Transmission Spectrum Analysis of Two-Dimensional Photonic Crystals Infiltrated with Nematic Liquid Crystal

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Abstract— In the past two decades, there has been a growing interest on artificially fabricated material called Photonic Crystal as a material for controlling the electromagnetic waves due to its remarkable properties. The Photonic Band Gap of the Two-Dimensional Photonic Crystal containing nematic liquid crystal is investigated using Plane Wave Expansion (PWE) Method. Then, the Band Structure and the Reflectance Spectrum analysis are also done. The results show that the Two-Dimensional Photonic Crystal can be tuned according to desired properties by means of introducing the liquid crystal. Thus with the proper use of design parameters of PBG, many advanced devices can be modeled with desired properties. Here a simple waveguide is designed which makes the signal propagation horizontally.

Key words: Photonic Crystal, Photonic BandGap, Reflection Spectrum, Nematic Liquid Crystal, Plane Wave Expansion

I. INTRODUCTION

Photonic Crystals are artificial dielectric periodic structure similar to semiconductor crystals in the way that it affects the propagation of electromagnetic (EM) waves as do the semiconductor crystals affects the flow of electrons through it. The wavelengths which are allowed to travel through these Photonic Crystals are called as modes. A group of such modes is called bands. Conversely, those wavelengths which are not allowed through them are called as Photonic BandGap (PBG) like the Forbidden Energy Gaps in the semiconductor crystals [5-7]. Thus, Photonic Crystal seems to be a periodic modulation In the dielectric properties. The property of the Photonic Crystal varies according to the type of the constituent used and the geometrical property of it. The PBG of the Photonic Crystals depends upon the polarization and the incidence angle of the electromagnetic waves [1-4]. In this paper, Two-Dimensional Photonic Crystal is chosen which shows periodicity of the permittivity in two directions while in the third direction the medium becomes uniform. Basically, the 2 D Photonic Crystal exist in two types of configurations viz. hole type and cylinder type. Here, a hole-type 2 D Photonic crystal is infiltrated with a liquid crystal in nematic phase. Liquid Crystals are which posses the features of both solid and fluid state and the variation of their phases is due to their mobility of the individual atoms or molecules. Due to their elongated shape, under certain conditions, the molecules orient themselves orderly and axes line up and form the Nematic Liquid Crystal. Aligned Liquid crystals possess uniaxial properties of crystals which makes them useful in wide range of applications. Because of the high speed, broader bandwidth, low losses of the Photonic devices, they can be used as optical ICs[14-18]. 2D Photonic Crystal has wide range of application like lasers, high speed switches, waveguides, mux/de-mux, sensors, lasers, solar cells, etc.,.

The rest of the paper is organized as follows: Section II presents the Plane Wave Expansion Method. Section III presents the Design Approach. Section IV presents the Results and Discussion and finally the paper is concluded in Section V.

II. PLANE WAVE EXPANSION

Plane wave Expansion is done by calculating the eigen vectors and eigen values from the matrix formed by the electrical wave equations and the solving the Maxwell's equation. The biggest advantage of PWE method is that it gives high performance and allows computing band structure for even more complicated structures. Here a numerical method is used rather than reflecting a plane wave on the structures and the analyzing with the help of Spectrometer. In this analysis, the finite thickness of the waveguide is neglected and the 2D is assumed to be pure where it has uniform dielectric constant along the third dimension.

Then we consider that the hole radii and the shapes of the 2 D hole type Photonic Crystal are of same sizes which in practical may have some deviations. Also all kinds of dispersion and the absorption of the material of PhC are neglected. The Fourier Expansion Coefficients are calculated from the dielectric functions and then inversed lattice vectors are found which will be useful in finding the matrix differential operator. Then the eigen states and eigen vectors are calculated from the matrix where transforming the eigen states to form the normalized frequency for the band structure computation.

III. DESIGN APPROACH

In order to utilize the Photonic Band Gap property of the 2 D photonic crystal for designing different optical devices, the PhC should be able to tuned according to the requirements. Hence, the Liquid Photonic Crystal, Nematic is introduced in between the holes of the 2 D Photonic Crystal. Here, the structure is designed as an 7X7 square array with 4.65 X4.65 micron dimension with 0.45 space in between the structures. The permittivity of the Liquid crystal is taken as 6 which is filled inside the Silicon Photonic Crystal as 11.7.

