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DESIGN OF A WIDEBAND 1×2 Y-BRANCH OPTICAL BEAM SPLITTER USING GaAs BASED PHOTONIC CRYSTAL

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ABSTRACT

In this paper we have designed a two dimensional GaAs based photonic crystal Y-branch beam splitter which has one input terminal and two output terminals. Using single mode light source and FDTD analysis we have found a higher bandwidth valued 78% and also increased output power efficiency which is valued 93%. This increased bandwidth will give us faster data transfer capability which can be a great aspect for respective communication system.

KEYWORDS: Photonic Band Gap (PBG), Bandwidth, Photonic Crystal (PHC), Finite Difference Time Domain (FDTD), Gallium Arsenide (GaAs).

I. INTRODUCTION

Beam splitter is a very useful waveguide device, which divides the power in an input equally between the designed numbers of outputs. Like the bend, the photonic band gap eliminates radiation loss and we need only deal with the possibility of reflection [7]. Unlike the bend, it turns out that we cannot eliminate reflections by a symmetry argument, and must do something counterintuitive. We need to obstruct the output in order to increase transmission. In the year 2000 Mehmet Bayindir, B. Temelkuran, and E. Ozbay [8] achieved nearly 45% transmission at each arm for certain frequency range in a Y-branch beam splitter. Rab Wilson, Thomas J. Karle, I. Moerman and Thomas F. Krauss proposed a design of Y-branch beam splitter having high power transmission upto 84%. In 2002 Alongkarn Chutinan, Makoto Okano and Susumu Noda [1] seen that high transmission of more than 90% can be obtained in a certain frequency range using FDTD simulation. Chii-Chang Chen, Hung-Da Chien and Pi-Gang Luan [3] in the year 2004 proposed a 2-D photonic crystal beam splitter with one input ports and two output ports by introducing a point defect into orthogonally crossed line defects. In the year 2008 Mohammad Danaie, Amir Reza Attari, Mir Mojtaba Mirsalehi and Sasan Naseh [9] had achieved the bandwidth 24%. Our aim is to design a 2D single mode photonic crystal that will give us higher bandwidth with a moderate value of transmission coefficient and also increased output power efficiency.

II. MATERIALS AND METHODS

The physics of Photonic Band Gap (PBG) materials, or photonic crystals (PHCs), is conveniently described in similar form to the solid state physics of electronic materials, where electron wave scattering due to the periodically varying electric potential [10] is replaced by scattering of light from the periodic variations in the dielectric constant [5]. In this simulation we have used TM mode signal as our input at the input port. And we have used FDTD i.e. Finite Difference Time Domain analysis for our simulation. The Transverse magnetic(TM) mode is electromagnetic mode in which the magnetic field vector is normal to the incident plane (xz plane) in Figure 1 In the case of Transverse electric mode (TE mode), the electric field vector is normal to the incident plane (xz plane).

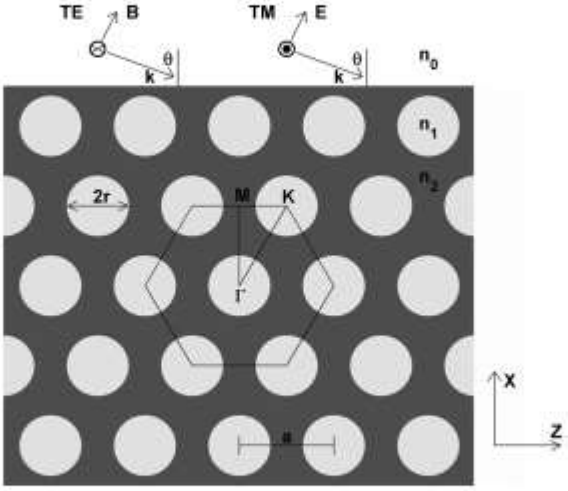

Figure 1: Schematic of beam splitter (which consists of dielectric holes with refractive index n_1 and radius r arrayed in triangle lattice in dielectric bulk with refractive index n_2, the incident wave vector k, and the electromagnetic mode convention. E and H are electric and magnetic field vectors, respectively [2].

The beam splitter we have designed has two types of materials. The dielectric rods of this photonic crystal lattice are made GaAs of refractive index (n) of 3.4 and Relative permittivity (ϵ) of 11.2. And rest of the structure is filled with air of Refractive index of 1.

