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Band Gap Computation of Two Dimensional Photonic Crystal for High Index Contrast Grating Application

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ABSTRACT
Two Dimensional Photonic Crystal (PHc) is convenient type of PHc, It refers to the fact that the dielectric is periodic in Two directions. The study of photonic structure by a simulation method is extremely momentous. At optical frequencies the optical density contained by two dimensional PHc changes periodically. They have the property to strong effect the propagation of light waves at these optical frequencies. A typical linearization method which solves the common nonlinear Eigen values difficulties has been used to achieve structures of the photonic band. There are two method plane wave expansion method (PWE) and Finite Difference Time Domain method (FDTD). These Methods are most widely used for band gap calculation of PHc's. FDTD Method has more smoothness and directness and can be explored effortlessly for simulation of the field circulation inside the photonic structure than PWE method so we have used FDTD Method for Two dimensional PHc's calculation. In simulation of Two Dimensional band structures, silicon material has 0.543nm lattice constant and 1.46refractive index.
KEYWORDS: Band Gap, FDTD, PWE, Photonic Band-gap material, Two Dimensional Photonic Crystal, High Contrast Grating.

I. INTRODUCTION

A nanotechnology explores very small structures of the size of a few nano-meters up to several 100 nano-meters. The wavelength of light is often greater then these miniature structures. The PHc are an important class of substantial structure studied in nanotechnology. [1]

Photonic crystal is the works of E.Yablonovitch and S. John [2-3]. These papers are committed to the possibility of spontaneous emission executive as well as the possibility of the radiation propagation control by using periodic structures. PHc are commonly 'honeycomb' configuration made of silicon. PHc can be alienated into three broad categories, namely one dimensional (1D), 2 dimensional (2D), and three dimensional (3D) Photonic Crystal structures. Illustration of 2D is shown in figure (1). [16]

2D Photonic crystal can have comparatively large variety of configurations, because it possesses periodicity of the permittivity along two directions, while in the third direction the medium is uniform. A good example of the 2D Photonic crystal is porous silicon with periodically arranged pores, which is represented by the silicon substrate with etched holes. Another example of 2D Photonic crystal is a periodically arranged system of dielectric rods in air. 2D Photonic crystal can also be found in nature. For instance, the pattern on the butterfly's wing and its rainbow play is caused by the light reflection from the microstructure on the wing.

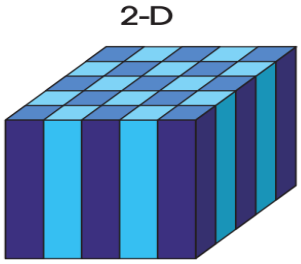

Fig. (1) Two Dimensional photonic crystal possesses periodicity of the permittivity along two directions, while in the third direction the medium is uniform.

Spontaneous radiation management [2–3]. This property of Photonic structures was predicted on dawn of Photonic crystal structures and it plays important role for the design of light sources on the basis of Photonic crystal structures. For the instance, the Photonic structures can be used to increase the efficiency and to lower the threshold current of semiconductor lasers. The 1D, 2D or 3D Photonic structures can also take a function of distributed reflectors [11-12], [15]. The second way to use the Photonic structure as the element for spontaneous radiation management is the design of principally new radiation sources [12–13]. In such sources, both pure Photonic crystal structures and Photonic

structures with defects which form the high quality resonators and provide the strong radiation localization inside the defect can be used for spontaneous radiation management and improvement of laser characteristics [8,9], [14].