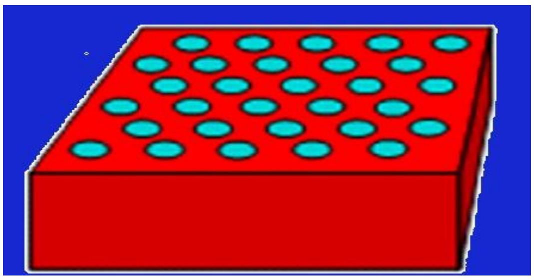

Fig. 1: 2D hole type Photonic Crystal

This introduction behaves as the defect in the crystal so that the material can be tuned accordingly.

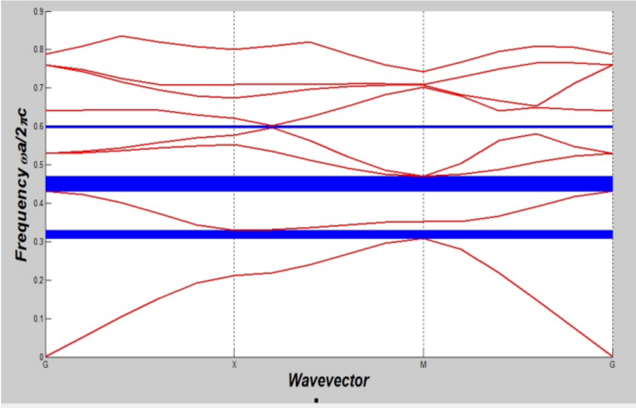

Fig. 2: The Band Structure of 2 D Photonic Crystal

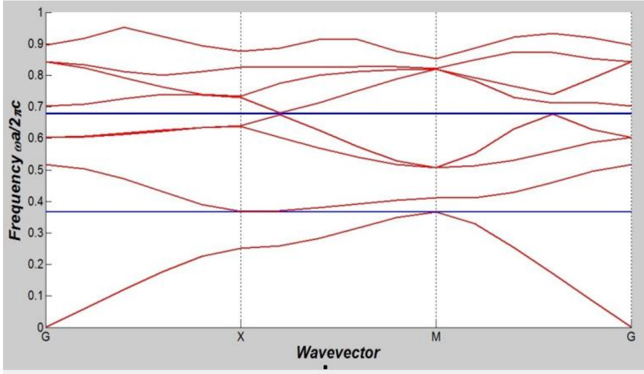

Fig. 3: The Band Structure of 2 D Photonic Crystal with defect

The Figures 2&3 show how the different ranges of bands with varying widths are formed inside the material which is called the Band Structure. The blue lines in the figure represent the bands in which the signal gets reflected and no propagation is done. While introducing the defect, the band structure gets changed and thus the propagation and the reflection bands varies as seen in the above figures, which shows that the liquid crystal can be used in the effective tuning of the device.

In practical case, we need to develop a Photonic Crystal with the Photonic Band Gap at the specified set of frequencies for which certain parameters are needed like size of the elements. Hence PBG maps are used in this case, which is formed by the projection of the PBG obtained at different PhC parameter.

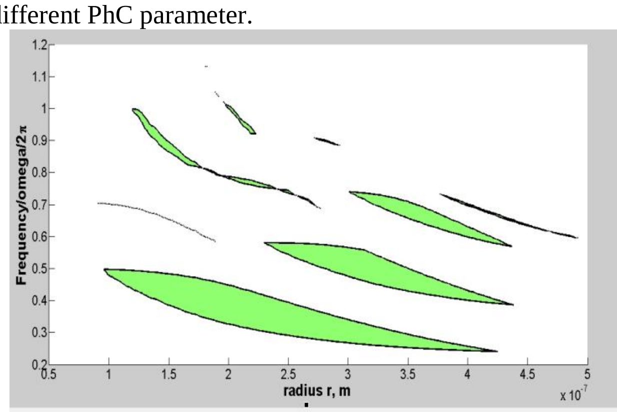

Fig. 4: shows the PBG map

The Figure 4 shows the PBG map which again gives a clear view of band structure computed for making the calculation and the design of the optical device much easier.

