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Electromagnetic Wave Propagation in One-Dimensional Photonic Crystal

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Abstract : *The photonic crystal have become a rapidly growing area of research with their vast application areas. A Photonic crystal exhibits characteristics that depends on various parameters such as crystal lattice, dielectric used, defects dimensions, propagation of light etc. In this work, we have drawn photonic band gap (PBG) Crystal Layout and these structure are simulated using OptiFDTD simulator in Optiwave software. A report on various parameters of different crystal structures which are generally used for sensor designing application are given along with their some APML parameters in different frequency values which help designers to choose a better structure depending on the application requirements. In a Photonic crystal structure, there are number of geometrical and electrical parameters which can critically affect crystals characteristics. During simulation, none of the parameters were varied, which helped us in understanding the influence of each geometrical difference in a structure, with the help of simulation, we obtained best possible Photonic crystal structure.*

Keywords: *1D Photonic Crystals, PBG Layout, FDTD Method, opti FDTD*

Introduction:

Photonic crystals have been studied in one form or another since 1887, the term 'photonic crystal' was first used over 100 years later, after Eli Yablonovitch and Sajeev John published two milestone papers on photonic crystals in 1987. Before 1987, one-dimensional photonic crystals in the form of periodic multi layers dielectric stacks (such as the Bragg mirror) were studied extensively (Yablonovitch, 1987).

Photonic crystals are materials with a spatial periodicity in their dielectric constant. Under certain conditions, photonic crystals can create a photonic band gap i.e. a frequency window in which propagation through the crystal is inhibited (Sajeev, 1987). Light propagation in a photonic crystal is

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similar to the propagation of electrons and holes in a semiconductor (Pochi Yeh et.al, 1977).

Photonic crystals are artificial structures with a periodic variation of refractive index. Photonic crystals are the optical media represented by natural or artificial structure with periodic modulation of the refractive index. Such optical media have some peculiar properties which gives an opportunity for a number of applications to be implemented on their basis. On the basis of periodicity the photonic crystal can be divided into three broad categories: One-dimensional photonic crystal, Two-dimensional photonic crystal and Three-dimensional photonic crystal. The photonic crystal, which is periodic in one direction and remains homogeneous in other two directions, is called one-dimensional photonic crystals. The photonic crystal which is periodic in two directions and is homogeneous in third dimension, is called two-dimensional photonic crystal. The photonic crystal which are periodic in all directions, is called the three dimensional photonic crystals (Joannopoulos et.al, 1997).

One of the most interesting properties of photonic crystals is the localization of defect mode in the band gap frequency region. In ordinary solids or crystals, the band that is above the band gap is known as conduction band and the band which is below the band gap is known as valance band. When we add some foreign atom in this crystals then it breaks the translational symmetry of the atomic potential then we call there is some defects (Pendry, 1999).

In one dimensional photonic crystal, electromagnetic wave can be constrained to propagate in between two thin sheets when one surface supports transverse magnetic polarized surface waves and the other supports transverse electric polarized surface waves.

Materials and Methods :

(A) Maxwell's equations: In order to study the propagation of electromagnetic wave in photonic crystal, the Maxwell's time-dependent equations in c.g.s. unit were used,

$$\nabla . B = 0$$

$$\nabla . D = 4\pi\rho$$

$$\nabla \times E = -\frac{1}{c}\frac{\partial B}{\partial t}$$

$$\nabla \times H = \frac{4\pi}{C}J + \frac{1}{C}\frac{\partial D}{\partial t}$$

For free space, charge density, J=0 then the above curl equations reduces to

$$\nabla \times E = -\frac{1}{C}\frac{\partial B}{\partial t}$$

$$\nabla \times H = \frac{1}{C}\frac{\partial D}{\partial t}$$

For linear isotropic media, the constitutive equations are:

$$D = \in E$$

$$B = \mu H$$

Substituting $B = \mu H$ in the above curl equations, we get,

$$\nabla \times E = -\frac{\mu}{C}\frac{\partial H}{\partial t}$$

$$\nabla \times H = \frac{\in}{C}\frac{\partial E}{\partial t}$$

For nonmagnetic medium, where, μ is the magnetic permeability in free space. Then the above equation reduces to