Literature Review

The waveguide used to implement the beam splitter has a limited single mode bandwidth from 0.265 (a/λ) to 0.290 (a/λ) and it is desired to have a high transmission coefficient for all this region [9]. Therefore, it seems suitable to define the normalized bandwidth as the ratio of the transmission bandwidth of the beam splitter to the single-mode bandwidth of the waveguide. Using this definition the normalized bandwidth equal to $\frac{0.279-0.273}{0.29-0.265} = 24\%$ which can be seen from Figure 2.

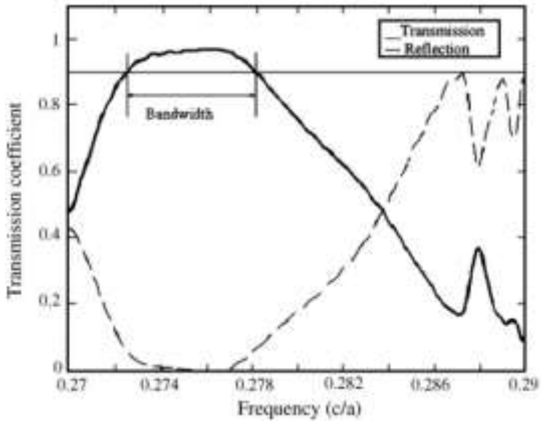

Figure 2: Transmission spectrum for a beam splitter of triangular slab of dielectric holes [9].

III. RESULTS AND DISCUSSION

Our proposed design shown in Figure 3. The structure of the beam splitter consists of three regions of input, bending and output. The bending is of 60°. The geometry is a (14 × 11) array of circular pillars in an air background. The dielectric rods are made of GaAs which have a high reflective index of 3.4 with a radius of 0.2a (where, a is denoted as lattice constant and its value is given in Table 1). The parameters of the proposed design is given in Table 1.Meshing size and mesh of beam splitter are given in Table 2 and Figure 4 respectively. The bandgap was determined using a dedicated software designed by some of the researcher of MIT which is shown in Figure 5. The bandgap was from 0.32(a/λ) to 0.44(a/λ) and light between this ranges is only allowed through the waveguide [6]. As we can see that light passes through the waveguide for a certain frequency 0.302(a/λ) (shown in Figure 6) and prohibited for another frequency 0.365(a/λ) (shown in Figure 7) in our proposed design.

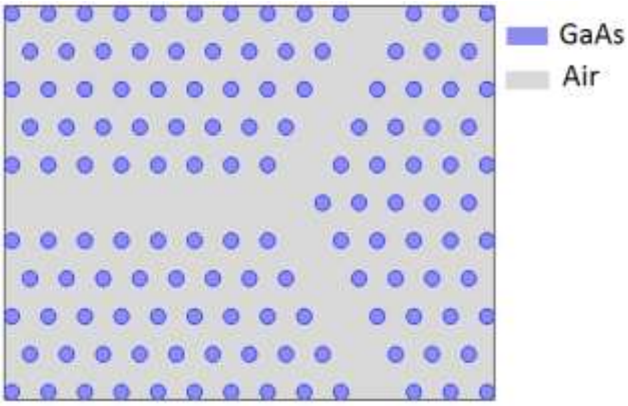

Figure 3: Proposed design of beam splitter

Table 1: Parameters of the proposed design

SYMBOL	EXPRESSION	DESCRIPTION
a	0.533 µm	Lattice constant
r	0.2a	Radius of GaAs pillar
w	13a+2r	Width of the boundary
λ	1550 nm	Center wavelength

Table 2: Meshing size of the proposed design

NAME	VALUE
Maximum element size	1.43
Minimum element size	0.114
Resolution of curvature	0.8
Maximum element growth rate	0.8
Predefined size	Extra Coarse