IV. RESULTS AND DISCUSSION

In continuation with the above computations, the reflectance spectrum of the material is investigated. It is done by taking the amplitudes of the backward waves and dividing them by the incident wave. Likewise, it is done for different wavelengths.

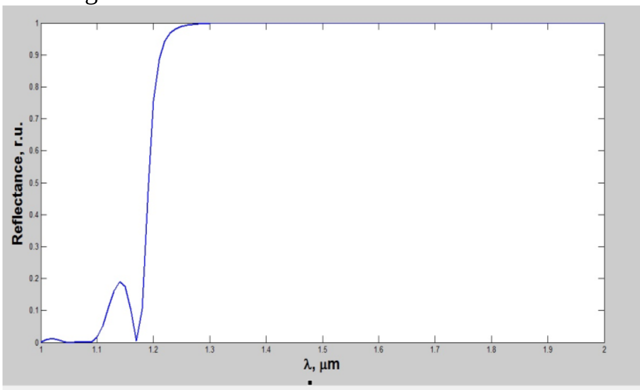

Fig. 5: Reflectance Spectrum of 2D PhC

Figure 5 shows the reflectance spectrum of 2D PhC. The Reflectance Spectrum gives the direct way of finding those set of wavelength which is accepted or rejected inside the material.

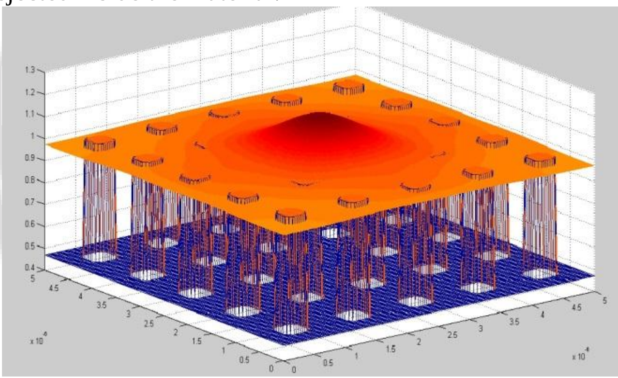

Fig. 6: Mode Distribution inside the Photonic Crystal

The figure 6 shows how different modes are distributed inside the 2D PhC which is actually the electric field distribution inside the material for 5X5 array structure.

Finally, the waveguide is designed by taking the above calculations (7X7 array structure) and the frequencies into consideration using FDTD Method. The FDTD method uses time-dependent Maxwell's Equation which is discretized by making approximations to space and time and the finite-difference equations are taken finally to get the solution. The computational domain specified, the E and H fields are determined at each and every point inside the computational region.

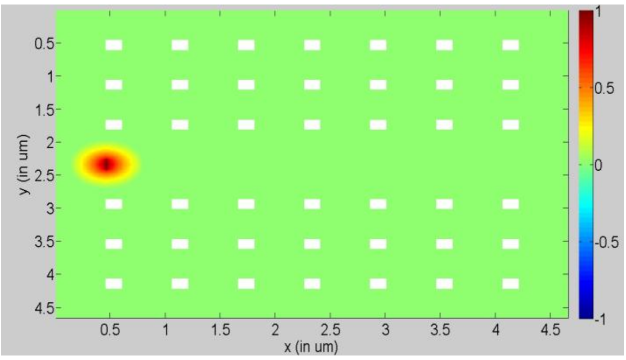

Fig. 7: Plot of Ez in the Waveguide at 2s.

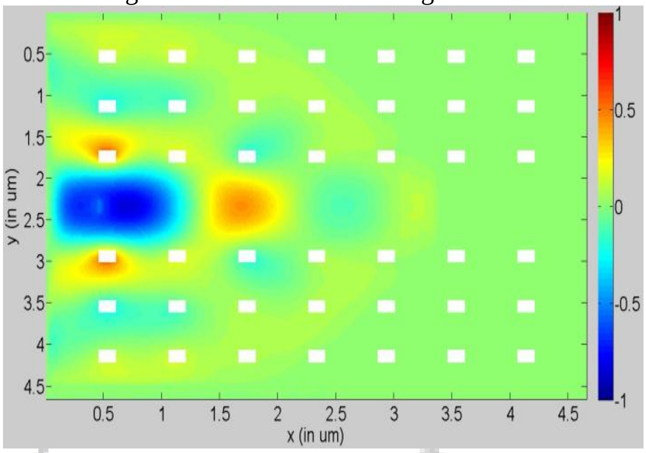

Fig. 8: Plot of Ez in the Waveguide at 8s.

