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Design and Analysis of all Optical Multiplexers using 2D Photonic Crystal

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ABSTRACT

The development of an all-optical, two-dimensional photonic crystal waveguide multiplexer (MUX) for optical signal processing and networking is the focus of this study. The paper proposes the design of 4×1 all optical multiplexer based on 2-D photonic crystal. The architecture, which has an air-filled background, uses two silicon square lattice rod T-shaped waveguides and one silicon square lattice rod Y-shaped waveguide. All-optical MUX developed the use of nonlinear materials, such as Kerr, to address challenges of less profit and nonlinearity. The beam-interference phenomena serve as the inspiration for this design. The performance of the optical MUX is modelled using a finite-difference time-domain method, and the results are then verified to employ the 1.55 m wavelength optical field distribution.

KEYWORDS

Crystal lattice; Photonic crystal (PhC); Multiplexer, Optical fibers; Photonic Band Gap (PBG).

1. INTRODUCTION

All-optical devices will ultimately replace electrical equipment due to their benefits over electrical equipment, such as their quick operational speed, low power consumption, and ability to tolerate noise, etc. Photonic crystal (PhC) devices are crucial for making optical devices with dynamic microstructures. Many times, all-optical multiplexer (MUX) devices employed data transfer systems to transport signals over single, shared channel as opposed to channels. Devices handle photon mobility by defining allowed and prohibited bandgaps. Faults can be introduced into the design that alter the characteristics of PhC devices by multiplying or removing dielectrics from some locations for fabrication of wavelengths. PhCs are always in demand in the field of communications systems because they require very little input to change and firmly restrict light. With the use of plasmonic waveguides, Kerr material, Mach-Zehnder interferometers, self-collimation techniques, and other all-optical innovations, researchers build all-optical devices.

One of the most promising technologies to date is the all-optical photonic integrated circuit (PIC) [1], which is also thought to be inescapable in the design of the parts for next-generation supercomputers [2]. The photonic crystal (PhC) [3-5] is one of the most promising platforms among the several design environments of all-optical PICs because the light propagation in it is governed by its special phenomenon, the photonic band gap. It has long been recognised that photonic crystal (PC) structures are the ideal medium for directing and controlling optical waves [6-8]. Scalability, photonic band gap (PBG), low loss, and cross-connected waveguides are the primary benefits of PC-based structures for developing optical devices [9]. Such devices are being investigated as prospective options for future optical computing and communication systems since they have a greater operational power requirement for switching but do not have a control on phase issue [10-13]. The goal is to reduce their operational power and miniaturise them.

In comparison to traditional waveguide devices, PhC-based optical devices provide several advantages, including power consumption and compactness. With a period of the order of an optical wavelength, PhCs are periodic structures. PhCs are the source of the photonic bandgap (PBG) because of the periodic distribution of the dielectric permittivity [14-15].

No electromagnetic waves are allowed to propagate inside this frequency range, regardless of the wave polarisation or wave vector. For regulating the optical beam propagation in PhC waveguides, the photonic band gap (PBG) resulting from periodic refractive index in one, two, or three dimensions has been exploited.

Localized modes in PBG are caused by PhC defects, and incident light sometimes propagates in PhC waveguides with nearly no diffraction along a specific direction [16]. New optical digital integrated circuits and all-optical signal processing systems use all-optical logic gates that are built on PhC waveguides as their fundamental building blocks.

2. PROPOSED STRUCTURE

Figure 1 presents the proposed design of 4x1 all optical multiplexer based on 2-D photonic crystal. The size of the proposed structure is 20µmx20µm with radius of silicon rods 0.25µm and lattice constant 1µm. Circular Si rods with a refractive index of 3.4 are selected as the dielectric rods surrounded by air for the design. Table 1 lists the important parameters for the proposed design of the multiplexer.