II. Mathematical Preliminaries for calculation of band gap of two dimensional photonic crystal

To Compute the Band gap structure of two dimensional PHc, It play vital role to solve the Eigen problem for the two dimensional Helmholtz equation. [16] The Helmholtz equation for the Electric field is given in (a) equation.

$$\frac{\partial^2 Ez(x)}{\partial X^2} + \epsilon r(x)\frac{w^2}{c2} + Ez(x) = 0 \qquad (a)$$

So replication of Band gap structure is more appropriate to carry out using the equation for Magnetic field component. The equation in Magnetic field component takes as follows:

$$\frac{1}{\epsilon(x)} = \sum_{G''\epsilon G} x(G'').e^{(J.G''.x)} \qquad (1)$$

The distinction of above equation from the equation (a) lies in an operator. Here in equation (1) dielectric function stands in the interior of the co-ordinate derivatives, while in equation (a) it is exterior all derivatives. The dielectric function in the interior of operator occur some tribulations when finding for field distribution within the structure, such a form of Helmholtz equation is quite useful for band gap structure simulation. [5]

In order to resolve the Eigen value equation (a) some methods should be used which applied in the periodicity of the permittivity distribution. Some time, the Eigen function of an infinite periodic structure will also be periodic and infinite. That is way the Bloch theorem should be used for recitation the Eigen function of PHc. In the Bloch Theorem, such function has the following form. [6]

$$H(x) = h_{k,n}(x).\, e^{(j.k.x)} \qquad (2)$$

Where:-

$h_{k,n}(x)$ = periodic function with periodicity of lattice

n = state number

k = wave vector

As we cannot continue with the simulation of an infinite function in the equation, so we enlarge the function (1) to Fourier series by reciprocal lattice vectors.

$$H(x) = \sum_G h_{k,n}(G)e^{(j.(k+G).x)} \qquad (3)$$

Where:-

$h_{k,n}(G)$ - formerly defined periodic function in describing of wave vector

Now spread out the Fourier series not permittivity but the inverted dielectric function as it written in equation (1) when it expand, after that we substitute all infinite function in equation (1) is:

$$\sum\frac{\partial}{\partial x}(x(G'').\, e^{(J.G''.x)}\ \frac{\partial}{\partial x}\ \sum h_{k,n}(G)e^{(j.(k+G).x)}$$

$$+\frac{w^2}{c2}\quad \sum_G h_{k,n}(G)e^{(j.(k+G).x)} = 0 \qquad (4)$$

Now Substitute G=G'+G"

So G" = (G-G') form [7], [17]

$$\sum_G\sum_{G'}\frac{\partial}{\partial x}(x(G\text{-}G').e^{(j.(G-G').x)}\cdot h_{k,n}(G')$$

$$\frac{\partial}{\partial x}.\, e^{(j.(k+G).x)} + \frac{w^2}{c2}\sum_{G'} h_{k,n}(G)\, e^{(j.(k+G).x)} = 0 \qquad (5)$$

Then taking Derivative and added the exponents and then we get

$$\sum_G\sum_{G'} x(G\text{-}G').h_{k,n}(G').\, e^{(j.(G-G'').x)}\ X\ (j.(K+G).j.(k+G)$$

$$+\frac{w^2}{c2}\sum_{G'} h_{k,n}(G)e^{(j.(k+G).x)} = 0 \qquad (6)$$

The opinion on the basis $e^{(j.(k+G).x)}$ gives the equation.

$$-\sum_G' x(G\text{-}G')((k+G).(k+G').h_{k,n}(G') + \frac{w^2}{c2}h_{k,n(G)} = 0 \qquad (7)$$

This is known as 'Master Equation' for two dimensional PHc. where x (G") is Fourier expansion coefficient of the reversed dielectric function. [16]

III. USING FDTD ALGORITHM CALCULATION OF BAND-GAP

One of the finest ways to control the problems of Plane Wave Expansion method is to apply the FDTD method. In opponent to PWE method, The FDTD assign the possibilities of the refractive index changes during the numerically calculation procedure. [4]. which gives authorization to take into account losses and nonlinearity, when solve the band-gap structure. In 1966, H. Yu. D. Yang proposed FDTD algorithm. The most proficient used numerical method in meta-materials study is FDTD method. It is used for the directly solve the Maxwell equations. [16]

In general, PBG simulation using FDTD should be carried out as follows:-

(1.) Analyze the computation area.

