'time' t that is the product of the real time and the velocity of light in vacuum, thus t is measured in meters.

3. Discussion of simulation

The wave number $k = 2\pi/\lambda$ is varying within the so-called single-wave frequency range, providing validity of the relation $W^T(k) + W^R(k) = 1$. Parameters ε and σ are the relative permittivity and conductivity of the rods' material; λ is a wavelength; $W^T(k)$ and $W^R(k)$ are the parts of the input energy carried by spatial harmonics propagating to the transmission ($z < -h$) and reflection ($z > 0$) zones of the periodic (along coordinate y) structure [4]. The process of band gaps formation in the structure was studied within numerical experiments consisting in the crystal's thickness h increase; that is, the process of formation of sufficiently wide bands of the parameter variation k, where $W^T(k) = 0$ has been simulated. It turned out that for the four- and five-layer crystals; the band gaps (BGs) or stopbands contours become clearer and finally formed for the crystals containing 10 or more layers.

Here is one of examples of synergetic operation of joint fifteen layers crystal designed by means of putting together three blocks of five-layer crystals. Each block is constructed of dielectric rods of the radius $r = 0.38l$ and permittivity varying from $\varepsilon = 10.9$ to $\varepsilon = 6.1$. Model excitation was performed by H-polarized pulse. Consider three values of ε, providing each corresponding crystal in the single-mode range $0.05 \le \kappa = l/\lambda = kl/2\pi \le 0.95$ with stopbands, covering such intervals of frequency range, that if these bandgaps are put in the same draft all together, they all together cover without breaks a fairly wide range of the frequency parameter κ (see three upper fragments in Fig. 2). In such way we obtained a structure with a bandgap $0.357 \le \kappa \le 0.815$, having the width $B_\kappa = \left[2\left(\kappa_{upper} - \kappa_{lower}\right)/\left(\kappa_{upper} + \kappa_{lower}\right)\right]\cdot 100\%$, that is approximately equal to 78.16% Important, that the bandwidth of such stopband is practically insensible to the sequence of five-layer crystals blocks, see two lower fragments in the Fig. 2.

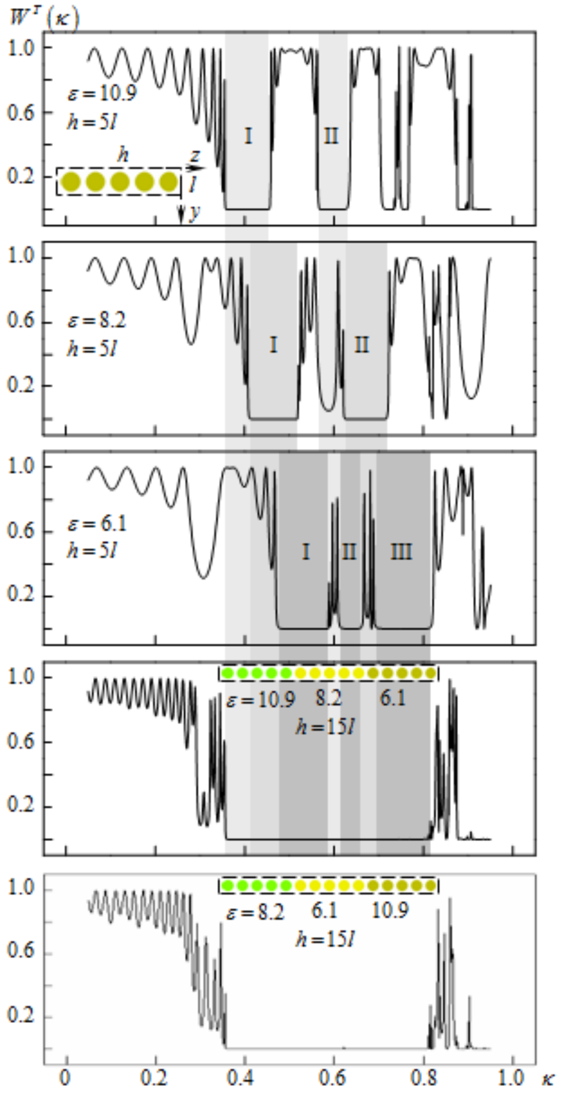

Figure 2: The synergistic effect of the joint operation of the three thick photonic crystals $h = 5l$.

4. Conclusions

The bottom-up approach for band gap photonic 2-D crystals construction is applied. It had been performed on the base of EAC.

The results of simulation proved: bandgaps (stopbands) of limited in thickness 2-D photonic crystals can be significantly increased due to the synergistic effect of the joint operation of several photonic crystals differing only in the internal structure of the crystal's unit cells.

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