DUJASE Vol. 2(1) 21-23, 2011 (July)

Threshold Refractive Index For Bandgap In Photonic Crystal

Mohammad Zahir Uddin Suja, Md. Ahsan Habib, Sunayna Binte Bashar, Muhammad Sharifuzzaman Khan and Subrata Kumar Aditya

Department of Applied physics, Electronics & Communication Engineering, University of Dhaka, Dhaka-1000, Bangladesh.

E-mail: *zahir.suja@yahoo.com, ahsantonmoy2007@yahoo.com, sunayna.bashar@gmail.com, sharif.apecedu@yahoo.com* and *aditya@univdhaka.edu*

Received on 12. 10. 2010. Accepted for publication on 02. 08. 2011

Abstract

Threshold values of refractive index contrast for opening a complete photonic bandgap in two dimensional (2-D) photonic crystals have been calculated for two structures, square dielectric rod in air background and square air hole in dielectric background. Consequence of various parameters on this threshold value like rod/air hole orientation angle, filling fraction have also been investigated. These results will be useful in fabricating planar low-index photonic crystal structures.

Keywords: Threshold refractive index, complete photonic bandgap, orientation angle, filling fraction.

1. Introduction:

Photonic crystal is a periodic nanostructure that can affect the propagation of photon in much the same way a semiconductor affects the properties of an electron [1]. If the periodicity and symmetry of the crystal and the dielectric constants of the materials used are chosen well, the band structure of such a crystal shows a photonic bandgap (PBG) for one or both polarizations, i.e. at particular frequencies light propagation is prohibited in any direction in the crystal. When the bandgaps for two different polarizations (TE & TM) overlap, they create a combined bandgap known ascomplete photonic band gap [2]. Several structures are known to possess photonic band gaps for one of these polarizations and for both polarizations simultaneously, as examined comprehensively for high values of the refractive-index ratio in the two dimensional geometry [3].

One of the classical results in the theory of photonic crystals is the existence of the critical (minimum) value of the refractive index contrast to open a full spectral bandgap in a three-dimensional geometry [4]. For example, as wasfirst shown by Ho et al. [5], a diamond structure requires the minimum refractive index contrast larger than 2. Similarly, the threshold values of the refractive index appear in the theory of two-dimensional photonic crystals [6].

In this paper, two structures with square lattice: square air hole in dielectric background and square dielectric rod in air background have been investigated to find the threshold value of refractive index contrast for opening a complete bandgap using plane wave expansion method. Square rod/air hole has chosen because, when the lattice and rod/air hole have the same symmetry the structure has shown the maximum bandgap [7]. "PWE band solver" of the software package of optiFDTD™ has been used for the band diagram calculation. In this simulation hybrid polarization is considered with mesh size, 16×16 and tolerance, e^{-7}.

2.1 Square dielectric rod in air background:

First, we consider a two dimensional photonic crystal created by a square lattice of dielectric rod in air background. The photonic band is a dispersion relation between frequency, ω and wave vector, k.

2.1.1 Threshold value of refractive index:

Photonic crystal structure withsquare dielectric rod in air background has been considered which possesses the maximum complete bandgap for filling fraction, $f = 0.47$ and air hole orientation angle, $\theta = 0°$ [8].

This structure showsthe threshold value of the dielectric constant, 6.10(Fig. 1.1) for opening a complete photonic bandgap, which equates to a refractive index contrast of 2.46982.

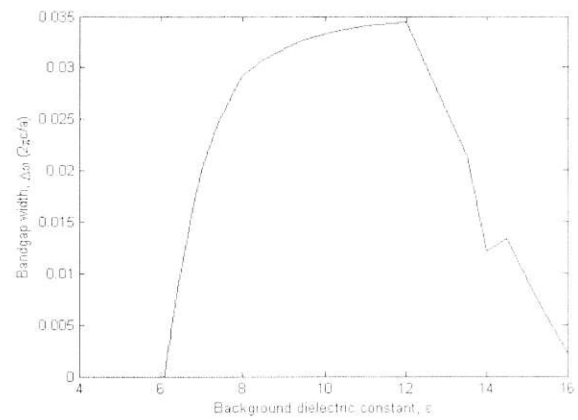

Fig. 1.1: Dependence of the bandgap width,$\Delta\omega$ on the dielectric constant, ε of the dielectric rod.

Thus, there will not be any complete photonic bandgap for dielectric constant, $\varepsilon = 6.10$ or less. Therefore, it is safe to rule out attempts at producing photonic bandgap devices in any system with a refractive index lower than this limit. Figure 1.2 displays the band diagram for square dielectric rod which have the permittivity, $\varepsilon = 6.10$ with$f = 0.47$ and $\theta = 0°$.