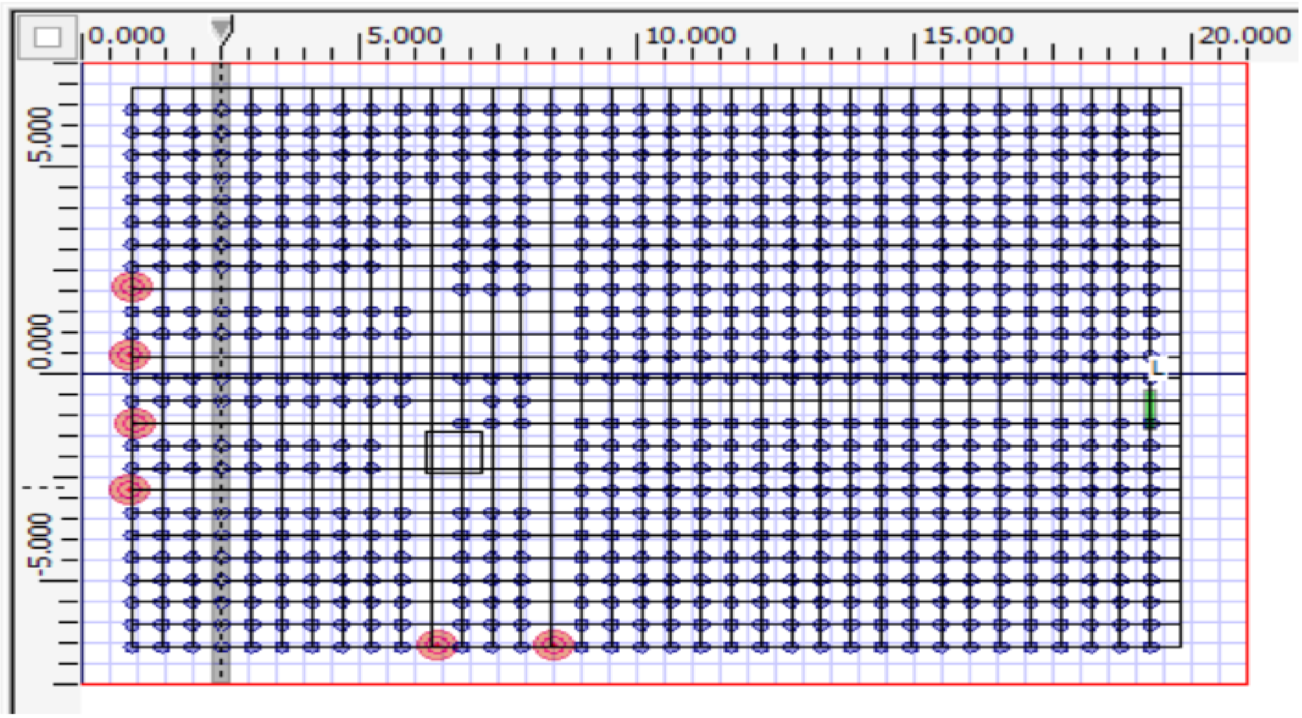

Fig.1: 4×1 multiplexer made by using 2D photonic crystals.

Table 1: Parameters of the presented structure of 4X1 mux:

PARAMETERS	MATERIAL/VALUE
Dielectric Rods	Silicon
Wafer Size	20µmx20µm
Size of crystal lattice	18x18
Refractive index of the rods	3.4
Radius of Rods	0.25µm
Lattice constant	1µm

The 4×1 multiplexer has 4 input lines, 2 select line and 1 output that has been shown in the layout above.

The simulation for 4×1 multiplexer made by using 2D photonic crystal. The 6 impact points in the picture shows the 4 inputs and 2 select line input present in the 4×1 multiplexer.

3. RESULT AND DISCUSSION

The recommended structure is modeled by finite difference time domain (FDTD) method utilizing several combinations of input. In this study, an all-optical 4×1 multiplexer was built without the need of nonlinear material employing 2-D PhC Y and T-shaped waveguides and square lattice silicon rods. Using the FDTD approach, the performance of the revised work was projected and validated. Figure 2 shows the Band diagram of 4×1 multiplexer. Figure 3(a), Figure 3(b), Figure 3(c), Figure 3(d), shows simulated results provided 4×1 mux for inputs s_0 =0 s_1=0, and s_0=0 and s_1=1, s_0=1 and s_1=0, and s_0 = 1 and s_1=1 respectively.