(2.) Arrange the periodic boundary conditions.

(3.) Clarification of the radiation excitation function. The radiation spectrum should be wide sufficient to cover fully investigate the frequency range.
(4.) Takeaway the spectral scrutiny of the Time dependent response of the construction on the probe pulse by finding all of local maxima and then plotting them over frequency axis.
(5.) Reproduce the steps from b to d at different values of the phase shift in periodic boundary conditions equivalent to all selected points within the PHc Brillouin zone the Band Structure is solve for the program initialization is execute inside the 1st block.

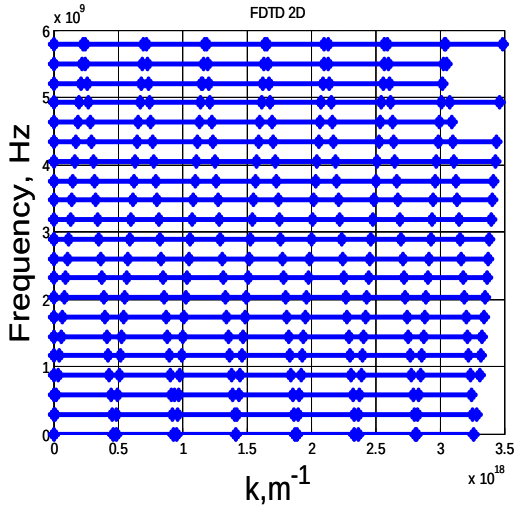

Fig.2. Two Dimensional Photonic Band-Gaps in between the frequency wa/2πc is plotted versus the wave vector k using FDTD 2D Method.

The program for the computation of 2D PhC band structure is much more complex than the one for 1D PhC. There are more peculiarities such as definition of permittivity distribution inside unit cell. That is why the program has seven blocks. Let us consider them in detail. The first block is for the variables initialization. Here, the parameters of the structure and the computation accuracy are defined. The PhC is defined by the lattice constant and the elements radius. The number of plane waves and the number of points in k-path determine the accuracy of the computation. In the second block, the permittivity distribution inside the unit cell is defined. Here, we consider the PhC with square lattice and circular elements so the definition is carried out by one loop. After this block is computed, we have three 2D arrays containing x-coordinate of each point, y-coordinate of each point and the permittivity values within these points. The third block sets up the k-path and the set of reciprocal lattice vectors. Since we consider the PhC with square lattice with side a, the Brillouin dimensions are equal to 2π/a. In the fourth block, the Fourier expansion coefficients are computed for each value of G and Gwithin the above selected set. As in case of 1D PhC, the Fourier expansion coefficients are computed before the matrix differential operator formation since it does not depends on the wave vector. The fifth block forms the matrix differential operator using stored values of the Fourier expansion coefficients. In the sixth block, the eigen-values of matrix differential operator are found at each value of wave vector within the k-path and stored to the array. The stored eigen-values are then plotted as function of the wave vectors taken from the k-path array. We may plot several lower eigen-values only since the PBGs are usually observed at low frequencies in strictly periodic 2D PhCs. The axes are then signed.

TABLE I
BAND GAP OF TWO DIMENSIONAL PHOTONIC CRYSTAL

PARAMETERS	Values
Lattice Constant	0.543nm
Refractive Index	1.46
Accuracy	48
Thickness of Layers	L1= 0.2 L2= 0.8
Light Speed in Vacuum	3e8
Method used	FDTD
Material	Silicon

The results are shown in Fig. (2). However, the values on the horizontal axis differ from those of 1D band structure. Here, we set the wave vector values from the Brillouin zone symmetry points. Only with this technique we can plot the 2D PhC band structure.

IV. CONCLUSION

The Band-gap from Fig (2) I have concluded the band-gap of silicon material is uniform and hence it can be used designing nano-optical devices like High Contrast Grating and the program for the computation of 2D PhC band structure is much more complex than the one for 1D PhC

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