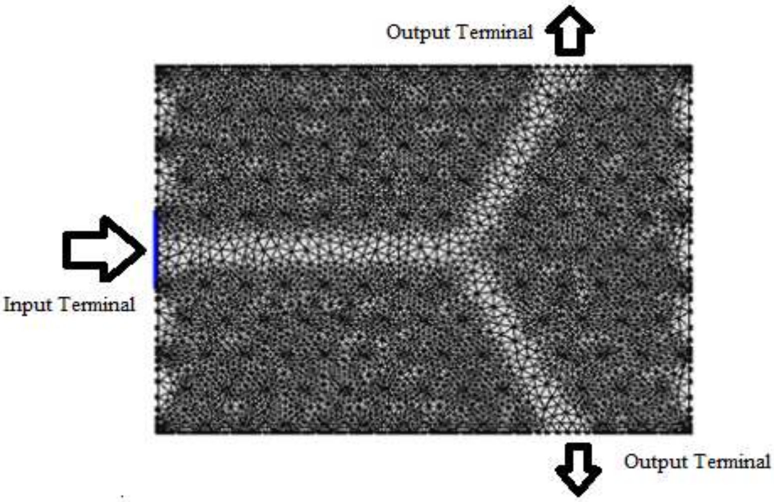

Figure 4: Mesh of the designed beam splitter

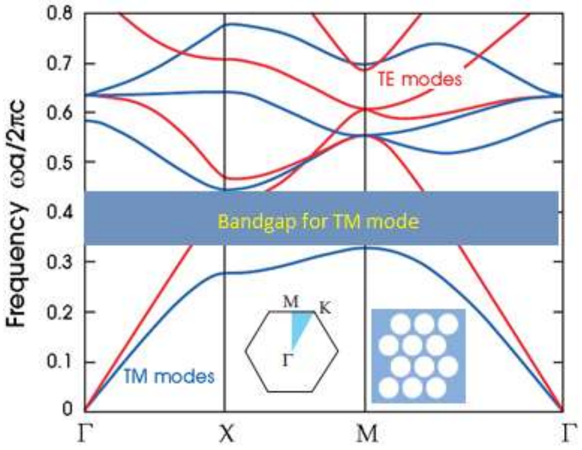

Figure 5: Bandgap of triangular lattice photonic crystal [4].

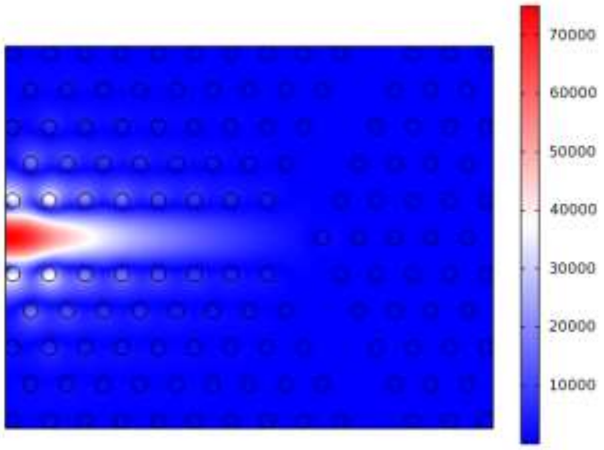

Figure 6: Signal prohibited to pass through the photonic crystal waveguide at normalized frequency of 0.302(a/λ)

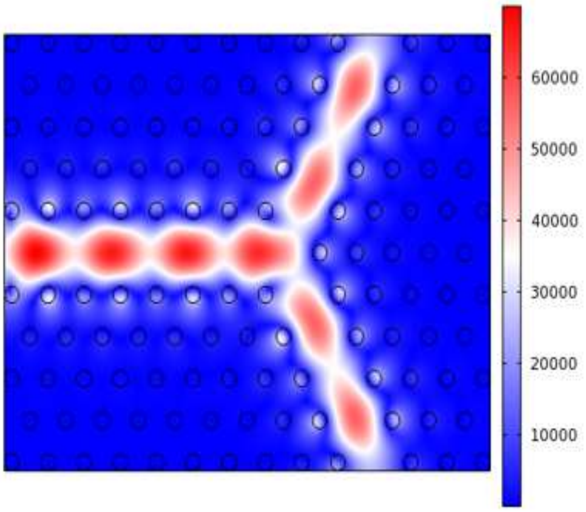

Figure 7: Signal allowed to pass through the photonic crystal waveguide at normalized frequency of 0.365(a/λ)