$$\frac{\partial H}{\partial t} = -\frac{c}{\mu}(\nabla \times E)$$

$$\frac{\partial E}{\partial t} = \frac{C}{\in}(\nabla \times H)$$

(B) Finite Difference Time Domain Method: Finite difference time domain (FDTD) method solves Maxwell's equations in the time domain using finite-difference approximations. Being a time domain method, FDTD is more intuitive than other techniques and works by creating a 'movie' of the field flowing through a device (Johnson and Joannopoulos, 2002). Finite-difference approximations are used to approximate time and space derivative in Maxwell's differential equations. The Yee algorithm, the FDTD algorithm as first proposed by Kane Yee in 1966 employs second-order central differences (Schneider, 2010). The algorithm can be summarized as follows:

1. Replace all the derivatives in Ampere's and Faraday's laws with finite differences. Discretize space and time so that the electric and magnetic fields are staggered in both space and time.
2. Solve the resulting difference equations to obtain update equations that express the (unknown) future fields in terms of (known) past fields.
3. Evaluate the magnetic fields one time-step into the future so they are now known (effectively they become past fields).
4. Evaluate the electric fields one time-step into the future so they are now known (effectively they become past fields).
5. Repeat the previous two steps until the fields have been obtained over the desired duration (Robinson and Nakkeeran, 2012).

(C) Stability Condition: One-dimensional stability condition is given by,

$$\Delta t = \frac{\Delta x}{c}$$

(D) Boundary Condition in One-dimension: Periodic boundary condition for one-dimensional photonic crystal is given by,

$$E^{n+1}(i,j) = E^{n-1}(i,j+1) + \frac{c\Delta t+\Delta y}{c\Delta t-\Delta y}[(i,j+1) + (i,j)] - [(i,j) + (i,j+1)]$$

Results and Discussion:

For simulation, the number of anisotropic PML Layers: 10, theoretical reflection coefficient: 1.0e-12, real anisotropic PML tensor parameters: 5.0, power of grading polynomial: 3.5 and wavelength: 1.9µm was taken in boundary condition dialog box. After putting these values PBG layout of 1-D Photonic Crystal was run in OptiFDTD Analyzer and result obtained is shown in Fig 1.

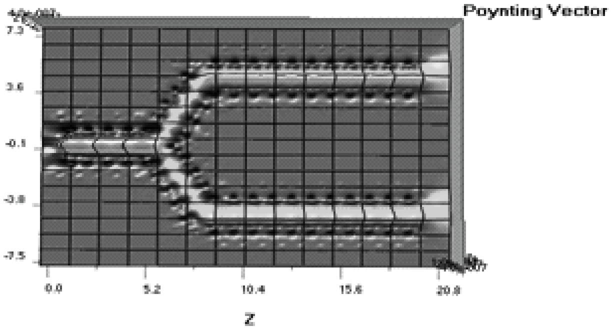

Fig. 1. PBG Layout in OptiFDTD Analyser

After simulation, the observation point analysis was started and observation area analysis in dynamic time domain and frequency domain in TE Mode was obtained as shown in Fig 2.

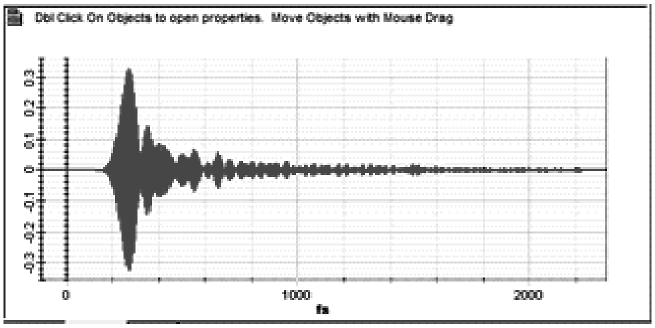

Fig. 2. Dynamic time domain and Frequency domain response in TE Mode

The observation area analysis in dynamic time domain and frequency domain was seen as shown in Fig 3.