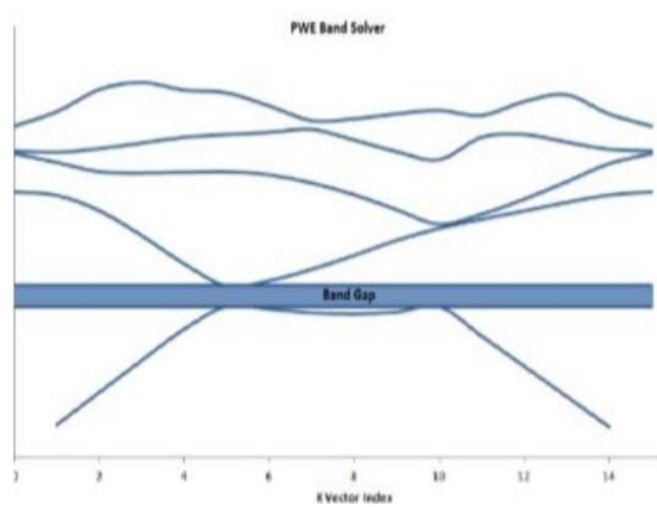

Fig. 2: Band diagram of presented structure of 4×1 multiplexer.

The blue colored portion represents forbidden gap. The band gap ranges from 0.316417<=0.359838 having a band gap breadth of 0.0425.

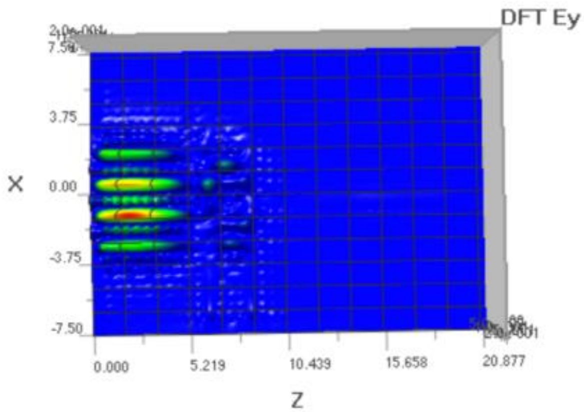

Fig. 3(a): Simulated results provided 4×1 mux for inputs s_0 =0 and s_1=0

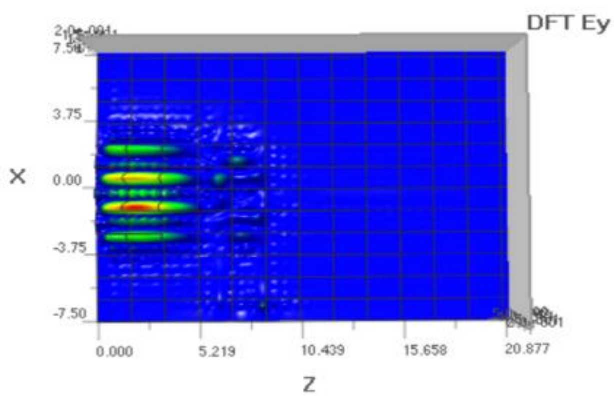

Fig. 3(b): Simulated results provided 4×1 mux for inputs s_0=0 and s_1=1

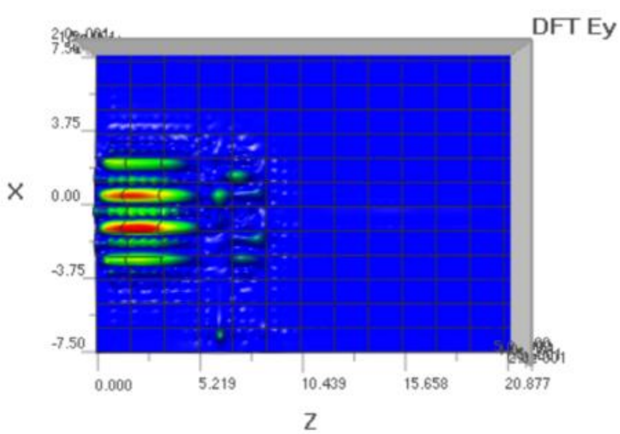

Fig. 3(c): Simulated results of provided 4×1 mux for inputs s_0=1 and s_1=0

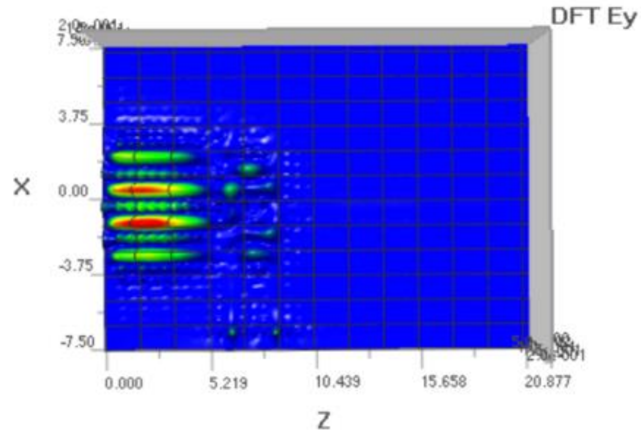

Fig. 3(d): Simulated results provided 4×1 mux for inputs s_0 = 1 and s_1=1

Table 2: Truth table of the proposed 4×1 MUX for Logic1 transfer.