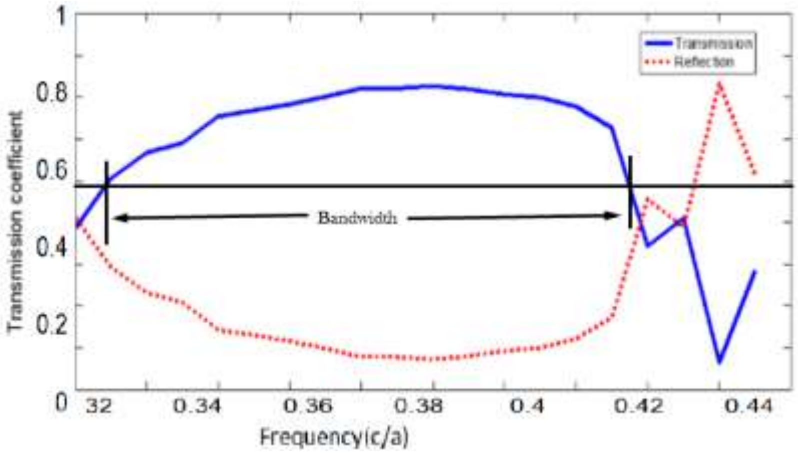

Figure 8: Transmission spectrum of proposed design

The final result of the proposed design was shown in Figure 8. The beam splitter has a normalized bandwidth equal to $\frac{0.415-0.322}{0.44-0.32} = 78\%$ which can be found by Figure 8. But as we know gain and bandwidth has inversely related to each other or for gain bandwidth mismatch the gain is slightly less i.e. 83% approximately. The total output power which is 93% approximately is shown in Figure 9. The comparison of the results is given in Table 3.

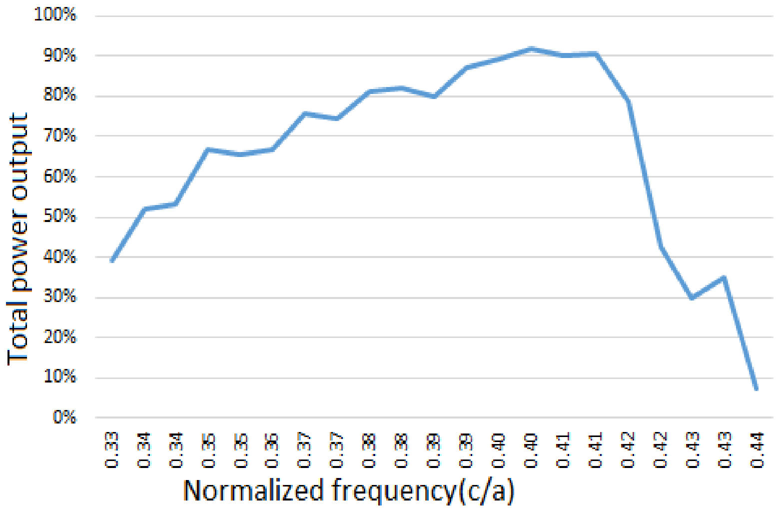

Figure 9: Total output power of the proposed design

Table 3: Comparison between proposed design and existing designs of beam splitters

DESIGNS	NORMALIZED BANDWIDTH	POWER EFFICIENCY
M. Danaie et al.'s sense [9]	24%	-
M. Bayindir et al.'s sense [8]	-	90%
Proposed Design	78%	93%

IV. CONCLUSION & FUTURE WORK

In this paper, light guiding properties of 2D defective photonic crystal waveguide based beam splitter and power efficiency have been investigated on Finite Difference Time Domain (FDTD) method with scattering boundary for mainly communication application. The design of a triangular lattice photonic crystal i.e. the ratio of lattice constant to the radius of GaAs pillars ensures wideband information transmission. The simulation results reveal wide normalized frequency band of 78% and efficiency about 93% which is the higher value comparing with other existing designs. This beam splitter has a modest number of design parameters and also the design is easy to fabricate as the radius of the circular pillar is more of the proposed design than the existing designs. Due to its noteworthy guiding and splitting properties, the designed Photonic Crystal Band gaps may be excellent candidate for communication application. This study can be extended to achieve appealing results while compensating the reflection coefficient and power loss. In this paper the input light signal is only single mode. A future task will be the compensation of reflection coefficient. Also multimode light source can be considered.

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