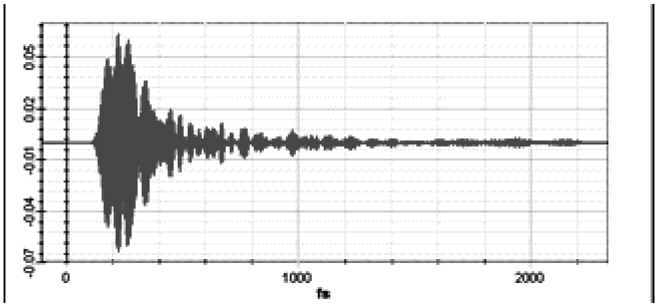

Fig. 3. Dynamic time domain and frequency domain response in TM Mode

The minimum frequency 1.5µm and maximum frequency 2.3µm in Frequency DFT was taken and the observation area analysis graph in TE mode was seen as shown in Fig 4.

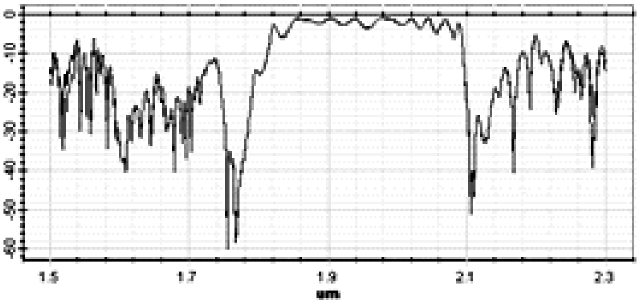

Fig. 4. Observation Area Analysis Graph in TE Mode

By putting the same values of frequencies and the observation area analysis graph was obtained in TM Mode as shown in Fig 5.

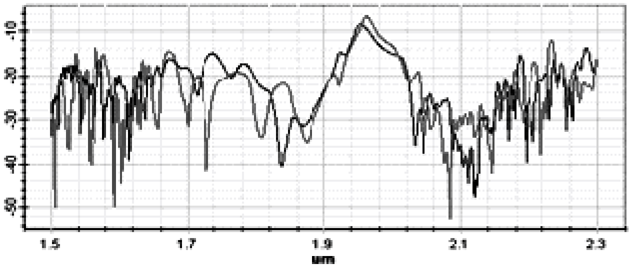

Fig. 5. Observation Area Analysis Graph in TM Mode

The minimum frequency 1.5µm and maximum frequency 2.0µm in Frequency DFT was taken and seen the observation area analysis graph in TE Mode as shown in Fig 6.

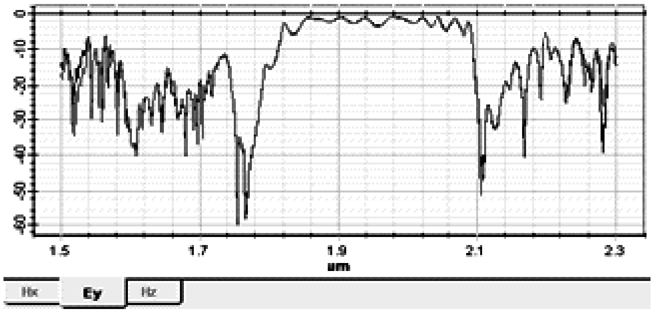

Fig. 6. Observation Area Analysis Graph in TE Mode

The same values of frequencies (minimum= 1.5µm and maximum= 2.0µm) was taken and the Observation Area Analysis Graph was obtained in TM Mode as shown in Fig. 7.

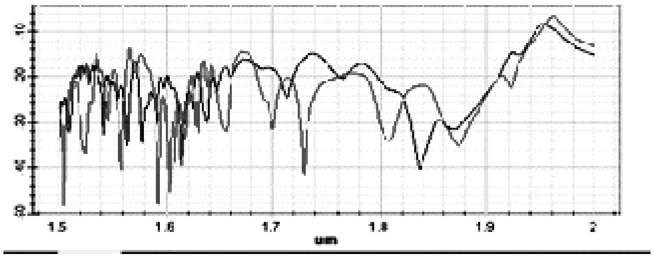

Fig. 7. Observation Area Analysis Graph in TM Mode

The minimum frequency 1.0µm and maximum frequency 2.3µm in Frequency DFT was taken and the observation area analysis graph was obtained in TE mode as shown in Fig. 8.