Input A	Input B	Input C	Input D	Input S0	Input S1	Output	In terms
1	1	1	1	0	0	5.196	High
1	1	1	1	0	1	4.344	High
1	1	1	1	1	0	1.638	Low
1	1	1	1	1	1	5.062	High

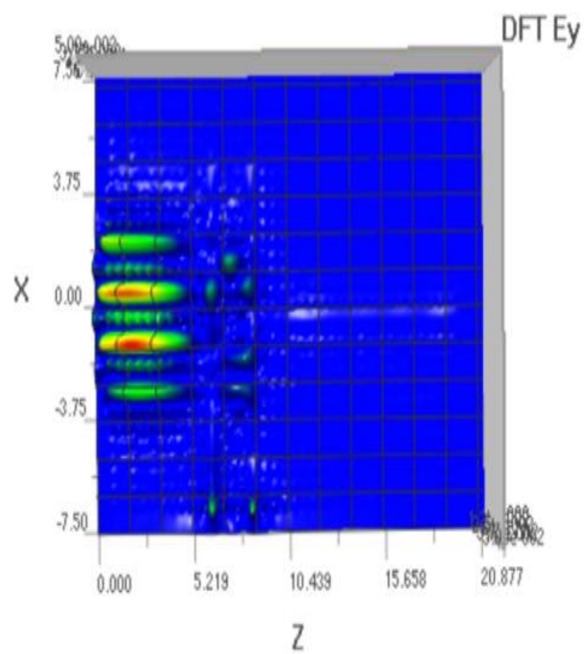

Fig. 4(a): Simulated results provided 4×1 mux for inputs s_0=0 and s_1=0

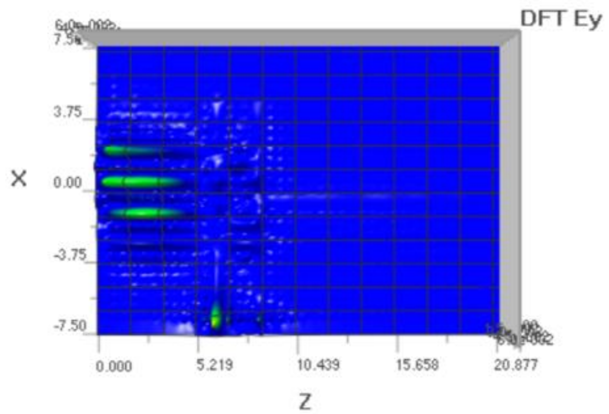

Fig. 4(b): Simulated results provided 4×1 mux for inputs s_0=0 and s_1=1

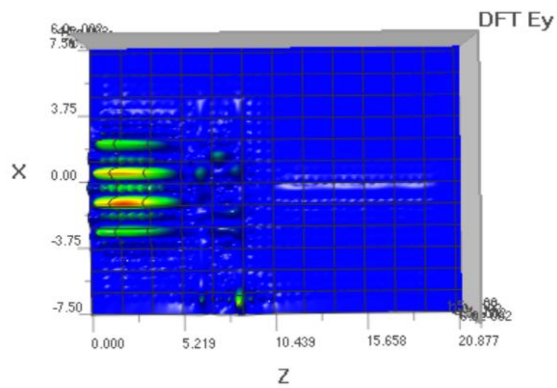

Fig. 4(c): Simulated results of provided 4×1 mux inputs s_0=1 & s_1=0

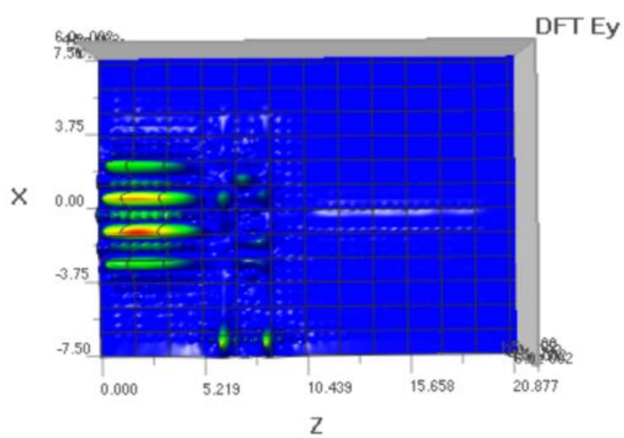

Fig. 4(d): Simulated results of provided 4×1 mux inputs s_0=1 & s_1=1

Table 3: Truth table of proposed 4×1 MUX for Logic 0 transfer.