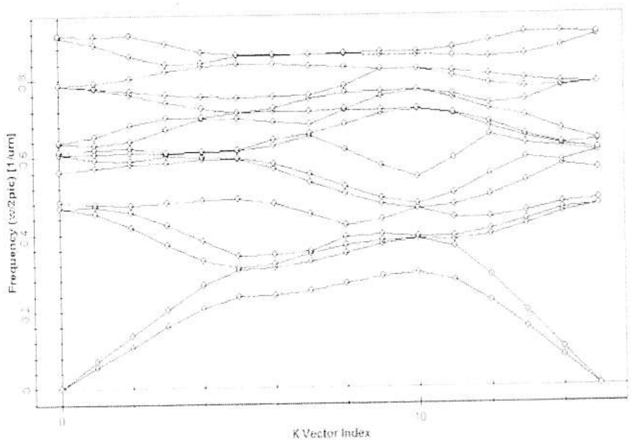

Fig. 1.2: The band structure for square dielectric rods (for dielectric constant, $\varepsilon = 6.1$) in air background for filling fraction, $f = 0.47$ and rod orientation angle, $\theta = 0°$.

Dependence of threshold dielectric constant on orientation angle and filling fraction has shown in the figure 1.3 and figure 1.4 respectively.

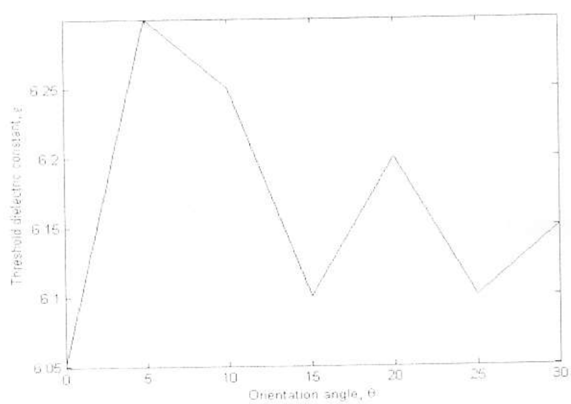

Fig. 1.3: Dependence of threshold dielectric constant, ε on the orientation angle, θ (with filling fraction, $f = 0.47$).

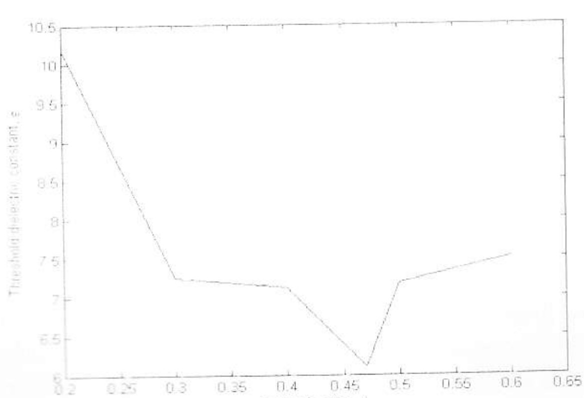

Fig. 1.4: Dependence of threshold dielectric constant, ε on the filling fraction, f (with orientation angle $\theta = 0°$).

2.2 Square air hole in dielectric background:

Next, we consider a two dimensional photonic crystal created by a square lattice of square air hole in dielectric background.

2.2.1 Threshold value of refractive index:

This structure with square air hole in dielectric background exhibits the maximum complete bandgap with filling fraction $f = 0.68$ and air hole orientation angle $\theta = 30°$ [8].

The structure exhibits the threshold value of the dielectric constant, 7.10 (Fig.2.1) for opening a complete photonic bandgap, which equates to a refractive index contrast of 2.66458.

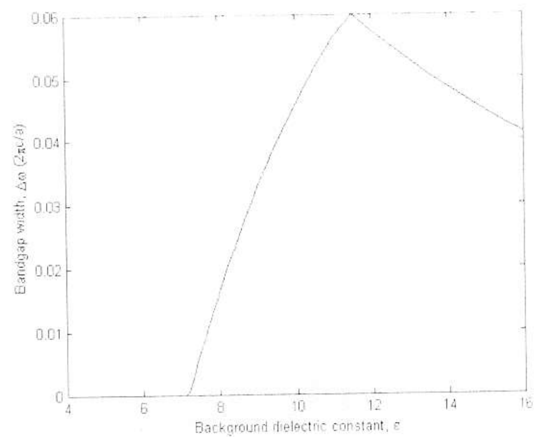

Fig. 2.1: Dependence of the bandgap width, $\Delta\omega$ on the dielectric constant, ε of the background material.

Thus, there will not be any complete photonic bandgap for dielectric constant, = 7.10 or less. Figure 2.2 displays the band diagram for background dielectric constant, $\varepsilon = 7.10$ with $f = 0.68$ and $\theta = 30°$. This plot is generated by the 'PWE Band Solver Simulator' of the software optiFDTD™ by plane wave expansion method (PWE).