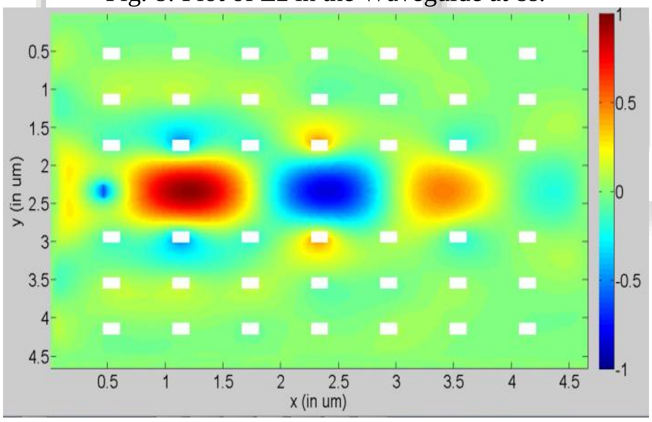

Fig. 9: Plot of Ez in the Waveguide at 20s.

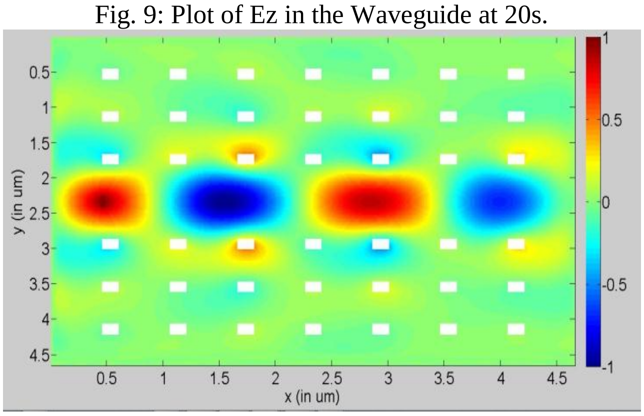

Fig. 10: Plot of Ez in the Waveguide at 35s.

The above figures from 7-10 show the propagation of the signal inside the waveguide along Z-direction. It represents the Ez field of the signal which travels in the waveguide

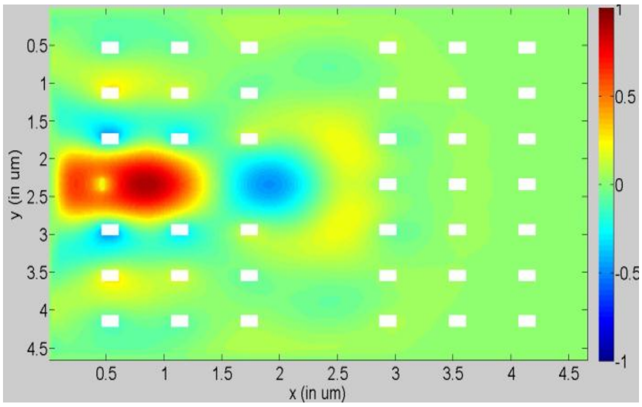

Fig. 11: Plot of Ez in the T-Waveguide at 5s.

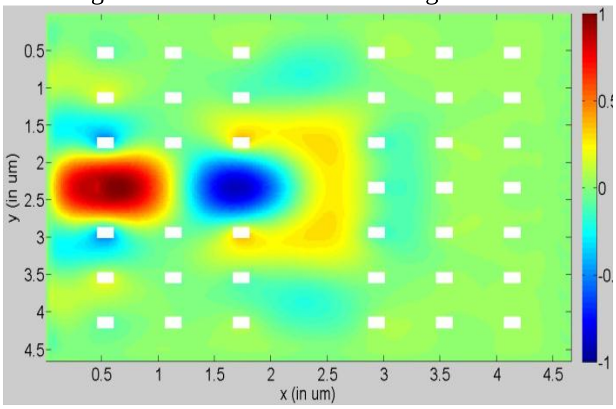

Fig. 12: Plot of Ez in the T-Waveguide at 10s.