Input A	Input B	Input C	Input D	Input S0	Input S1	Output	In terms
0	0	0	0	0	0	1.749	Low
0	0	0	0	0	1	1.689	Low
0	0	0	0	1	0	3.211	High
0	0	0	0	1	1	1.490	Low

Figure 4 displays the modeled optical field design of proposed 4×1 mux for input combination s_0=0 and s_1=0, or when all inputs are short. Logic 0 may be inferred from the observed power output of 1.749072 W/m, which really 50% below power supplied by the input port. Figure 3 displays simulated optical field pattern of present 4×1 mux for input amalgamation A=1 and B=1, or when all inputs are high. Logic 1 may be applied to the output power of 5.196027 W/m, i.e. is 50% stronger than source port's applied power. Table 2 provides a summary of the return power levels obtained for input combinations.

Refractive index and rod radius were discovered to be best at 0.2a and 3.4, respectively. This design delivers a contrast ratio to 29.66 dB whenever select input is provided and 23.2 dB whenever select input is lacking, with a transmission ratio of much more than 92%. The suggested gadget is significantly smaller than earlier designs described in the literature and operates at a wavelength of 1550 nm [17-19]. The predicted 4×1 MUX is purely optical, which is advantageous.

3.1 Output Power

In this section, the output- difference in powers at signal-input has been shown. The total power generated is 1.749072 W/m. In these models, the power of bias input is maintained at a fixed value, while the power of signal input adjusted to range from 0 to 1. As the signal input power rises, destructive interference btw input signal and bias at bias and output-1 port likewise rises [20-25]. Consequently, the output-1 receives less power. However, some of input power unimpeded delivered to the output 2. As a result, as the input signal power grows, power at output-1 decreases while output-2 increases at the same time.

3.2 Contrast Ratio

Given that noise margin is proportional to parameter, the contrast ratio is a crucial factor in determining how well a logic device or switch performs while producing an output. The brightness difference between the brightest white and the darkest black that a monitor can. High contrast ratio defines a better performance of the device. The power at logic-1 divided by power at logic-0 is known as the contrast ratio. Normally, it is written as CR = 10Log P1/P0, P1 and P0 stand for the signal power levels for logic-1 and logic-0 at the output port, respectively. These results show that at a wavelength of 1550 nm, an ideal contrast ratio is discovered for output ports 1 and 2 to be 11.3 and 11.4 dB, respectively, for a Z1 radius of 40 nm, Z2 radius of 30 nm, and Z3 radius of 52 nm. This is the justification for the design parameter's selection of these usual values for radii. 5dB is the obtained contrast ratio for the presented structure.

4. CONCLUSION

An appropriate 2-D photonic crystal-based layout to create an all-optical 4X1 multiplexer is presented in this paper. A 32-bit reproduction is executed and assessed using Finite Difference Time Division (FDTD) and PWE. The 18 m × 18 m tiny dimensions of the suggested mux, which are acceptable for construction of photonic circuits, are among its benefits. A forbidden gap of 0.31276 in the range of 0.735940 (1/) 1.048702 has been found the Transverse Magnetic (TE) mode. 5dB is the obtained contrast ratio for presented structure.

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more than 240 SCI, Scopus and other publications in journals and Scopus book series. He is the Editor of 11 books published by LNEE, Springer. He has developed a Pedagogy e-learning course on VLSI Design under NMICT Govt. of India, now it is used by all Technical Universities and Institutions. He is Editor-in-Chief of International Journal of Microsystems and IoT published by ISVE Ranchi (India). He is mentor of India Semiconductor Mission. He is a member of several professional Society ISVE, IETE, ISTE & IEEE, etc. He provided many valuable feedback and suggestions to prepare this article. This work was carried out under his supervision. He also helped in reviewing and updating the manuscript.

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