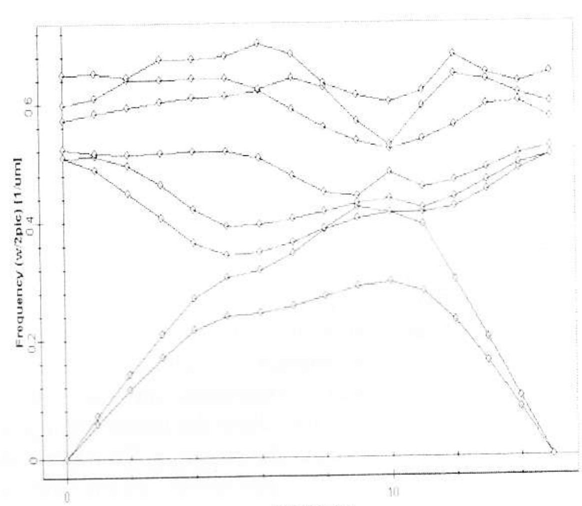

Fig. 2.2: The band structure with complete photonic band gap for square air holes in material of dielectric constant, $\varepsilon = 7.1$ for filling fraction, $f = 0.68$ and air hole orientation angle, $\theta = 30°$.

Dependence of threshold dielectric constant on orientation angle and filling fraction has shown in the figure 2.3 and figure 2.4 respectively.

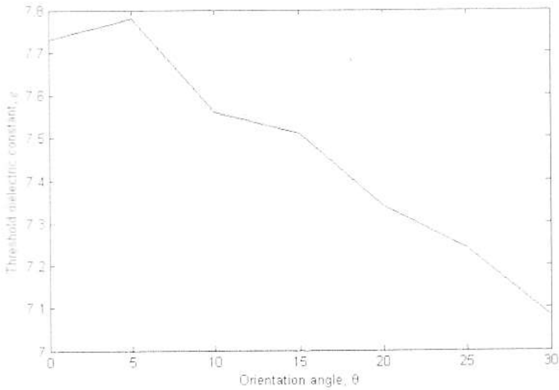

Fig. 2.3: Dependence of threshold dielectric constant, ε on the orientation angle, θ (with filling fraction, f = 0.68).

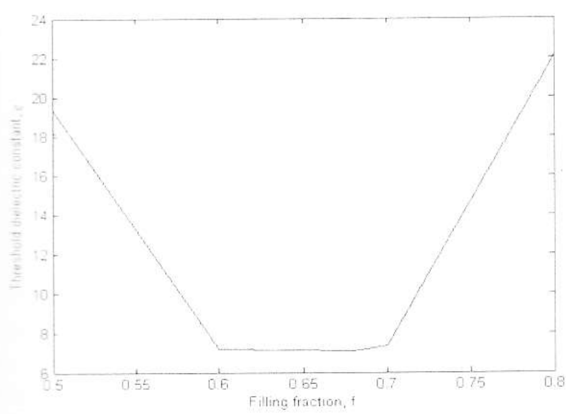

Fig. 2.4: Dependence of threshold dielectric constant, ε on the filling fraction, f (with orientation angle θ = 30°).

3. Conclusion:

The bandgap properties of two dimensional photonic crystals created by square lattices of dielectric rods in air background and air holes in dielectric background, for different refractive index contrast, have been investigated. By reducing the refractive index from some large values (e.g. for Si) to lower values slightly above the threshold, it can be possible to obtain far more fabricable periodic structures for experiment due to an increase in the wavelength-to-period ratio [9] and also it can also be possibleto fabricate planar photonic crystals structures based on dielectric materials with low refractive index contrasts.

References:

1. J. D. Joannopoulos, Pierre R. Villeneuve and Shanhui Fan, "Photonic Crystals", solid state communications, 102, pp. 165-173(1997).
2. J. D. Joannopoulos, S G. Johnson, J. Winn, R. Meade, "Photonic Crystals: Molding the Flow of Light," Princeton University Press, New Jersey, 2008.
3. R.Z. Wang, X.H. Wang, B.Y. Gu, G.Z. Yang, "Effects of shapes and orientations of scatterers and lattice symmetries on the photonic band gap in two-dimensional photonic crystals," J. Appl. Phys. 90, 4307 (2001) .
4. J.D. Joannopoulos, R.D. Meade, J.N.Winn, "Photonic Crystals: Molding the Flow of Light," PrincetonUniversity Press, Princeton, pp. 133 (1995).
5. K.M. Ho, C.T. Chan, C.M. Soukoulis, "Existence of a photonic gap in periodic dielectric structures," Phys. Rev. Lett. 65, 3152 (1990).
6. R.D. Meade, K.L. Brommer, A.M. Rappe, J. Joannopoulos, "Existence of a photonic band gap in two dimensions," Appl. Phys. Lett.61, 495 (1992).
7. C. M. Anderson, K. P. Giapis, "Symmetry reduction in group 4mm photonic crystals," P. Review B, Vol. 56, pp. 7313(1997).
8. Md. AhsanHabib, ChowdhuryGolam Sufi Al-Amin, Muhammad Sharifuzzaman Khan, Ibrahim Azad, Saeed Mahmud Ullah and ShahidaRafique, "Complete Bandgap in 2D Photonic crystal with square Bravais lattice," International Conference on Photonics, 2010, Langkawai, Malaysia.
9. A. Argyros, T. A. Birks, S. G. Leon-Saval, C. M. B. Cordeiro, F. Luan, P. St. J. Russell, "Photonic bandgap with an index step of one percent," Optics Express, Vol. 13, pp. 309-314 (2005).