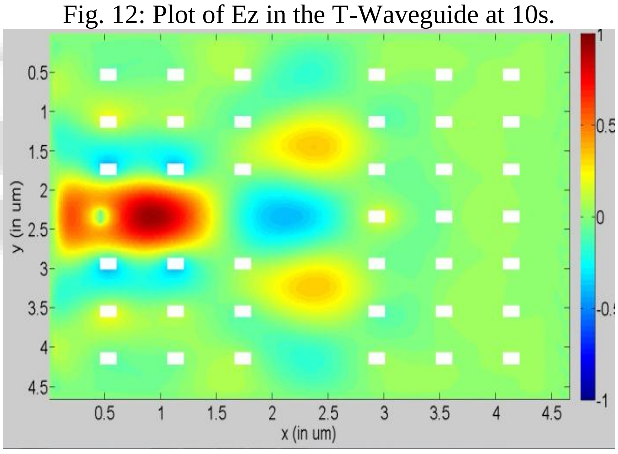

Fig. 13; Plot of Ez in the T-Waveguide at 10s

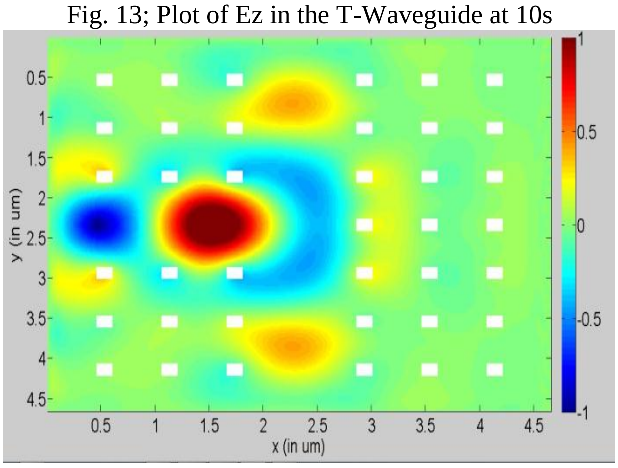

Fig. 14: Plot of Ez in the T-Waveguide at 20s.

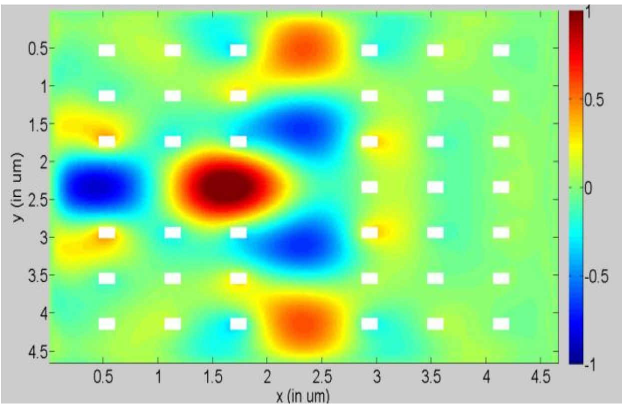

Fig. 15: Plot of Ez in the T-Waveguide at 35s.

Figures 11-15 shows the propagation of the signal inside the T-junction Waveguide. The same analysis was done for T-junction of the waveguide maintaining all the other parameters and dimensions of the material as same. Thus the feasibility of using the Photonic Crystal as waveguide is tested with both straight line transmission and T-junction type of waveguides.

V. CONCLUSION

The tunability of the 2 D Photonic Crystal with the Nematic Liquid Crystal is investigated. The Band Structure and Reflectance Spectrum Computations are done and finally the waveguide is designed for horizontal propagation and a T-junction propagation. The above analysis shows how the light wave inside the Photonic Crystal can be wisely tuned according to the desired requirements, which opens up applications in designing the Photonic Integrated Circuits. Further experiments and analysis are required to make the devices realizable.

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