Modification of band gap properties and beam propagation in 1D photonic crystals with surface roughness.

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During the last years the field of photonic crystals is characterized by the tendency to miniaturization with the main aim to scale down the working range of photonic devices to the near IR and visible regions. Since defects and inaccuracy in the determination of the geometrical parameters of real structures are inevitable phenomena in sub-micrometer fabrication, the disorder-induced modifications of the properties of a photonic crystal must be taken into account. The problem of surface roughness is of particular interest since surface imperfections inevitably appear during the fabrication of nanometer and micrometer-sized photonic structures.

In perfectly periodical structures electromagnetic (EM) waves propagate as Bloch modes. However, if the periodicity is somehow disturbed (random variation of layers thicknesses or dielectric constants, surface roughness, etc.), the propagation becomes diffusive and an EM wave can be scattered at any angle. The effect of size and positional disorder have been investigated earlier [1,2]. But in our opinion, the problem of surface roughness has got much less attention. Thus, in this work we study the influence of surface roughness on the beam propagation and the photonic band gap properties of 1D high-contrast photonic crystals.

In our 2D model each high-index layer is constructed of narrow rectangles (Fig. 1). Uniformly distributed random variation of the height of each rectangle in the direction perpendicular to the strata interfaces creates the surface roughness with some "resolution" which is defined by the width of rectangles. The perfect structure consists of 6 high-index layers with refractive index $n_h=3.1$ and the width of the air spacing between the plates is $d_l=0.53a$ (a is period of the lattice). In all cases we consider normal to interfaces incidence of EM waves.

By means of 2D FDTD simulations we show that the strong surface roughness destroys the beam-like propagation of an electromagnetic wave. As a result, an incident wave can scatter at angles up to 90°. Thus, we propose to characterize the scattering effect of surface roughness by the following parameter:

$$q = \frac{(\text{max size of surface irregularities})}{(wavelength)}$$

We consider two cases for different wavelengths of an incident wave: (i) in the transmission band and (ii) near the center of a band gap.

We show that in the case (i) the scattering significantly increases for q>0.1 resulting in a reduction of the transmission by one order of magnitude with respect to a perfect structure. On the other hand, when q<0.02 the effect of surface roughness is weak and transmission is not noticeably changed.

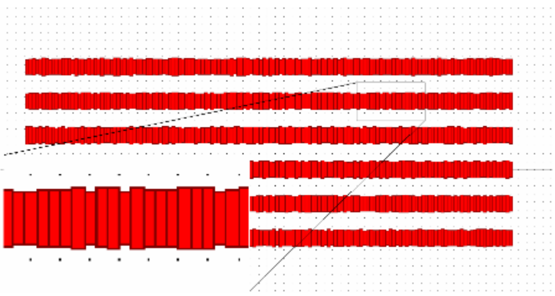

Fig. 1. The model of 1D photonic crystal with surface roughness.

In the case (ii) for a perfectly periodic structure there is almost total reflection of the incident wave. For q<0.05 the roughness practically does not influence the reflection, while for q>0.15 the reflectivity usually does not exceed 50%.

References
[1] M.A. Kaliteevski, D.M. Beggs, S. Brand, R.A. Abram, V.V. Nikolaev, "*Statistics of the eigenmodes and optical properies of one-dimensional disordered photonic crystals*", Phys. Rev. E **73**, 056616 (2006)
[2] R. Meisels, F. Kuchar "*Density-of-states and wave propagation in two-dimensional photonic crystals with positional disorder*", J. Opt. A: Pure Appl. Opt., **9**, 396 (2007)