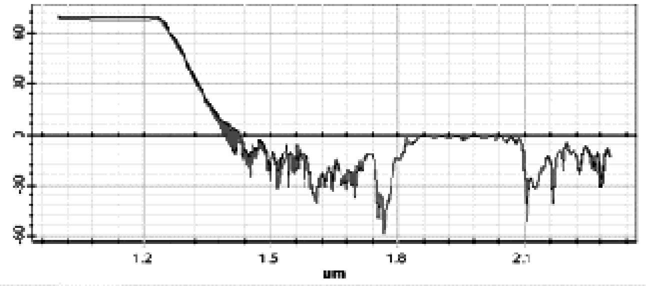

Fig. 8. Observation Area Analysis Graph in TE Mode

The same values of frequencies (min.-1.0µm max.-2.3µm) was taken and the observation area analysis graph in TM Mode was obtained as shown in Fig. 9.

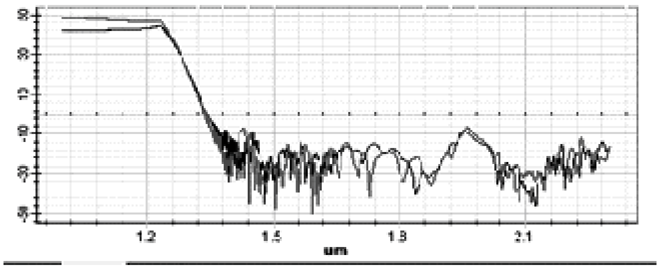

Fig. 9. Observation Area Analysis Graph in TM Mode

The minimum frequency 1.8µm and maximum frequency 3.0µm was taken in Frequency DFT and the observation area analysis graph in TE mode was obtained as shown in Fig. 10.

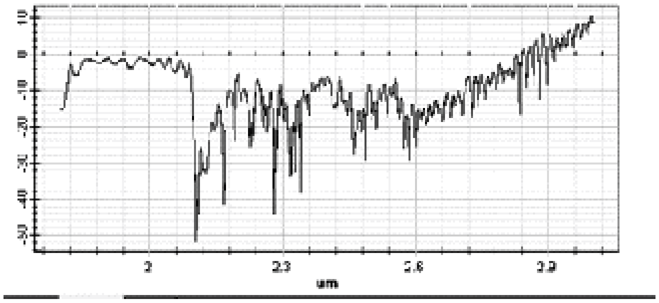

Fig. 10. Observation Area Analysis Graph in TE Mode

The same values of frequencies (min.-1.8µm max.-3.0µm) was taken and the observation area analysis graph in TM Mode was obtained as shown in Fig. 11.

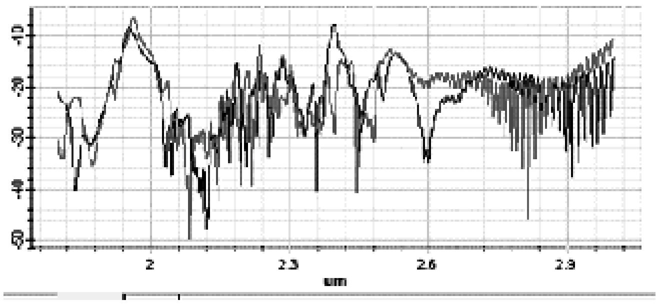

Fig. 11. Observation Area Analysis Graph in TM Mode

Conclusion:

Simulation of electromagnetic wave propagation in one dimensional photonic crystal was studied, whose structure was generated starting from the PBG layout crystal. After finding the defective atom at point (8,0,0), (13,0,5) and (3,0,10) a new wave path in PBG layout was found. It was simulated at wavelength 1.9and finally lower frequencies and upper frequencies were taken as (1.5, 2.3 respectively and the observation area analysis graphs were obtained.

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